An Approach For Creating Low-fidelity Prototypes That Allow for Testing Integrated Digital And Physical Interfaces

by

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Abstract

With the development of electronic products and electronic technology, the interaction between the user and the device design ushers in new challenges. Touch operations are gradually replacing traditional physical operations, and in the process of this transformation, problems arise. The advantages and shortcomings of new interactive interfaces have been exposed in terms of safety, ease of use and convenience. How to take advantage of the advantages of new interactive interfaces and optimize or eliminate the shortcomings of new interactive interfaces has become a challenge for today's designers in interaction design. The understanding of usability in design during the product development stage enhances the significance of usability testing of digital devices in early development stage. Therefore, a large number of prototypes are needed for testing. In the development process, various simulation models are produced and applied for usability testing. However, existing models are not sufficient to evaluate the usability of user interfaces (UIs) because they do not allow one to assess usability in both cognitive and physical ways. The challenges of prototyping are also great and involve knowledge of circuitry, programming, and other areas that are often unfamiliar to industrial designers. This study utilizes the tools and techniques that designers are familiar with to enable the creation and testing of prototypes, that can help designers better balance the choice of the implementation medium when designing new interactive interfaces.

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Table of Contents

List of Figures

Chapter 1 : Introduction

1.1 Problem Statement

As touch-screen interfaces are becoming used in a wide range of applications, they also pose a number of safety hazards. These safety hazards can be detrimental to people's lives and property and in emergency situations. Designers often overlook the safety benefits of physical buttons and controls when designing touchscreen interfaces. The physical user interface is converted into a touch interface, which is not user-friendly in most environments. In addition to the safety aspect, the use of touchscreens is also inefficient. A large number of controls are not adapted to different environments or objects. Such irregularities run counter to the goal of improving the user experience. In many cases, safety and efficiency go hand in hand, and efficiency cannot be achieved without safety. For example, the windshield wipers in the Tesla model 3 are integrated into a touchscreen interface. In extreme cases, the user is unable to adjust the wipers quickly and without distraction, a situation that is extremely dangerous. In this case, a physical wiper control interface is necessary. Touchscreens offer advantages that cannot be replaced by physical user interfaces. At the same time, the necessity of replacing a physical interface is something that touchscreens cannot do. Combining these two approaches maybe a more effective way to increase safety and efficiency by allowing designers to better tailor the choice of interfaces to different situations.

Therefore, a lot of prototype testing is needed in order to design products that meet the needs of users. However, existing prototype methods are often not sufficient for testing both digital and physical interfaces at the same time. The combination of both requires cross-departmental, time intensive, and costly prototyping. Therefore, a simple and efficient way to

create prototypes is needed. When prototypes can be produced efficiently in a short period of time, a large number of tests can be performed to select the most appropriate solution.

1.2 Need for Study

  This thesis will study the development of user interfaces and the opportunities and challenges encountered in the process of development. Specifically, whether touch-based interfaces, represented by touch screens, could be a substitute for traditional physical interfaces, such as buttons, knobs, joysticks, and so on. If not, what are the reasons? It will also explore the relationship between the physical interface and the touch interface and the relationships between the two. It will address the question whether both can coexist, and what is needed to get the most out of the system design.

  This thesis will also study the commonalities and differences between different design processes and procedures in order to find ways to improve design efficiency.
In addition, this thesis will explore methods for rapid prototyping and the impact of new technologies on the workflow of designers. The thesis will investigate the impact of new technologies on designers' design process, as well as the effective and efficient testing of different interaction interfaces through prototyping. It will also focus on the general process of prototyping for designers, the steps involved and the different departments involved. The efficiency of the production and the possibilities of optimization.

1.3 Objectives of Study

  Objectives:

- This study will focus on whether there is still a need for physical control interfaces in the age of touchscreens, and whether touchscreens can replace physical operator interfaces. If not, under what circumstances and under what conditions the physical operator interface must be used.

- To identify the need for a physical interface (conjecture), the need for a touchscreen, and the need for both, and the need for both to complement each other.

- To contrast a new-old definition of interaction design and the underlying purpose behind it, and to discuss the possibilities and operability of physical and touchscreen interfaces in the light of existing theoretical papers.

- To develop a prototyping approach, allowing the testing of interaction user interfaces that combine physical and touchscreen interfaces much more easier. To achieve the most efficient user interface possible with this standard design, given the technology and cost available.

- To investigate the possibility of integrating the physical interface with the touch screen. To combine the two into a new system that combines the best of both worlds.

- Find new ways to build prototypes and perform accurate, low-cost testing of previously conceived interaction interfaces

1.4 Assumptions

- Most of the paper is based on proof and evidences, except, when discussing future solutions, as it is possible that some of these ideas may not be based on current technology and may not be achievable due to time and resource constraints.

- The integration of physical control elements into the touch screen results in better efficiency.

- Future interactive interfaces will continue to rely heavily on direct interaction between users and machine. Speech recognition AI cannot completely replace touch interaction.

- There will be more literature to support my argument.

- The existing prototyping process does not allow designers to test a large number of prototypes to find the optimal solution

- With an inexpensive, fast, and accurate prototyping method, designers are more likely to do more testing and get better results.

1.5 Scope and Limits

This research will be limited to the areas it can be used to cover, there is no way to cover all areas.

Scope.

This research will include an analysis of existing good interface design practices and a combination of theoretical lessons learned from traditional interface designs to provide new references. The study will focus on the macro design, not specific UI design requirements.

Limit.

New methods and references may not be widely available to prove their reliability and usefulness. Time constraints do not allow for large-scale experimental applications to determine commercial value.

1.6 Anticipated Outcome

The physical interface has precise maneuverability and cannot be completely replaced by the touch interface. Touch interfaces provide more useful information and are more flexible and efficient ways of interacting with users, and touch interfaces are the future. In order to achieve maximized outcome, prototyping and testing is needed. Only by integrating physical and touch interfaces can the efficiency and accuracy of interaction be tested and determined.

While researching physical and touch interfaces, it is possible to standardize the UIUX design of touch interfaces so that they are compatible with physical interfaces and can be used more effectively.

This research will not only help designers build prototypes faster. It will allow designers to quickly extend better user interfaces into all areas of life without sacrificing the user experience.

1.7 Definition of Terms

Touchscreen control panel: The control interface mainly include display and touch control features.

Physical/transitional control panel: A general term that refers to an operator interface consisting of physical keys and display modules that are not directly involved in operation.

1.8 Procedures And Methods

- Compare the differences between the physical and touch screen user interfaces, by finding existing research and publications.

- Find out in what way a more efficient interface are able to give user adequate instruction and feedback. The strengths and weaknesses of the two interfaces need to be identified by researching existing publications.

- Identify scenarios where touch interfaces are used extensively in daily life, as well as scenarios where they could be used but are not by researching existing books and papers.

- Analyze the weaknesses and strengths of existing layouts by searching for new technologies that can be used to simulate the accuracy of a physical user interface on a touch screen through existing books and papers.

- Explore the use of new methods to rapidly produce prototypes.

- After verifying the feasibility of the new approach, construct a structure for making the prototype and develop a detailed step-by-step approach guideline by using past experience.

Ch 2. Literature Review

2.1 General Design Process

While design processes vary by designer, most approaches are similar. According to Ichida and Voigt (1996), planning is always the first step in the product development cycle; once the decision has been made about what needs to be done, it is time to figure out how to proceed. How much will the project cost and how much time will be consumed? After these steps the designer comes to the real design-related aspect. First, the designer will complete the concept design phase by utilizing existing knowledge, experience and analysis. After that, the initial design starts to take shape by clarifying the purpose of the design and the target user. This is also known as the definition stage. The next stage is the general design stage, which works with existing outlines to ensure that no essential elements are left out. The refinement of the design details will be the next step. Then the prototype is created and tested and the design process is documented in detail. Finally, the design becomes a complete product.

These processes can also be streamlined into ten different elements: "constraints, synthesis, framing, ideation, envisioning, uncertainty, selection, visualization, prototyping, and evaluation" (Moggridge, 2007, p.729).

These steps are often performed sequentially; some will involve some circularity to achieve a better design solution. In fact, most design processes do not strictly adhere to these sequences. There are even times when the process can be completely random, just like a pinball machine. However, this does not mean that every element may be skipped. Each of them plays an essential role in the design process (Moggridge, 2007)..

Among various different design processes, many similar elements are present in each process and hold important roles, such as ideation and prototyping.

2.2 User Interface

User interface is a common component to be designed in the field of industrial design, whether it is the traditional control panel or a screen cased UI interface, such as in a modern mobile phone, or a virtual interaction interface such as a voice assistant. The development of interactive interfaces has gone through many iterations. Understanding the different trends and problems encountered can help designers to design in a better way.

2.2.1 User Interface Trends

First, this section will define the different stages of interfaces, and then introduce the evolving state of user interfaces. It will show the advantages and disadvantages of different interfaces. User interfaces can be separated into two main categories: input and output. The operation of a machine or device is performed by a person using input such as a handle, switch, a knob, or the giving of command, while output refers to the information delivered by the machine or device by sending out notifications such as faults, warnings, operating instructions status, etc. (Kroemer & Grandjean, 1997).

Command Line Interface (CLI), the only interactive input in the early period of computing uses the keyboard which evolved from the typewriter, to performs operations by entering the appropriate commands, and the computer completes the interaction process by feeding back the results to the monitor according to the received commands (HMI Guide, n.d.). The GUI (Graphic User Interface) is an interface format enabling human-computer communication where users manipulate icons or menu options on the screen using input devices

such as a mouse to select commands, access files, start programs, or perform other everyday tasks. GUIs have many advantages over character interfaces ("What Is a Graphical User Interface (GUI)?", 2020).

Then came touch controls, essentially replacing physical buttons with fingers or a stylus. While buttons evolved in parallel with current trends and kept pace with technology, their form and operational logic were undoubtedly inspired by actual physical control interface objects of the past (Reid, 2019).

While both CLIs and GUIs require users to learn actions pre-set by software developers, the Natural User Interface (NUIs) only require users to communicate with the machine in a more natural way like voice, facial expressions, gestures of movement, moving the body, or rotating the head, thus getting rid of the keyboard and mouse. Voice user interfaces are helping to improve all kinds of user experiences (Dobry, 2017).

Users are starting to expect new ways of interacting with digital products, which usually do not involve buttons at all.

2.2.2.1 Human-Machine Integration

Human-machine integration can be traced back to when machines were first created. The essential idea is that the user gives the machine a command, then the machine executes it, and then gives the user feedback in a specific form, after which the cycle continues. In the early days, the focus on human-machine integration was not quite the same as it is today. Machines were extremely powerful, fast, accurate, and large. At the same time, humans had much less energy and range of motion than machines, so combining these two vastly different systems was a

challenge (Boy, 2020). All the feedback equipment and command input equipment were located close to each other and were developed as a whole during the development process. (Figure 1)

Today, the principle of human-machine integration has not changed, but the development process is quite different. Designers are often ill equipped for being industrial designers and UIUX designers at the same time, so a system is often split into two for development (**Jayathilaka**, 2020). The traditional design process is split into several different departments responsible for R&D, which will encounter new challenges in terms of integration. It cannot be said that a separated approach is doomed to lack performance, and there are many good designs that still illustrate the need for communication between the two teams. However, from a certain point of view, the advantage of human-machine integration in terms of integration is still lost.
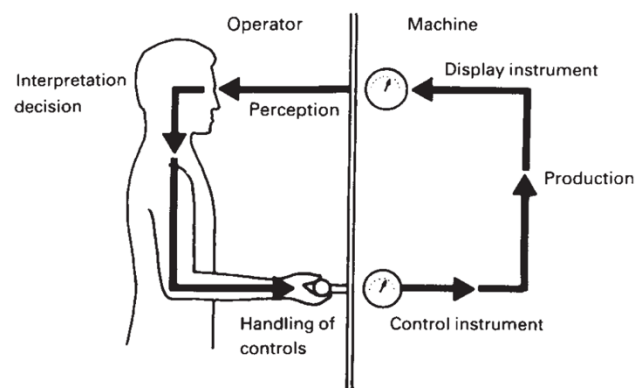
Figure 1: Human-machine respond process (Kroemer, 1997).

2.2.2 Traditional User Interface

The user interface design has evolved from the earliest physical interaction designs all the way up to the virtual interactions of today, and many things are common to all these designs. They are interconnected, and significant ergonomic considerations are involved. The distance, presentation, orientation and size of the buttons we see on an electronic screen are all inherited from traditional physical buttons. Since the Second World War, interaction design in industrial design has evolved rapidly, first allowing soldiers to operate weapons more quickly. Followed by major breakthroughs in aviation aircraft (Kroemer, 1997). Since then, these design theories have been slowly applied to a variety of other fields.

2.2.2.1 Visual & Tactical Response

When talking about haptic feedback, the most likely experience that comes to mind is the 3D-touch feature that Apple uses on the iPhone. This technology allows the user to get similar tactile feedback on the glass panel as with physical buttons (Campbell, 2013).

Nevertheless, haptic feedback can also provide users with more options than the traditional physical control interface. The "Push and turn" button is an application used by BMW on their own vehicles (Figure 2). It can be turned, pushed, and shifted. The knob can change its shape to respond to different functions. To begin, by rotating the knob, the motor under the knob will provide the user with force feedback so that the user can be aware of how the menu is operating. This allows the user to control the menu without visual localization. In addition, the adaptive control components can dynamically change their shape to transmit such information to the driver in an eyes-free manner (Kern, & Pfleging, 2013）.

11
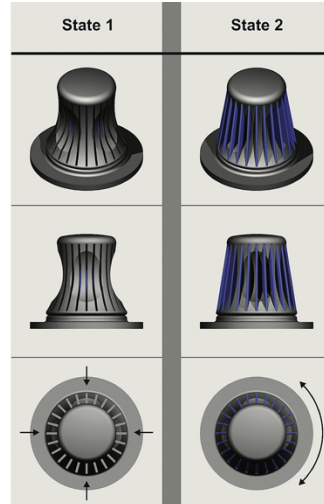
Figure 2: BMW adaptive control knob (Kern, & Pfleging, 2013)

2.2.3 Touchable Display User Interface

In light of the above literature, it can be inferred that one of the major differences between physical and touch interfaces is that touch interfaces require more visual intervention than physical interfaces. Both physical and touch interfaces require visual localization of the object before the operator can manipulate it. Touch interfaces require extra visual localization, both at the beginning and at the end of the process. The physical interface, however, requires visual positioning only at the beginning and is much less dependent on visual positioning once the user is familiar with the interface layout and functionality (Suh &Ferris, 2015). To achieve the same efficiency and safety of a physical user interface, the touch interface must be less dependent on visual positioning. This characteristic and design need is similar to the characteristics and design demands of people with visual impairments. There is a different set of standards and applications for visually impaired people interacting with electronic products.

A more extreme example is how a touchscreen addresses the input process in a situation where the user has no visual orientation. For the visually impaired, Apple has a suite of solutions that provide a variety of approaches. Among them, voice-over is relevant to the topic involved in the discussion. According to Celusank's article (2016) on how to teach users to use the iPhone's voice-over feature, we can see that Apple uses a different interaction system for the visually impaired than the existing operating logic. According to Apple, VoiceOver describes exactly what's happening on the iPhone, iPad, Mac, Apple Watch, or Apple TV, so users can navigate the device just by listening. Apple's built-in apps support VoiceOver, which will talk through the tasks user do with them.

The most important feature of this interaction is that in cases where visual positioning is unavailable or is limited, voice feedback through touch is used instead of visual positioning. The regular tap to select is replaced with a tap to locate, using sound to enable the user to determine the different selection elements and then hear the selection read aloud. The original visual positioning is broken down into two steps: touch and read aloud. The tap to select becomes a double tap to select, allowing interaction with the device without relying on visuals. There is no doubt a learning curve for Voiceover, and the experience of it is fundamentally different from traditional touch interaction. The user's attention to the entire page is also narrowed to increase efficiency (Celusank, 2016). On the other hand, the scenarios in which this haptic audio feedback interaction seems to be used is for simple basic operations. It does not apply to complex tasks.

2.2.3.1 Digitalization physical control interface

Digitizing physical buttons and other forms of control into the glass screen can lead to problems. Touch screens generally provide only audible and visual feedback (Moggridge, 2007, p.631). Traditional controls in physical forms can provide feedback in addition to audio and visual feedback, like tactile responses. Meanwhile, touch screen interaction utilizes technologies that makes the experience closer to traditional buttons. "With this tactile feedback system, a very small actuator vibrates the surface of the glass, so that you can sense a subtle feeling on your finger. It feels almost like pushing a physical button, so this is a tactile interface" p. 631). This technology is used in Apple's MacBook touchpad, the feedback given to the user is adjustable, allowing for different usage settings.

This approach, in comparison to traditional controls, has limitations. The traditional grip/knob is designed in different shapes and lengths, and the user can determine the different knobs by the different feedback provided by the different shapes, lengths, sizes (Moggridge, 2007) which the touchscreen can hardly achieve. Yet touch screens also have their own advantages: electronic displays can also quickly ship the shape, color, or format dramatically of the control (Figure 3). These manners are difficult to implement on physical representations with current technology (p.32). Other forms of digitization are also used in different fields: TUI (Tangible User Interface) is one of them and is unlike touch screens, which tend to be similar to traditional physical interaction. "The key idea is giving a physical form, a tangible representation, to information and computation" (Kroemer, 1997). This application transfers physical controls into digital input and, finally, output back to the physical form to communicate with the user.
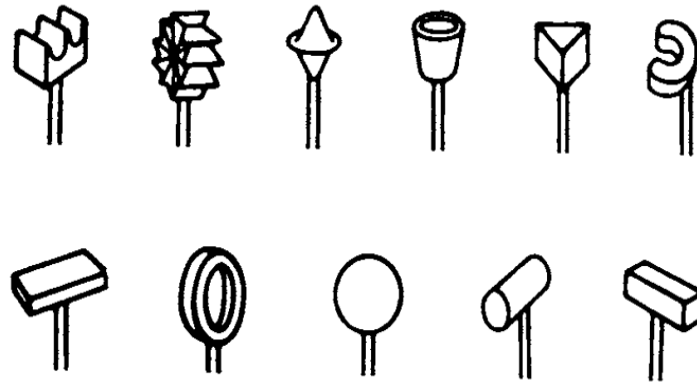
Figure 3: Different shape of stick (Kroemer, 1997)

Meanwhile, touchscreens solve one of the biggest problems with traditional physical control interfaces, which is reading errors. In the age of physical buttons, especially when it comes to scaling displays, all readings are limited by space and cannot be read efficiently and accurately (Kroemer & Grandjean, 1997). Studies have shown that black letters on a white background are better for reading than white letters on a black background. White characters are more diffuse at night when illuminated, which affects reading efficiency. However, because white letters on black backgrounds more easily meet the needs of production and night lighting, they are widely used instead (p.160). In the age of displays, however, readings can be adjusted in real-time by software, and more information can be displayed in a smaller area. And that information will have better readability. One thing to keep in mind is that traditional meters also provide other information in addition to the readings, such as speedometers, which provide real-time speed as well as the trend and how fast or slow the speed is changing. In the touch screen era of design, this hidden information cannot be ignored and also needs to be cleverly displayed, helping the user to build a better user experience.

2.2.4　The Problem of The Touchable Display User Interface Trend

In the age of digitalization, more input methods and output options are being introduced for human-machine interaction. In addition to the traditional hand/finger gesture, other input methods have been added, such as head tracking, different body parts movement, eye tracking, facial expression monitoring such as blinking and eyebrow movements, speech recognition, brain wave detection, and so on. These new methods open up new ways of interaction, but Margiene and Ramanauskaite's (2019) research shows that the efficiency of different interaction methods varies. The accuracy of operation input and feedback is highest with the hand method, whether with a standard or non-standard hand. Eye tracking and blinking have problems with recognition accuracy, and there is a delay between recognition and feedback for mouth and eyebrow movements. The efficiency of speech recognition also depends entirely on the language used and the speech engine (Margiene & Ramanauskaite, 2019). In general, hand-touch operation is the optimal solution in terms of accuracy and feedback speed.

At this moment, although hand gestures are the most accurate compared to other methods, there are still differences between operating with a touch screen versus tactical buttons and switches. These differences can be seen in the study by Suh and Ferris (2015) as follows:

Breakthroughs in interface technologies have encouraged automakers to increasingly replace physical control elements with touchscreens for the center console interface. Whereas the physical elements provide natural haptic and auditory cues supporting interactions even when they are not visually attended to, touchscreen interactions necessitate visual attention because there is not much to feel on the flat screen. Therefore, in-vehicle touchscreens may lead drivers to divert more glances to the touchscreen and

16

away from the roadway, possibly resulting in greater time with eyes off the road and serious safety concerns. (p.1)

The effects on automotive touch interfaces versus traditional physical interfaces impact on driver focus and multitasking. Ferris et al. (2015) experimentally set up two user interfaces, physical and touch of the same size. Conclusions were reached after recording and analyzing the driver's concentration and multitasking performance with the same control variables. Touchscreen interfaces are more distracting because they require visual intervention from the driver to multitask while driving. The physical interface requires less visual confirmation from the driver, which makes it more efficient to complete design experiments.

There is also a trend toward touchscreen interfaces that integrate more basic driving functions. When these functions are integrated, it means that the driver needs to interact more with the touch interface while driving. In this context, it increases risk and decreases the safety of the driving process. For example, the design of the Tesla Model 3 removes the windshield wiper control stick, and the corresponding wiper movements are automatically controlled by the vehicle's onboard computer (ABN, 2018). The human-controlled interface is integrated into the touchscreen, and manual controls are located in the second-level menu.

This setup, in extreme conditions, prevents the driver from gaining immediate control of the wipers and requires the driver to select the wipers by operating the interactive screen, which often requires visual intervention and confirmation. This is also mentioned in another paper: "The distracting secondary input task required drivers to orient visual attention frequently" (Suh & Ferris, 2015, p.15). In some cases, this may result in irreversible consequences and serious danger. As a result, Tesla's automatic wiper control system was ruled illegal in Germany (Benzinga.com, 2020).

At the same time, it is necessary for the user to adjust the display angle of the touch interface. "In fact, many operators reported annoyance by reflections if they could adjust the screen" (Kroemer & Grandjean, 1997, p. 89). Touch interfaces are essentially a screen and inevitably encounter problems with reflections and unclear displays in extremely bright outdoor environments. Most existing touch interfaces cannot be angled by the user due to size limitations. Increasing display brightness can partially solve the problem but at the same time increases the cost and post-maintenance. Problems such as outdoor glare and reflections can only be solved by early design and later remediation.

While the necessary basic operations are integrated into the touch interface, the general size of the touch interface does not allow for all the options to be presented to the operator at the same time. While touch interfaces are more intuitive and clean, they are also less user-friendly in a certain way. When touch interfaces are widely used in mobile vehicles like train, ship, plane etc., the problems are not only limited to multitasking and ease of attention. Tao et al. (2021) argued that the vibration caused by the movement of a vehicle could affect the driver's handling of the vehicle. Experiments and tests were conducted to quantify the extent to which subjects were affected by vibrations while performing different simple tasks. These conclusions were drawn:

> The degree to which the test subject is affected is proportional to the vibration amplitude. The vibration reduces the operator's task completion time and operation accuracy. Maneuvering accuracy was highest in the stationary condition, and manipulation accuracy was most affected by vibration compared to the other test results (p.7).

To some extent, it can be shown that the touch interface itself is not suitable for use in situation prone to high level of vibration. While Tao et al.'s (2021) study did not involve any modification of the touch interface, the experimental design itself only discussed the effects of vibration on the operation of the touch screen; in Ferris et al.'s study (2015), however, the effect of modifications to the touch interface were addressed. It was found that the operating efficiency was higher when the touch element of the screen was larger. At the same time, it also found that "with richer synthetic feedback through visual, auditory, and vibro-tactile cues, a similar level of multitask performance and safety can be achieved" (Ferris et al, 2015, p.21).

Operability can be improved when touch interfaces provide more effective and targeted haptic feedback. Ferris et al.'s (2015) paper does not go into detail about the specific effects of touch feedback on interactive interfaces or on the potential for improvement. Touch feedback itself comes in different forms and categories, and its impact on the efficiency of the interactive interface is theoretically different. According to a study on the relationship between haptic feedback and driving habits (Beruscha, et al., 2017), shows that although the addition of haptic feedback does not significantly improve operating efficiency, haptic feedback was effective in reducing the number of times a driver's eyes were taken off the road while driving. The amount of time the driver's eyes were focused on the road increased by 40%, and the safety and reliability of driving improved with haptic feedback compared to operating an interface without haptic feedback (Beruscha, et al., 2017, p.5). The literature effectively demonstrates that, although touch interfaces are not inherently suitable for mobile platforms, they can, with various improvements, be effectively used for mobile platforms.

2.2.4.1 Integration of Tactical Control with Digital UI

In different industries, people have started to try to combine physical buttons and screens organically, so that the traditional way of control and touch screen gesture can be combined. Microsoft Dial plays a big role in Studio, as it can directly fit the Dial on the screen (Figure 4). Studio will automatically recognize the Dial, and the user can rotate it to perform the corresponding operation. There are several levels of operation, and by pressing down, one can switch between different levels. These levels are the operation of the current interface, the history of the action back, etc. Specifically for the application, it is possible to switch levels back to the previous drawing action by rotating and selecting a different palette color (Stodart, 2021). Such operation is very natural and user-friendly - one hand holds the brush, and the other controls the Dial knob.

Figure 4: Surface dial on Surface Studio (Stodart, 2021)

The Ford mach-e dashboard has a large center screen with a physical knob to control the volume (Figure 5), which has the texture and damping of a traditional physical knob when rotated. The UI on the screen also responds to the control. The principle behind this is that the plastic rotor) tricks the screen into thinking it is being operated by a finger (Burns, 2020). This

approach is simple in structure and does not compromise the overall feel of the screen. The cost

is minimal, and the benefits are significant.

Figure 5: Ford mach-e On-Screen knob (Burns, 2020)

Mercedes-Benz used a different approach in its vehicles, combining the screen with

buttons and knobs (Figure 6). Located on the left side under the steering wheel is a slidable touch

screen with push buttons. In the center of the right-hand knob is a small screen. This design is

designed to reduce driver distraction, and its function allows the driver to control the entire

infotainment system without having to remove his or her hands from the steering wheel ("What

Does the New Mercedes-AMG® Performance Steering Wheel Look Like?", 2018).

Figure 6: Mercedes-Benz buttons with screens

2.3 Prototyping

Prototyping is an extremely important step in design. It tests whether a particular aspect or function would work as intended (Moggridge, 2007). Prototypes are used to solve a variety of problems and develop a better understanding of design requirements. In combination with sketches and other design methods, they help with creative exploration, user testing, communication, design validation, and standards testing. A single prototype often has more than one function (Hallgrimsson, 2019)

For interactive design or digital content, prototyping is not only about the physical form but also about what, how, and what form the interaction takes. This allows for better testing of the behavior (Moggridge, 2007,). There are more benefits to designing and testing a project as a whole. Plus, prototyping is more of a learning process, and making multiple prototypes helps designers to better refine their designs (Kelle & Littman, 2001,).

Prototyping also has new challenges compared to the era before display and touchscreens appeared. "The new challenge for interactive products occurs when the physical object and the electronic behavior are integrated" (Hallgrimsson, 2019, p. 3). The simplest cell phone, for example, has a screen and a button but also has more ways to interact, such as sliding buttons,

sound, vibration, etc. How to put all these functions into a proto-project? It is very difficult to put all these functions into a prototype. A simple mockup is useful in the early stages, but a later prototype will be a challenge, especially if the designer wants to prototype quickly.

One solution to this situation is called part prototypes, where once the system designer has defined the basic requirements, the person responsible creates prototypes for the parts that are within their reach. The initial prototype should cover most of the problems to be solved. Thus early identification of critical components allows more time to arrange for technical support. Those parts of the prototype that are not within the capabilities of the company or design team are handed over to another department, such as engineering. For any knowledge gaps that the company cannot fill, a supplier representative is usually the best and most cost-effective alternative (Ichida & Voigt, 1996).

2.3.1 Rapid Prototyping

Rapid prototyping is a relatively new term for the rapid creation of prototypes in their simplest form to visually and functionally evaluate the characteristics of a part or parts. Sometimes, individual parts are quickly created and assembled individually to test prototype products (Engineering Product Design, 2022). At the same time, using existing technology on hand is a key consideration (Ichida & Voigt, 1996). Rapid means using existing or familiar materials to make prototypes (Figure 7). Using unfamiliar methods only adds time and uncertainty.

When it comes to 3D printing, it is traditionally considered not to be part of rapid prototyping because it takes longer and costs more, but with the development of technology, 3D printing as a manufacturing process can now be very well applied to rapid prototyping

(Hallgrimsson, 2022). Nowadays, a variety of techniques can be applied to create rapid prototyping.
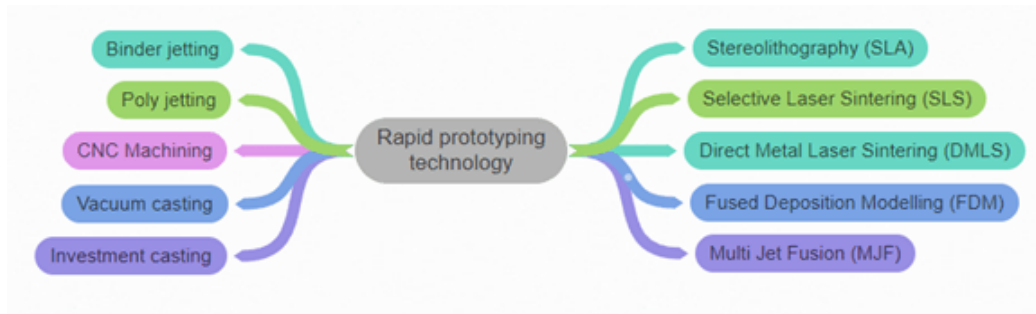
Figure 7: Rapid prototyping technology (Engineering Product Design, 2022)

Rapid prototyping has its own advantages and disadvantages; it can shorten the design and development time, reduce the overall product development cost, eliminate or reduce the risk, and evaluate human factors and ergonomics. But its lack of accuracy is an issue - if the functionality of the product depends heavily on the accuracy of the parts, rapid prototyping parts and assemblies may not have the same accuracy. Rapid prototyping tends to miss critical features such as digital content because they cannot be prototyped in a timely manner (Hallgrimsson, 2022), which can affect prototype testing, resulting in user confusion and customer misperception of completed projects/developer misunderstanding of user goals.

2.3.1.1 High/Low Fidelity Prototype

Rapid prototypes do not necessarily need to look like the final product and may vary depending on what the product designer is trying to achieve from the prototype. Rapid prototypes can be categorized by accuracy or fidelity. The accuracy of a prototype ranges from low to high fidelity in terms of functionality, appearance, user interface, and size.

Low fidelity prototypes are a very simple and rapid production to test a wider range of concepts. An example is a paper sketch of a cardboard model. This material can be tested quickly but often lacks in detail. High-fidelity models will be more accurate and usually need to be made from more robust materials, which also take longer to process (Hallgrimsson, 2019,).

Regardless of the type of prototype, there are two simple categories, Looks-like and works-like. A prototype can satisfy one aspect or both. When a prototype is both looks-like and works-like, it is generally considered to be a high-fidelity prototype (Hallgrimsson, 2019. However, depending on the needs of the desired test, a high-fidelity prototypes can also be low-fidelity in certain parts (Figure 8). There is a sweet spot in between, which allows for quick production and also ensures faithful reproduction to meet test requirements.

Figure 8: Dyson prototypes (Dyson, 2014)

2.3.2   Prototypes used by Engineers and Designers

Both industrial designers and engineers make prototypes, but there are many differences between industrial designers and engineers when dealing with prototypes. According to Yu et al. (2017), a study on the collaboration and differences between engineers and industrial designers reveals how the two different mindsets work together and differ. Engineers think more linearly

and have clear testing goals before the fabrication process. These testing goals are often

advancing the project forward. Industrial designers behave more flexibly, testing their ideas

incrementally and quickly. The tools to make prototypes are mostly the same, but it is worth

noting that sketching, which is a common tool for designers, is rarely utilized by engineers.

There is also a difference between the two in the use of the produced prototype.

Engineers mainly test functionality and features. The designer uses the prototype more for a

deeper investigation to find new opportunities and room for improvement (Yu et al. 2017, which

shows that in some aspects, the types of prototypes needed are different between the two. The

difference in mindsets makes it more difficult for the two to collaborate.

2.3.2.1 Current Physical Product Prototype Process

Regardless of the kind of prototype, the purpose of prototyping should always be the

same: to test the designer's idea, to verify whether an idea can be implemented, (Hallgrimsson,

2016), to test the appearance of the product, etc. For this thesis, the role of the prototype should

be to simulate sets of feedback from different manipulation methods by using easily available

materials and techniques so as to identify the most suitable design solution for the target user

under specific circumstances.

2.3.2.2 Current Prototype Method

There are many existing approaches to achieve both looks-like and works-like prototypes.

(Hallgrimsson, 2016). These methods include ones such as determining the shape by clay and

then transforming it into a digital model using 3D scanning, foam core, additive modeling with

adhesives and filler, 3D printing, polystyrene foam, polyurethane foam, wood, and others. These

are the more common ways to make prototypes, which can be used for both low-fidelity

prototypes and high-fidelity prototypes, depending on the goal and time spent. These methods

are suitable for a wide range of looks-like prototypes. For works-like prototypes, especially those

involving human-machine interaction, pre-made buttons, knobs, and microcontrollers are often

used to enable and implement the interaction. Common tools include, but are not limited to,

LittleBits, Arduino, and Raspberry Pi. Prior to these tools, in order to achieve the same or similar

functionality required, the prototype maker had to have electronic design knowledge and

capabilities. For more specific fields, the virtual device has been used instead. "Using a haptic

feedback device to allow the designer to "feel" 3D virtual geometry as part of the evaluation and

sculpting process" (Hallgrimsson, 2016, p.153). This approach partially eschews the traditional

approach of making a full physical part of the product, relying on technology and virtual

feedback to help designers test the product earlier in the design process.

2.3.3 Co-design

The core of co-design is to investigate and incorporate the opinions of more individuals

and to give equal value to the input of people external to professional designers in the design

process (Piller & Steiner, 2010). In order to accommodate the views of more cross-disciplinary

individuals, the co-design process needs to be optimized, often using an easy-to-understand

toolkit to optimize the efficiency of communication and understanding between personnel.

2.3.4 Current Combine Product Prototype Problem

When a prototype involves both testing the form and possessing the UIUX content on the screen, the situation is a lot different from traditional testing approaches. According to the prototype process for the ecobee3 described in Hallgrimsson's book (2012), user experience is the most critical key. The design process and prototype process should be based on understanding the users' needs as the first element. In the case of the ecobee3, the subsequent prototype process first tested the shape of the device and then added an electronic screen to test its functionality. The UI part was tested separately, using a low fidelity method like a paper prototype, where it can be noted that the testing of specific physical buttons was not combined with the UI content.

In another test, a comparable scenario occurred. The prototype of the Kurio interactive museum guide is a screen-based interface. In the test, the designers also utilized paper prototyping. The difference is that the designers used the paper prototype to test the position of the different buttons and the position of other interactive controls. "Important insights were gained from these tests even though the device did not actually work" (Hallgrimsson, 2022), which shows that more valuable information can be obtained by testing the system as a whole.

However, in order to achieve simultaneous testing, the designer needs to have some electronic knowledge and know how to use tools like a multimeter. There are also tools that can be used with simple solderless connections for electronics. For example, Arduino can be programmed. The need for additional knowledge and skills definitely add to the difficulty of prototyping.

2.4 Cross Department Collaboration

Industrial designers and engineers have their similarities and their differences. The industrial designer focuses on product aesthetics, usability, and manufacturability, including ideation, research, prototyping, testing, analysis, validation, commercialization, and maintenance. All of these continuously running processes are expected to ultimately lead designers to endless product improvements to meet the ever-changing users' preferences and market needs (CAD CROWD, 2020). The original idea for a product or object may come from a non-designer, but the further development process will likely require industrial design and engineering to transform the concept into a fully functional product.

Engineers, in comparison, have a better understanding of various types of raw materials, quality control, production processes and cost management than industrial designers (CAD CROWD, 2020).

Industrial designers build 3D models and render products, while engineers create 3D models for manufacturing equipment and facilities. Industrial engineers focus on function first, with form second. Their most important role is to ensure that ideas are indeed realistic and can be translated into products that do the job as expected.

During the early stages of design, it is important to have the voices of engineering partners in the room to inform the concept design and technical design of the product intended to be built. Often, it is difficult to know exactly when and how engineering will be involved in this phase (CAD CROWD, 2020).

To ensure understanding and eliminate potential points from conflict, the design process should include a review with various partners across departments (including engineering) at each stage of the design process. This allows engineers to incorporate their perspectives into the

design decisions that designers make and provide them with the direction they need to begin development (Feldberg, 2021). But this situation is ideal; engineers and other departments are not involved in the design process every minute of every day.

Another benefit from the fact that the industrial design and engineering teams work in an environment adjacent to each other, for example, when the industrial design department is next to a complete manufacturing shop, it is much easier to collaborate and test with engineers (Komlofske, 2021).

Such a setup allows both departments to walk to the workshop at the same time and test the prototype being built, but this convenience is not available in every company.

What can be found is that it is important for engineers and designers to work together from early in the product design cycle, but the engineering team has only limited time and resources, and the engineer's job is not just to tell the designer what can be done and what can not be done. Engineers also help make products better (Liu et al., 2021). Closer collaboration between engineers and industrial designers is fully appreciated, but the reality is that industrial designers often do not get what they need from the engineering team.

According to an interview with designers and engineers conducted by DesignX Community (Liu et al,2021), the earliest stages of product development and the prototype period are the times when industrial designers most want engineers to be present.

Helping people from different departments to understand what the design department is doing and communicate and share feedback with each other will make the overall work much more efficiently (Liu et al, 2021).

2.5 Controls

Interaction design has evolved from the earliest physical interaction design to the current

virtual interaction. Many things are common like the control logic (Kroemer, 1997). There is a

connection between them, which involves a lot of ergonomics. The distance, display form,

direction and size between the buttons we see on the electronic screen are all inherited from the

traditional physical buttons. Interaction design in industrial design has developed rapidly since

World War II to better allow soldiers to manipulate weapons quickly and have made major

breakthroughs in aviation vehicles. According to Kroemer (1997), there are several rules that

apply to design:

    1.As far as possible, display instruments should be located to. the controls which affect

    them. The controls should be placed either below the display or, if need be, to the right of

    it.

    2.If it is necessary for controls to be in one panel and display instruments in another, then

    the two sets should be laid out in the same order and arrangement.

    3 Identification labels should be placed above the control and identical labels above the

    corresponding display.

    4 If several controls are normally operated in sequence, then they and the corresponding

    displays should be arranged on the panel in that order, from left to right.

    5 If, on the other hand, the controls on a particular panel are not operated in a regular

    sequence, then both they and the corresponding displays should be arranged in functional

    groups, in order to give the panel as a whole some degree of orderliness. The grouping

    can be emphasized by choice of colors, labelling, using control sets that have different

    sizes and shapes, or simply by arranging members of a group in a row or column. Those

controls and displays that are used most often should be directly in front of the operator,

the less important ones to each side. (p.174)

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2.5.1 Physical Control

Different interaction options result in different experiences, efficiencies and accuracy.

Some controls require a lot of strength; some don't. In general, controls "which require little

manual effort: push-buttons, toggle switches, small hand-levers, rotating and bar knobs; all of

which can easily be operated with the fingers" (Kroemer & Grandjean, 1997, p. 154).

Alternatively, controls "which require muscular effort, such as hand-wheels, cranks, heavy levers

and pedals,… involve the major muscle groups of arms or legs" (Kroemer & Grandjean, 1997, p.

155). For the most part, operations involving the hands tend to be those that are rapid and

precise, whereas operations using the arms and feet require strength. The operating hands and

feet should be able to reach the operating interface quickly and accurately. The operating

interface should also be in the visual field where it is unobstructed (Kroemer & Grandjean, 1997,

p.156). At the same time, the feedback given by the machine should be unique, giving the users

only the information they need to quickly understand the operating status of the machine

(Kroemer & Grandjean, 1997, p.152).

2.5.2 Physical control interface

In contrast to touchscreen gestures, physical buttons give the user a fault-tolerant

mechanism with a stay-like effect. When the finger touches the button, the button is not

triggered. It is only activated when a certain force is applied, and according to Schmidtke (1974),

a knob needs to be rotated two newton-meter (nm) of force in order to activate. One-handed

buttons require 10 to 15 nm. Touchscreens do not have this capability in general. What is more, inputs may be recognized and executed by the machine even before the finger touches the screen (Marston, 2022), which is known as an over-sensitive touchscreen.

Different physical controls have their own design criteria. In general, the distance between two knobs or keys should not be too narrow, usually more than 15 mm, and the buttons must correspond with the feedback panel, or in small groups, as close together as possible . Push buttons, toggle switches, and rotating knobs do not require significant force to operate and are better suited for precise control. For some tasks that do not require precise manipulation, long-radius levers, cranks, hand wheels and pedals are suitable for operations (Kroemer, 1997).

As a common way to interact with precision and speed, rotary knobs can be shaped in a variety of ways, as long as they satisfy the human hand and can be easily turned. Some of these interactions have been replaced by touchscreens, but some ideas have been continued in touchscreens over time.

2.5.3 Touch Screen Control Interface/Gesture

The touch screen, while replacing most of the traditional physical buttons, offers new interaction gestures. The most basic interaction is to tap. Tap to open, for example, replacing a button with a screen that can detect the pressure of pressing. This creates a similar feeling to a physical button (Apple, n.d.).

Drag and drop is basically placing a finger on top of an object and moving the object to a new location. Many screens have a small visible area, especially mobile devices, and cannot display everything at once. Using swipe to scroll can solve this problem. View maps, phone book contacts, messages, and more can use this interaction gesture (Sorathia, 2015).

Another gesture requires pinching to zoom in and zoom out. To view every detail on a small touchscreen device, users need to zoom in and out of content to check details. When document size, photos, maps, etc. need to be increased or decreased, the pinch to zoom out and expand to zoom allows the user to see the necessary details (Sorathia, 2015).

As previously mentioned, many touch screen interaction logics are borrowed from traditional forms of control, such as Apple's slide-to-unlock (Figure 10), which, like the long-handle level, prevents accidental movements and allows for imprecise control by increasing manipulation formation (Lovejoy, 2020). The similarities between the landing gear interface and the iPhone's lock screen interface can be seen by comparing the two (Figure 9).

Figure 9: Boeing 737 Landing gear

Figure 10: iPhone slide to unlock page (Apple)

2.6 Custom Control Panel

The custom control panel gives the user the ability to customize the layout of the control panel, either in the form of a pure touch screen, mechanical buttons, or a combination of both.

2.6.1 Physical Custom Control Panel

Elgato Stream Deck's signature interface with 15 bright LCD keys can be customized for icons and actions or for controlling applications and tools (Benne, 2021), All functions are designed for visualization, including setting icons, setting menus up and down, program tracking, and more (Figure 11).
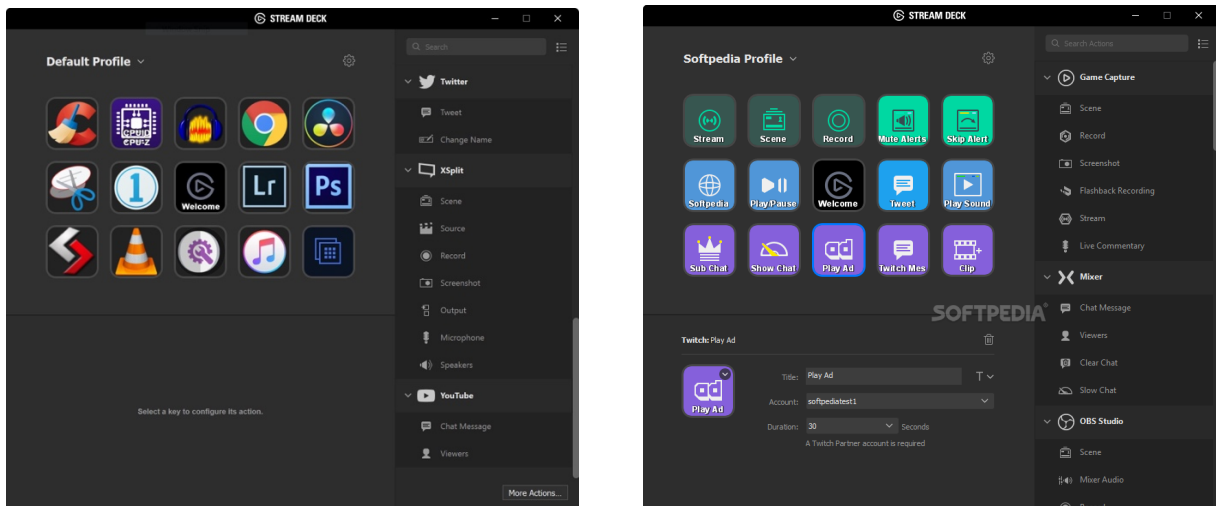
Figure 11: Elgato stream deck (Benne, 2021)

Figure 12: Elgato stream deck software (Benne, 2021)

The functionality is achieved through direct interface-level underlying communication between the driver and the software (Figure 12), rather than simply sending a few mouse-keyboard commands (Benne, 2021).

Figure 13: Stream deck teardown

The principle is to add physical keys to the screen and recognize the physical key's motion by the recognition layer as shown in figure 13 (tdxlabs, 2017). This product gives the user great flexibility to improve the efficiency of the application with a specific layout, but the layout is not modifiable and is somewhat limited. And it can only be used in a limited number of scenarios with only one kind of interaction: buttons.

2.6.2 Digital Custom Control Panel

Compared with the physical custom control panel, the digital panel is more flexible and has a great improvement on the limitation of the layout with different elements.

2.6.2.1 CCP Customizable Control Pad

With the Custom Control Panel (CCP), a user can turn their iPad or iPhone into a customizable keyboard/joystick/touchpad to control their PC/Mac (Figure 14).

Users can set and save "layouts" of buttons, tabs, virtual joysticks, sliders, and other interface elements and assign a specific input to each button to be replicated on the PC or Mac (Figure 15, 16).

CCP can also receive data from the PC, and through CCP's API, users can customize the application or game to display the data on the touchscreen device as needed (App Store, 2013).
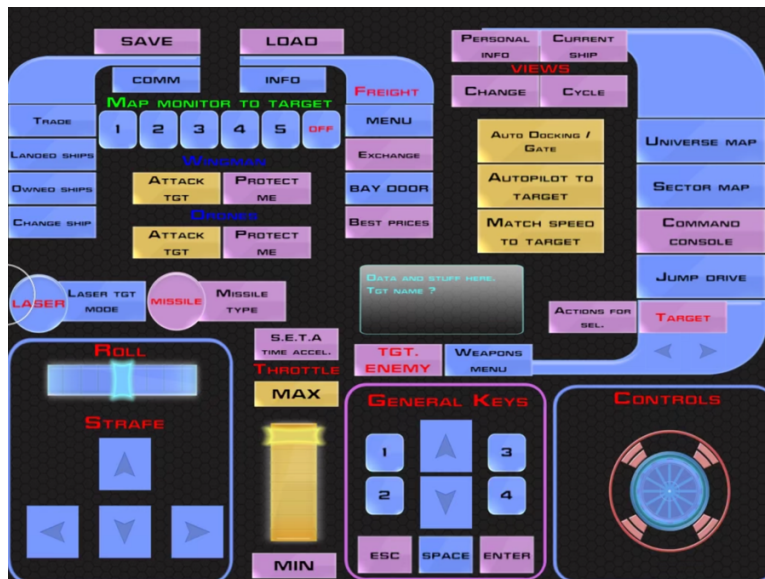

Figure 14: CCP logo

Figure 15: CCP page 1

Figure 16: CCP page 2

2.7 Touchscreen Principles

Capacitive touch screen technology is the use of the human body's current induction to work. The capacitive touch screen is designed as a four-layer composite screen: the inner surface of the glass screen and the interlayer is coated with a layer of the Indium Tin Oxid (ITO), the outermost layer is a thin layer of silica glass protection layer, and the interlayer ITO coating as a working surface. The four corners lead to four electrodes. When the finger touches the surface of the metal layer, due to the human electric field, the user and the touch screen surface to form a coupling capacitance, so the finger from the contact point draws a very small current. Thus the controller, through the four current ratios, accurately calculates the location of the touch point (Mahadi, 2020). This is why touch screens cannot be operated through gloves or underwater (Figure 17). Today, the majority of touch devices use capacitive screens.
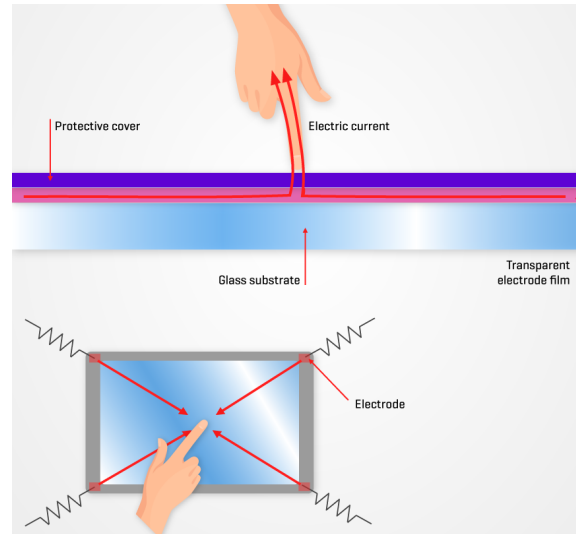
Figure 17: Touchscreen Principle (Mahadi, 2020)

2.7.1 Touchscreen Operation Aid

When the body's electric field is blocked or interfered with, for example, through gloves or underwater, it becomes difficult to operate the touch screen. Likewise, an object without an electric field cannot operate a capacitive screen. There are several different ways that a stylus can solve this problem. If the pen is metal, it can generate an electric field by contacting the user's hand. This type of stylus does not require a battery. There is also an active stylus that generates electrical production through the pen itself, which allows for interaction (Andersen, 2022).

The same goes for gloves. While thinner gloves do not completely block the body's electric field and thus allow the use of touch screens, for thicker gloves, other methods are needed. The use of fabric mixed with metal wool to produce gloves can ensure that the surface of the glove is a good conductor and can make the electrical field on the surface of the capacitive screen change, thereby controlling the screen (Fieldscale, 2019).

2.8 Usability Testing and Evaluation

It is equally important to test and evaluate the design, and its prototype, in a reasonable manner. A good evaluation can test the feasibility and accuracy of the design, thus better helping the designer to improve the design (Ichida & Voigt 1996). Common means of evaluation include the use of databases and knowledge bases. The key point of a database is that there is large amount of data available and the data is used to speculate on problems as well as future directions. This approach requires data that is kept up to date and determines the future of the product through a completely rational perspective. Artificial Intelligence (AI), as developing technology, can be well suited to this approach. The knowledge base, on the other hand, depends on the individual designer, who tends to need less data, and whose trace criteria tend to be stable and non-variable. The input of professionals is often needed.

On top of both, comments are a useful tool, and obtaining different opinions can broaden the horizon and find the ignored perspectives.

A checklist is also a rationalization tool; by listing design goals and testing objectives, one can quickly determine the direction of experimentation and prototype requirements. It is also possible to evaluate to different prototypes under the same rubric and get test results. This approach can be overlaid with the above to achieve better results. It can also be used in the early stage when there are not many test points, helping designers to find more test points (Ichida & Voigt, 1996).

In the later stage, user feedback is also very important in the testing method; even if the product has finished its development, it is still possible to find ways to improve the testing process and prepare for the next application (Ichida & Voigt, 1996).

The testing process and approach can be different in order and step, but the purpose is the same. Testing helps to find problems and solve problems better.

Literature Review Conclusion

Through the evidence presented in Chapter 2, it is clear that touch screen type user interfaces are becoming more and more common. While bringing more convenience and benefits to users, touchscreens also brought new problems, such as efficiency and safety issues. At the same time, these issues raise new challenges. Such challenges are not only for the user, but also for industrial designers who have a great impact and challenges in product development.

The appearance of touch-screen interfaces has overturned the traditional user interface development process, especially the creation and testing of prototypes. A large number of prototypes had to be tested and developed separately for digital and physical interfaces. This not only increased development time, but also reduced the effectiveness of testing, as fewer prototypes were used for testing.

To solve these problems, an innovative approach to prototyping is needed. If the prototyping is simple, fast, and easy, then numerous prototypes can be created and tested, which ultimately improves the user experience and product quality.

Chapter 3 Approach

3.1 Overview

Products with both a digital and physical interfaces, like dashboards, need an integrated process for rapid prototype testing at ideation. By combining rapid prototyping methods like 3D printing that allow for almost immediate form ideation, and user experience design tools like Figma, Adobe XD, or Sketch, that allow users to visualize and experience their digital interfaces at the click of a button, the intention is to be able to accelerate the design and testing of digitally integrated physical products by minimizing the need for engineering.

Traditional physical interface prototypes require the use of microcontrollers and various interactive devices that require wire connections. The approach in this thesis relies on 3D-printing to print out the physical interaction interface mockup and overlay it on a touch screen device. Then using a custom bridge software on the touch screen device and connecting to the computer, the actual physical interface can be created. This low fidelity prototyping approach allows the software and physical interaction to be tested as a whole (Figure 18, 19).
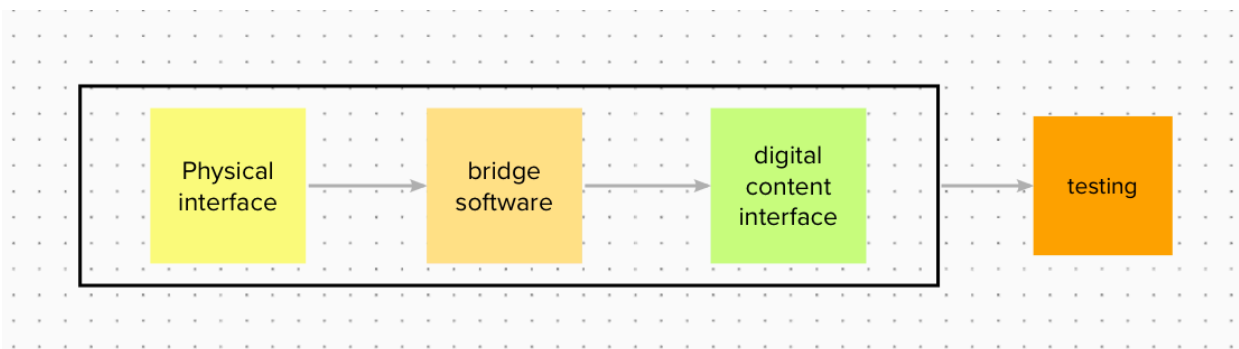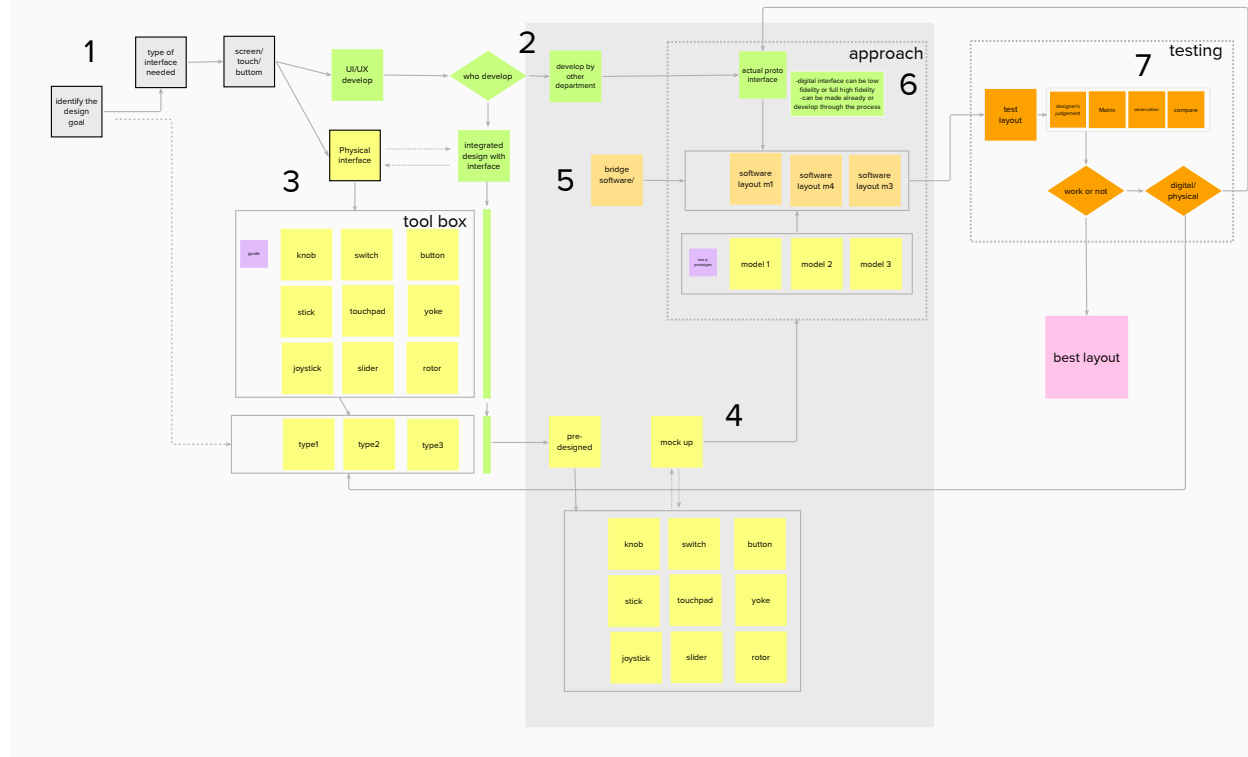

Figure 18: Overall approach method

Figure 19: Approach method

3.2 Identify Design Goal and Requirements

Defining the design goals, the design period, and the available resources and limitations is the first step in the design process (Figure 20). Based on different conditions, a corresponding prototyping process should be planned. This thesis provides an approach that allows designers to use the equipment and technology they already have on hand to produce a variety of prototypes quickly, inexpensively, allowing for more testing. Depending on the circumstances, the designer can create a low-fidelity prototype to implement certain features that can only be performed by a high-fidelity prototype. It is also possible to create high-fidelity prototypes to meet more testing needs by using the approach in the thesis. The decision will depend on the specific schedule.
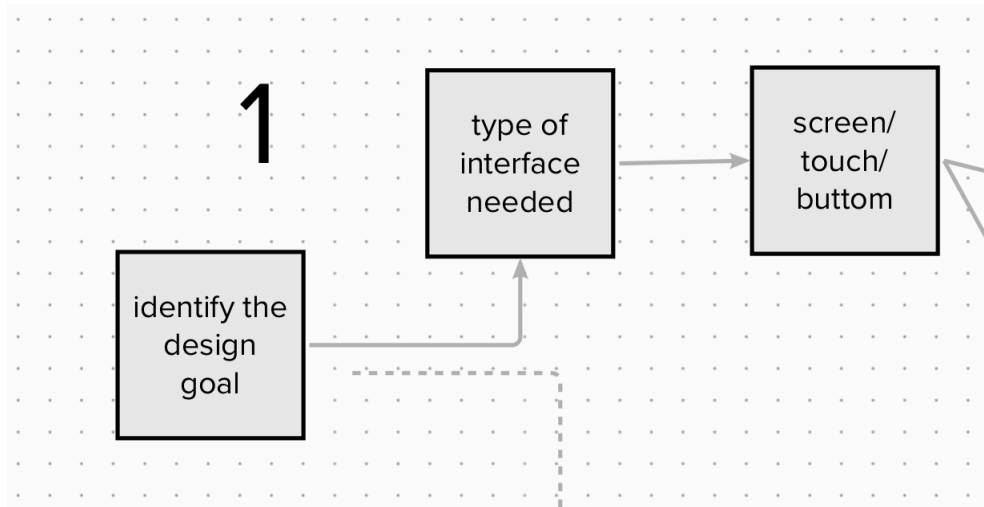
Figure 20: Step 1 details

3.3 Evaluation of The Need of Design

When designing a product, after defining the design goals, it is important to consider what kind of interactions should be considered.

3.3.1 Is A Digital Interface Needed?

Is a touch screen always needed? There are various factors to consider when thinking about this question. For users, what are the benefits of using a touch screen? For product development and manufacturing costs, which size screen is the most cost effective? Is it helpful for subsequent software updates and maintenance? These factors are not fully decided or controlled by the designer, but these factors need to be taken into account when designing.

The reality is that often, the touch screen needed or the final products used, from the size to the quantity, are predetermined. For example, the interior dashboard design of an automobile will often have large touch screens nowadays. Although the size of these touch screens may vary, in most cases the same parameter screen can be found in different models of different

companies. This is because in many cases, it is not the car company that determines the size of

the screen needed, but rather what kind of touch screen the upstream supplier can provide. In this

case, there are not many choices left for the designer, but the designer can still design the optimal

solution for the user and for the company with limited choices.

3.3.2 Is A Physical Control Interface Needed

The use of a physical control interface is not as restrictive as compared to touch screens.

On one hand, the technology of a physical interface is well established already, like buttons,

knobs, slider, stick etc., and the cost is relatively low. In addition, designers are likely more

familiar with physical controls. For users, this interaction method is also the most common and

most familiar.

When thinking about what kind of buttons and controls are needed, designers can leave

the physical interface alone, just like in Tesla's case, and leave everything to UIUX design and

future software updates. For some companies, this unified screen and relatively low-cost

software updates are more suitable compared to designs that have a lot of physical controls. The

touch screen style does not require a lot of experimentation, prototyping, and testing up front;

problems can be solved by Over-The-Air (OTA) update when encountered in a way that physical

buttons cannot.

On the other hand, designers can also design a set of physical controls and touch screen

design in combination with each other. After all, the physical operation method has

incomparable advantages in terms of accuracy and speed of operation. Imagine a hunter who

needs to adjust his scope after aiming at the prey: through the knob turning click, the hunter

quickly adjusts the scope and keeps his eyes on the prey. If the scope is a touch screen operated,

the hunter's eyes would have to be moved and focused on the touch interface, and the hunter

would probably not be able to find the prey after the adjustment. The touch screen is not a

panacea, and this is something designers should always be aware of. But more physical buttons

are not always better. Users want a clean, simple, intuitive interface, not a nuclear power plant

with hundreds of buttons. It's the designer's job to find the balance between the two. That's what

prototyping is all about.

3.4 Decision Making for Design/Prototype Process

  Ideally, the design department would have no constraints and could produce designs that

best suit the user. But this is often not the case. Different companies have different needs and

constraints, and designers have to make different adjustments for these situations (Figure 21).
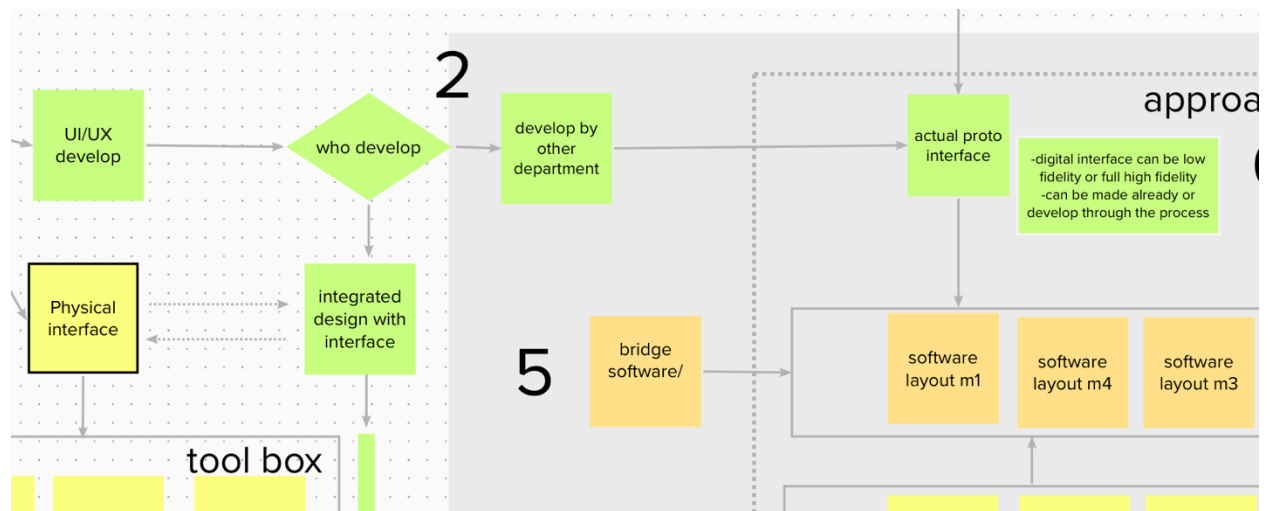
Figure 21: Step 2 details

3.4.1 Who is Designing the UI?

Cross-departmental collaboration is critical and important. But not all departments are able to cooperate effectively. Each department may have multiple ongoing projects, and different factors may affect cross-departmental collaboration. Some difficulties can be solved through communication, and some cannot. Therefore, when designing a system, designers should be clear about who is developing what, especially the UI - is it a UI that has already been developed and needs to be adapted to the user interface? Which department is responsible for the design of the UIUX, or whether the designer has the privilege to modify the interface during the development of the interactive interface? The answers to these questions will affect the prototype production.

3.4.2 Will the UI be Developed Along With the Control Interface?

The reason for clarifying who is responsible for UIUX design is that, ideally, the design of the physical interface and the digital interface should be integrated and developed together as a whole. The position of the buttons and the feedback given on the screen by the function to be controlled need to be matched one-to-one. Many studies and practices have identified optimal solutions for interface design regarding the input and output options. After the adoption of the digital interface, the original system developed as a whole was split into two different systems. The advantage of co-development is to avoid the risk of rework, improve the integration of the two systems, and bring the best experience to users.

When different departments are involved, effective communication is necessary, and frequent collaboration from the very early stages is important for both departments.

If the two systems can be developed together, doing so means the UI can be modified according to the most suitable physical operation method, in addition to choosing the

corresponding physical operation method according to the UI when creating the prototype. This will enable more alternatives prototypes to be tried out, making the prototype testing more efficient and accurate.

3.5 Digital UI Development

Whether a designer is responsible for the development of a digital interface or another department is, the difference is mostly in the quantity and quality of the prototypes. There are no special requirements for the design of the UI itself. However, there are some requirements that need to be met in order to adapt the prototype approach of this thesis, which is described in detail in the following subsections.

3.5.1 Design Approach

As shown in the flowchart (Figure 19), the steps will vary depending on the design approach. The UIUX part is the main focus, and is often the most underappreciated area by designers.

3.5.1.1 Separate UI Development

When the designer has absolutely no modification control over the UI, the UIUX section will be independent of the flowchart and will only be re-engaged during the final testing. This does not mean that the UI does not need to be considered when designing the prototype (Figure 22). On the contrary, since the UI has already been developed, the designer has to try different combinations of physical actions based on the existing interface. If the UI is in the development process, then frequent cross-departmental communication is recommended.
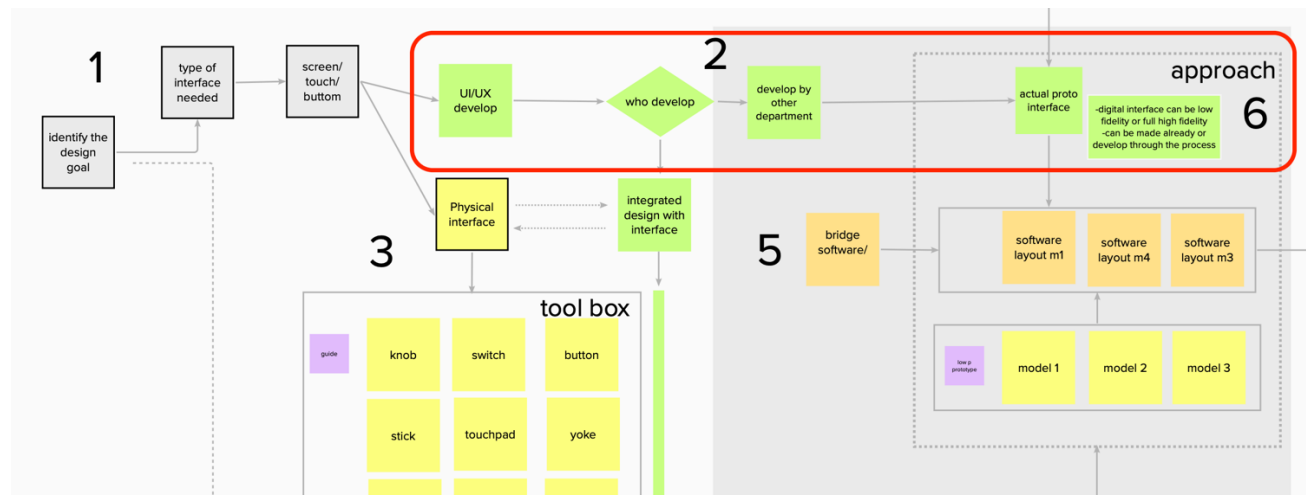
Figure 22: Approach method UI develop process – Pre-existing

3.5.1.2 Integrated/Co-UI Development

When the UI design and the physical interface are developed simultaneously, the process can be found throughout the prototyping step (Figure 23). It means that the designer can change and improve the UI interface according to determination of suitable controls.

In other words, compared to separate UI development, the final prototype stage has a variety of different physical interfaces for one type of UI. Integrated/co-UI development can have multiple sets of different UI interfaces that correspond to multiple physical interfaces.
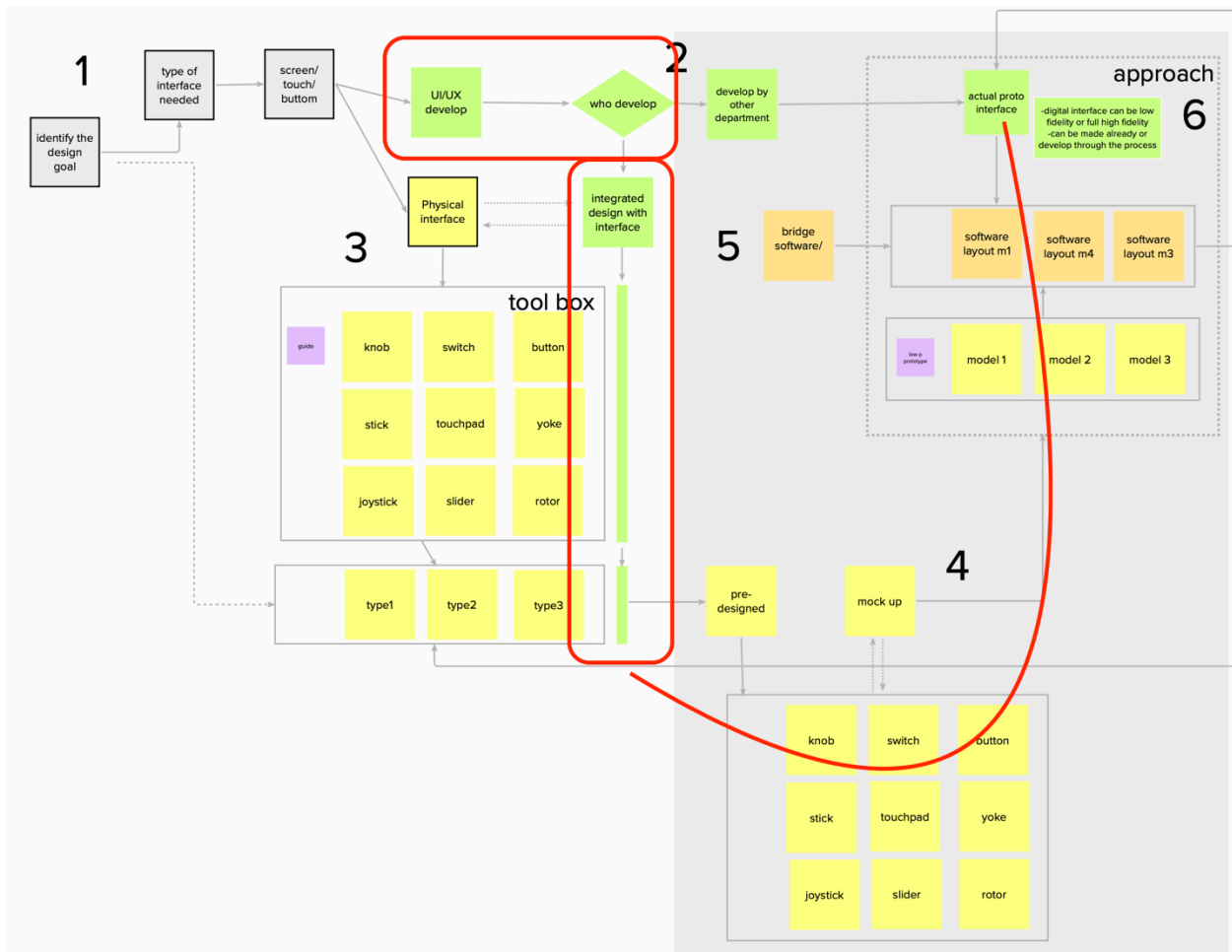
Figure 23: Approach method UI develop process- Along with mockup

3.5.2 Design Software Requirement to Bridge Software Ready

In order for the final UI interface prototype and the physical control interface prototype to be tested together, there are a number of software-level conditions that need to be met.

3.5.2.1 Demonstration/Demo Mode

Demo mode means that UI design software needs to have visual presentation capabilities, whether it is a high-fidelity prototype that is close to the final product, or a low-fidelity prototype at the beginning. This is so that when testing, testers do not have to test in their minds based on

51

their imagination of the visual feedback, but have a set of visual interfaces to give the most intuitive, real feedback. It's as if testing against code is not as intuitive as the final prototype.

3.5.2.2 Hot Key Assignable to Control the UI

After having the demo capability, the software should also have the ability to map keys (hotkeys). By assigning different keys, it gives the ability to control the prototype with a keyboard, mouse, etc. The reason for this feature is that the operation of the physical interface will be converted into a signal that the computer will be able to encode, simulating the operation of the keyboard and mouse to control the interface.

3.5.2.3 Gaming Controller Assignable to Control the UI

Game console interface design is also a part of UI design, and an increasing segment of app design software has started to support the connection of game controllers. This approach can also be used by physical interaction prototypes for key mapping. In the absence of hot key mapping, a game controller is a method that can be used. A specific process of mapping will be described in detail in the Bridge Software Section (Figure 49).

3.6 Physical UI Development

The development of a physical interactive interface needs to be accompanied with the matching digital interface to define desired functionality and form. Designers should use existing interaction logic to develop and test the extensions method (Figure 24).
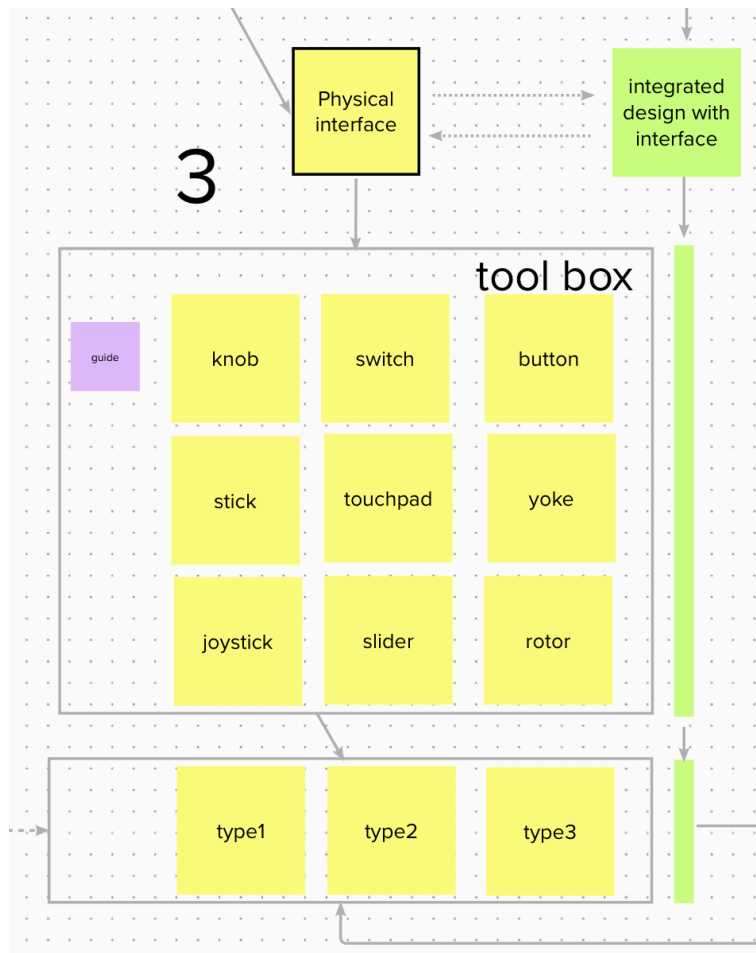
Figure 24: Step 3 details

3.6.1 Existing Tool to Utilize

Designers need to use the tools and knowledge available in the database and apply them to the right functionality. For example, if a user wants to select an object on screen, there are multiple ways to do so, such as a touch screen button, a separate and exclusive physical button, a joystick-controlled pointer for selection, a knob, and so on. Each method has its advantages and disadvantages, and the best one is the one that fits.

3.6.1.1 Knob

Knobs are ideal for operations that require both quick adjustments and precise selections. The feedback given by a physical knob is very intuitive, usually one click at a time.

Take, for example, a radio unit. Compared to buttons, knobs allow for faster channel selection, while allowing for precise channel selection by slower rotation.

The knobs are usually raised over the operating surface, providing a certain elevation. This allows the user to locate and operate the knob without having to visually look for it. Different shapes, textures, and sizes of knobs can be used to distinguish different knobs for different functions (Figure 25).

Figure 25: Garmin flight control board

In the field of aviation, knobs are used in many applications, from adjusting course heading to UHF frequency tuning. If a pilot needed to adjust from course 230 to 356, it would take several turns of the knob, but 126 clicks of the button. Alternatively, with a touch screen, the pilot can quickly change the heading by entering 356. But the knob still provides an additional capability. By controlling the speed of rotation of the knob, it is possible to control the steering (bank)rate of the aircraft and avoid harsh movements. (There are certainly other

functions that can avoid the effects of buttons and touch screens on the aircraft, but the operating logic is not as intuitive as that of the knob).

In addition to rotating, the knob can be used as a button for selection. In fact, many aircraft use two knobs and stack them together (Dual Rotary Encoder) (Figure 26), one being larger and one being smaller. This increases the number of knobs in a limited space and enables more functions to be achieved. At the same time, the stacking structure also implies that the two knobs are functional as a group. The format of the aircraft radio frequency generally looks like 121.500. The larger knob adjusts the first three digits, while the smaller knob adjusts the last three digits.

Figure 26: Dual rotary encoder

3.6.1.2 Stick Like

The stick-like controls have many similarities.

3.6.1.2.1 Stick

The stick and slider is a result of mechanical structure. The most common example of one is the control of the air conditioner air vents in an automobile. This mechanism often does not require the user's input to be converted into electrical signals to communicate with the machine.

In some earlier vehicles, the air conditioner was operated by a stick and slider structure, which was connected to a sliding resistor that controlled the amount of airflow and temperature by sliding.

In the Mercedes-Benz, the stick structure of the air vents is also integrated with the knob structure. The direction of the air is controlled by adjusting the stick, and the volume of the air is controlled by rotating the stick as well as the switch.

3.6.1.2.2 Slider/Lever

Sliders and small levers belong to this category. This structure often has a long travel, which can prevent accidental triggering. As mentioned in Chapter 2, some critical instructions and devices that should not be touched by mistake, will adopt this type of interaction, such as aircraft landing gear, flaps, etc. In the era of touch screens, the slider is also designed as a sliding block, which is suitable for some essential functions, such as starting the vehicle, emergency power off, etc.

3.6.1.2.3 Toggle Switch

The toggle switch comes in many forms, such as a stick-like switch, like those used in American lights. There are also flatter versions, such as the light switches used in Europe. These switches generally give the user very clear feedback: toggle up for on, toggle down for off. There are also some toggle switches that come with triple positions, with a middle state in addition to on and off. These depend on the application scenario. In the aviation field, to prevent accidental touch, the toggle switch needs to be unlocked by pulling it out, and then selected.

3.6.1.3 Joystick

A joystick is a very common interaction on gamepads. This interaction can be used not only as a button, but also as a stick. Compared to the buttons, the joystick adds vector direction control and allows the control of the speed of movement of the object by toggling the amount of the joystick.

3.6.1.4 Track Ball

The most common use of a trackball is as an alternative way to use the mouse in a limited space. Control points are operated by controlling the movement of the ball. In moving, vibration and other non-ideal environments can still give the user accurate control experience. Trackballs are also used in the field of aviation.

3.6.1.5 Scroll Wheel

Like the rotor, the scroll wheel has almost all the advantages of the rotor. It can also be used for fast and precise selecting. In terms of structure, the scroll wheel requires more space. Compared to a rotor, a scroll wheel does not require two fingers to operate, but only one.

3.6.2 Pre-design Different Type Layout

In addition to the control elements, it is important to be aware of where the control elements need to be located. Testing can only be effective when both aspects co-exist.

Depending on the application and environment, the screen and the designed physical interaction for it may not sit together. Different prototypes are created for different needs.

The layouts of prototypes can be completely different and applied to completely different usage possibilities. In this context, the advantages and disadvantages of the different prototypes can be compared, and the appropriate prototype can be improved.

3.6.2.1. Relationship Between Control Interfave to Digital Content

In a world where touchscreens are becoming increasingly popular, they are naturally featured as the main character in a system, while physical switches are used as supporting characters to help make the touchscreen experience more interactive and much smoother. The location of the physical interaction interface matters a lot. Depending on the environment, placement on the left side of the screen, right side, bottom side, or even away from the screen can shift the logic of the interaction. The principle of the traditional interaction interface is not always being fulfilled. For example, it is impossible to match all the options with a button.

In this case, the designer has to consider not only how to design the interface, but also other human factors. For example, whether the user's arm and hand will block the key information when operating the physical buttons, whether the user can operate the interface without eyesight, and whether the layout and shape of the interaction interface is intuitive to the user. Is the feedback of the interface direct enough? These considerations of location will ultimately affect the efficiency of the entire system.

In addition, by keeping mistakes, making prototypes and observing users, it is possible to find out and verify whether the design of the interactive interface is reasonable.

3.6.2.2. Efficiency Between Control Interface to Digital Content

The efficiency of an interactive interface depends mainly on two aspects: the speed of inputting info, and the speed between giving feedback to the user and comprehension by the user.

The speed of inputting information not only lies in the appropriate choice of interaction, but also in the arrangement and location of different functions. For example, the landing gear of early civil small airplanes was often damaged not during landing, but when the pilot tried to adjust the flaps on the ground, and mistakenly operated the landing gear level, due to the close proximity of the two in terms of position and interaction pattern. It can be concluded that in addition to fast input, accuracy must be ensured. The actions corresponding to successive steps in the flow should be separated, either in the form of interaction or in the location.

In addition, most interactions are not always performed in ideal conditions. For moving objects, motion and vibration are inevitable, and for non-moving objects, some critical actions are often used in emergency situations. This requires designers to take into account a variety of use cases and the corresponding variety of operations. One or more sets of redundant interactions can often solve most usage conditions.

Of course, too many interactions can be confusing to the user. Adding more interactions is not the only way to solve the problem. Whatever fits is the best.

The speed of user comprehension of information also depends on the feedback given by the action. In this regard, touch screens have a great advantage. Any feedback can be given visually through the touch screen. In conditions of limited vision, the feedback given by the touch screen is also limited. Audio feedback is one solution, but this still has some delay and inaccuracy compared to a physical interface like a knob. For example, if the user needs to turn up

the volume of the audio by five levels, if it is a virtual button, the user can get feedback by observing the change in sound level. But if it is a knob, the user can feel the click of the knob while observing the change of sound to judge. The knob gives the user feedback at the exact same moment the user operates it. This feedback is more intuitive and efficient.

At the same time, compared to the traditional interface, a touch screen requires more direct finger contact. Prolonged use will gather a lot of grease and dust, plus the different angles of the touch screen reflects the light, all of which will affect the touch screen display result. Thus the choice of the location of key information is very important. The designer must consider which areas are not set to toucha, which functions operate as much as possible with physical buttons, and which areas and angle is least likely to receive reflective interference. These issues require designers to pay attention, as they will affect the ultimate efficiency of the use of the system.

3.7. Physical UI Prototype Technic

This subsection will describe how to implement the prototyping process and production methods (Figure 27). Using 3D printing and some common prototyping materials, the prototype interface will be capable of being adapted to the bridge software. The general principles and steps can be found in the overview of this chapter.
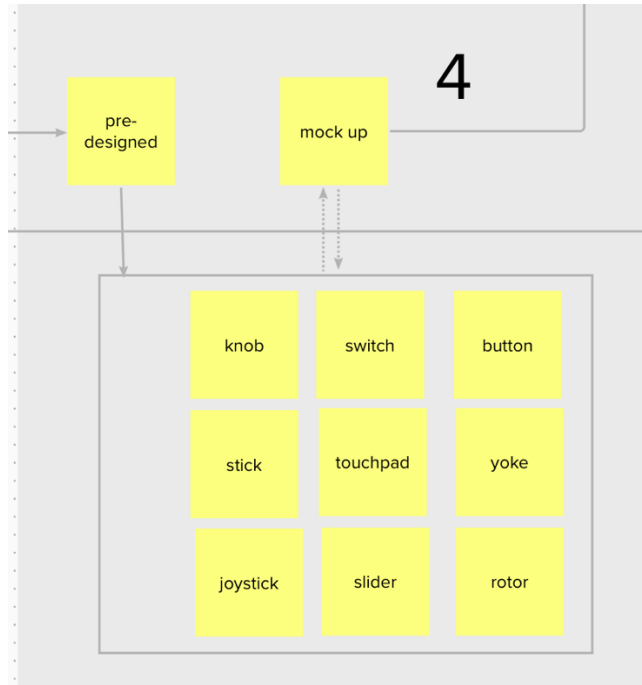
Figure 27: Step 4 details

3.7.1. 3D Print Test Frame

The 3D printed base is a key step to quickly replace the different test prototypes. These pedestals carry functions in both directions. One is the ability to carry all the physical interactive interface elements, such as buttons, knobs, sliders, and so on. The second is that they can be quickly overlaid and mounted on the touch screen that needs to be used. This ensures that the position of each operating element is accurate and allows for quick replacement.

3.7.2. 3D Print Control Element for test

Taking advantage of 3d printing, the principle of how capacitive screens work, most of the controls can be made in a relatively simple way. The tactile feel can be simulated through specific structures or various materials (Figure 25). And the use of conductive materials enables the mockup to interact with the touch screen.

The purpose of this section is to provide some examples to illustrate and expand the idea. In a real-world situation, designers can design their own mockups to meet their requirements. The structure and form of the unit is not specific yet not limited.

3.7.2.1 Buttons

Using soft rubber material like Thermoplastic Polyurethane (TPU) enable print out realistic soft rubber buttons. By controlling the thickness of the connection part of the keys, it is possible to simulate different force of the keys (Figure 28-32).
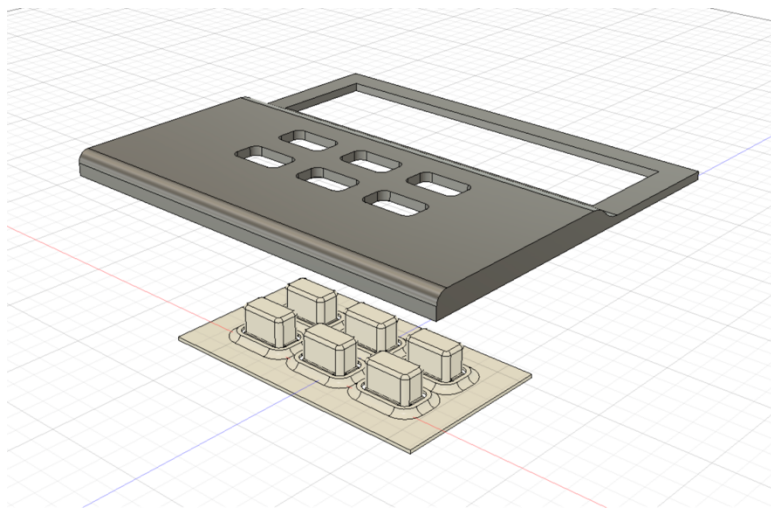
Figure 28: Buttons exploded view
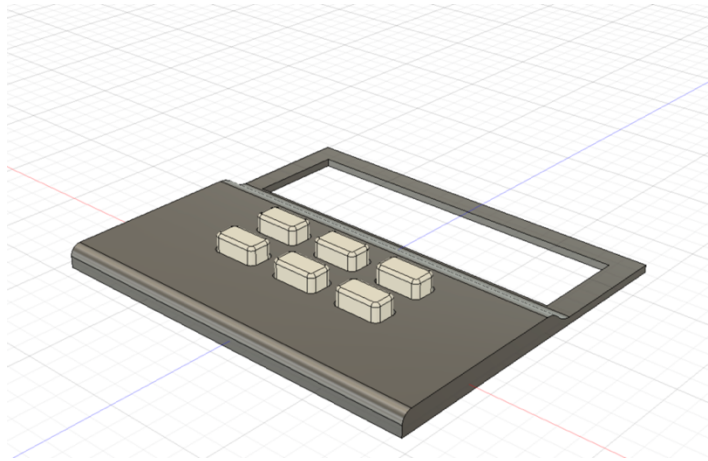
Figure 29: Buttons assembly
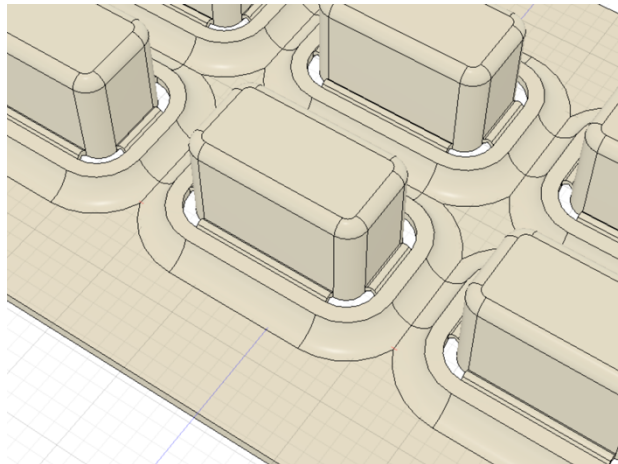
Figure 30: Buttons TPU parts detail 1
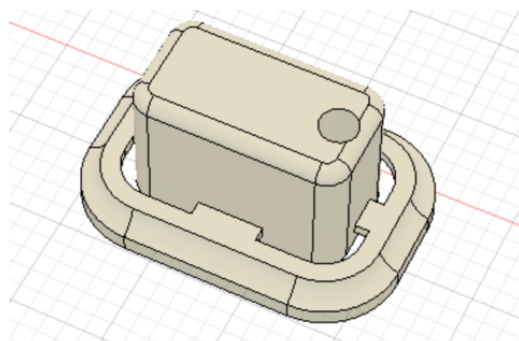
Figure 31: Buttons TPU parts detail 2
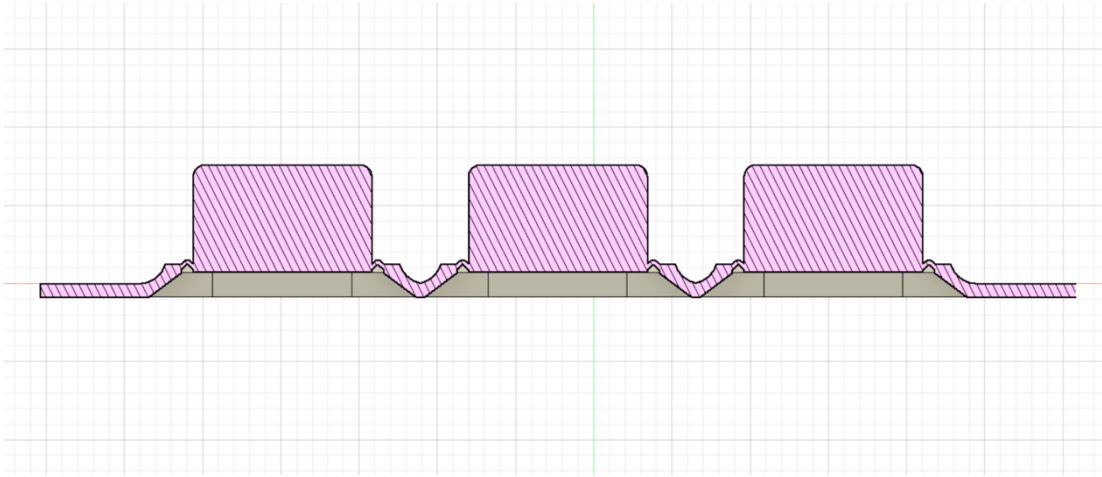
Figure 32: Buttons TPU parts section view

This very simple button can be used to accomplish specific test objectives. Different

force feedback can be achieved by adjusting the length of the button connection (Figure 33-35).
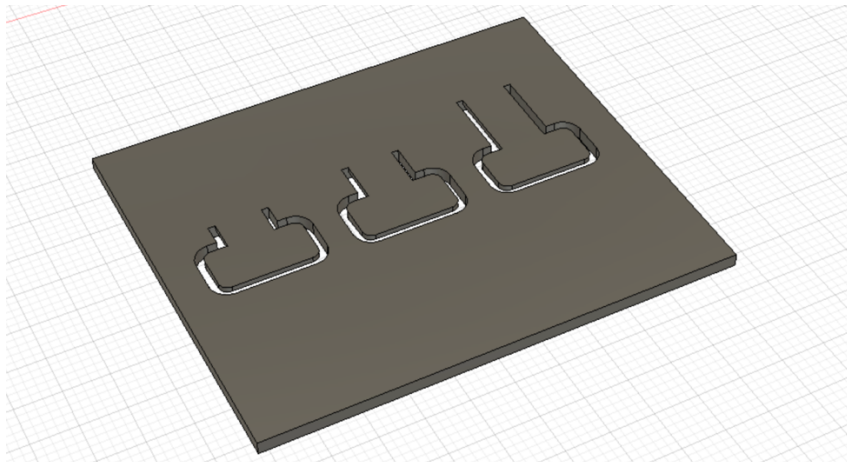
Figure 33: Flat buttons view 1
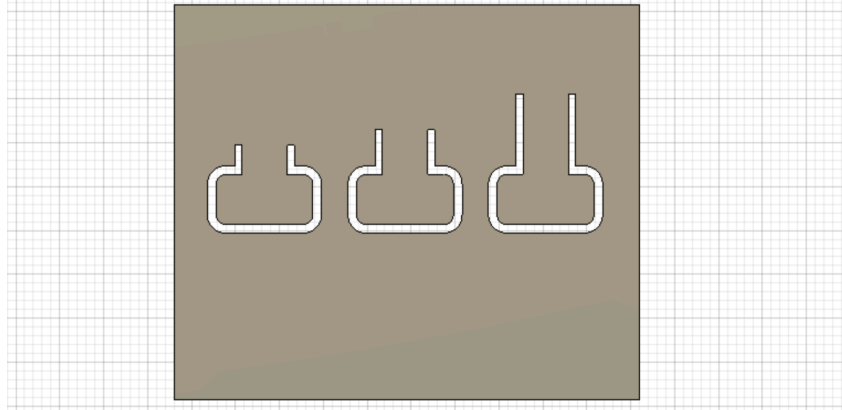
Figure 34: Flat buttons view 2
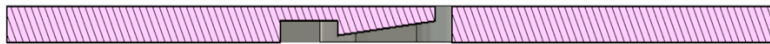
Figure 35: Flat buttons section view

3.7.2.2 Knob

Knobs are recommended to be printed with conductive filament in comparison to buttons, because the surface is often more complex. A simple knob can be used just for the rotating function. By adding a flexible structure under the knob, the function of a button can be achieved (Figure 36, 37).
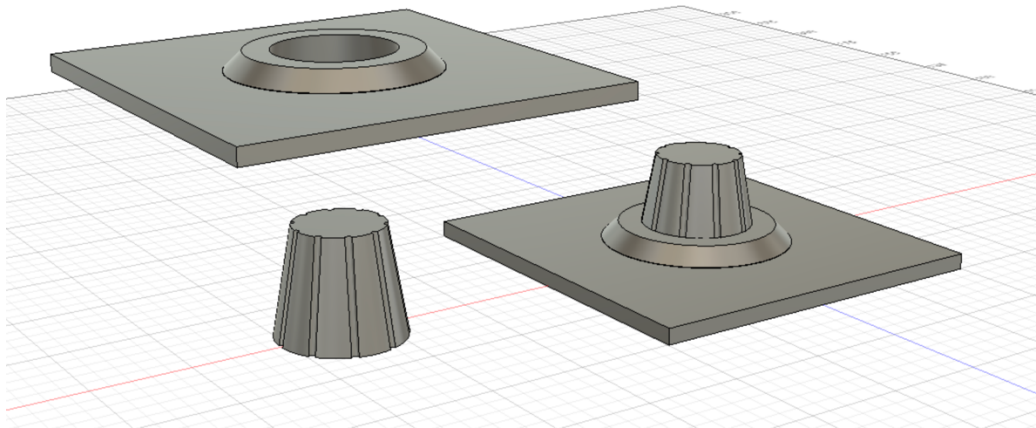
Figure 36: Knobs and exploded view
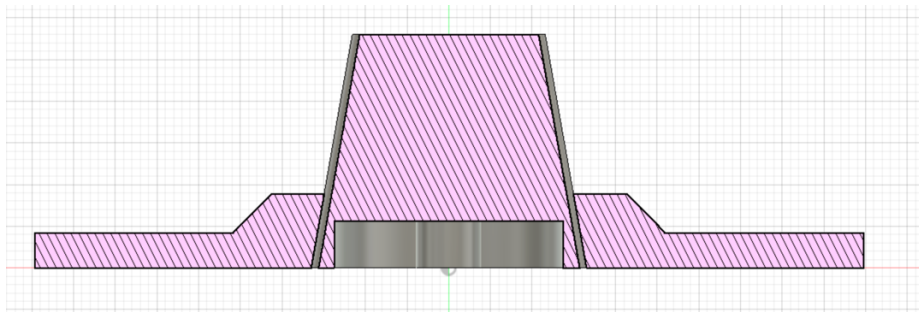
Figure 37: Knob section view

The bottom of the Knob can be a flat surface or, as shown in Figure 38 to 40, it can simulate a finger circling on the touch screen.
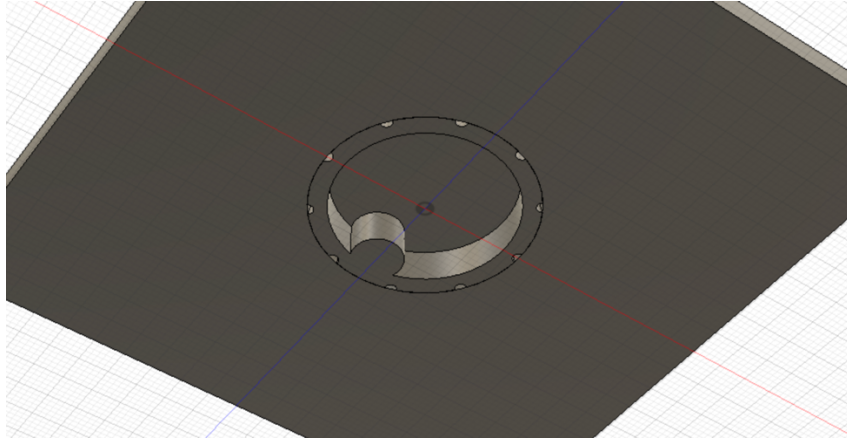
Figure 38: Knob bottom detail
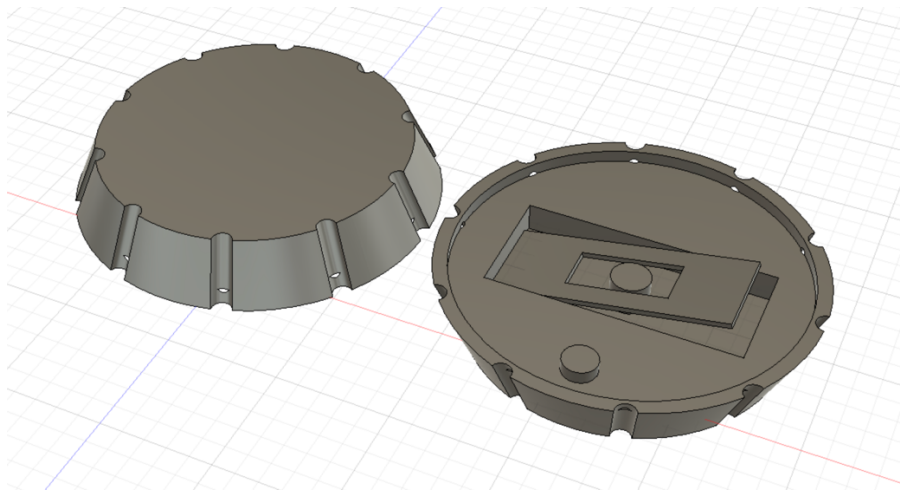
Figure 39: Knob-Button top and bottom detail
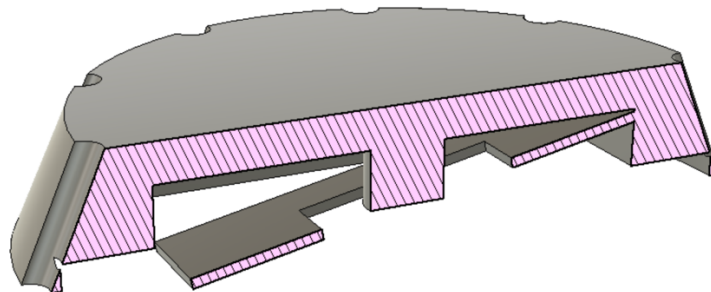
Figure 40: Knob-Button section view

2.7.2.3 Scroll Wheel

It is not easy to get the touch screen to recognize the scroll wheel scrolling directly, but the scroll wheel scrolling can be converted into a press operation through the structure, so that it can effectively interact with the touch screen (Figure 41-43). This is also true for many other operations, which can be converted into different methods of operation to achieve the same effect.
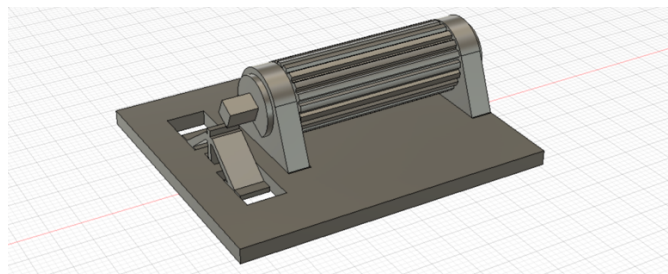
Figure 41: Scroll wheel
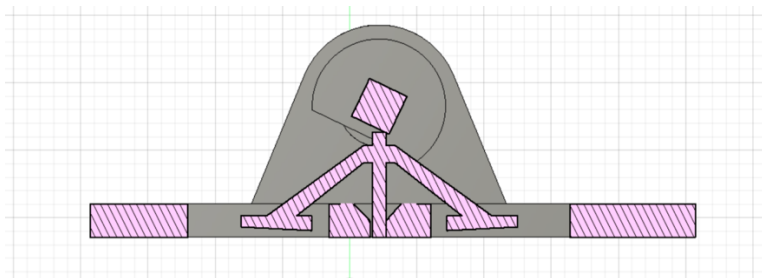
Figure 42: Scroll wheel section view 1
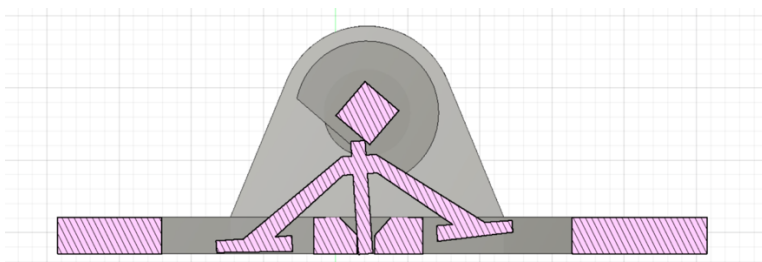
Figure 43: Scroll wheel section view 2

2.7.2.4 Stick/ Switch

Using the elasticity of the material, it is possible to make a stick/toggle switch in the traditional meaning (Figure 44-46).
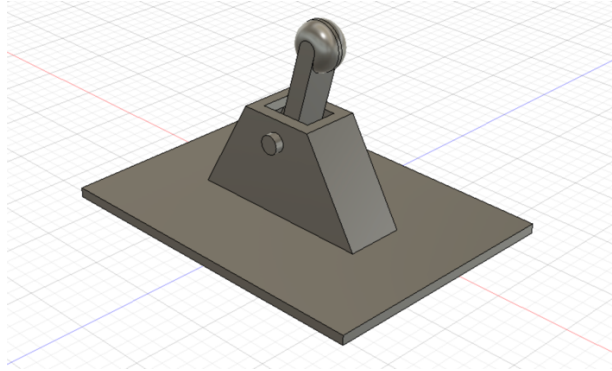
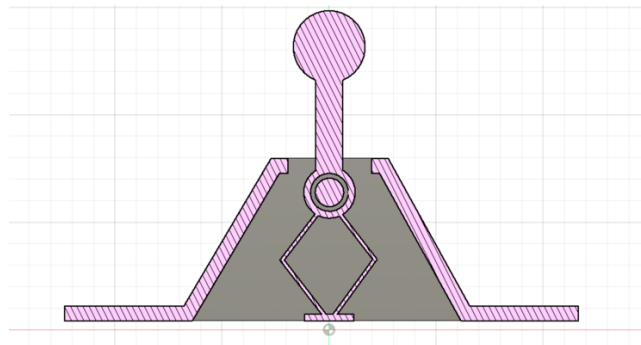
Figure 44: Toggle switch

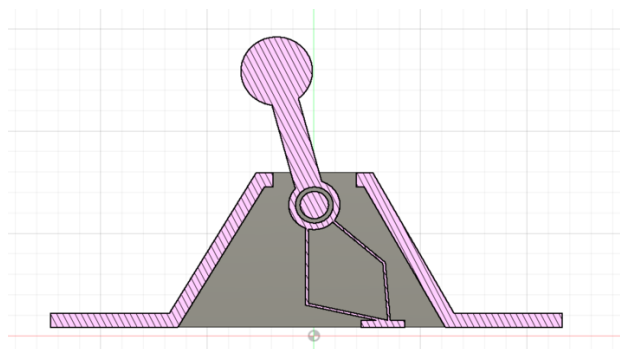Figure 45: Toggle switch section view 1

Figure 46: Toggle switch section view 2

2.7.2.5 Joystick

Joystick can be flat or columnar. By printing the spiral shape spring, the joystick can be kept in the middle position after operate (Figure 47, 48).
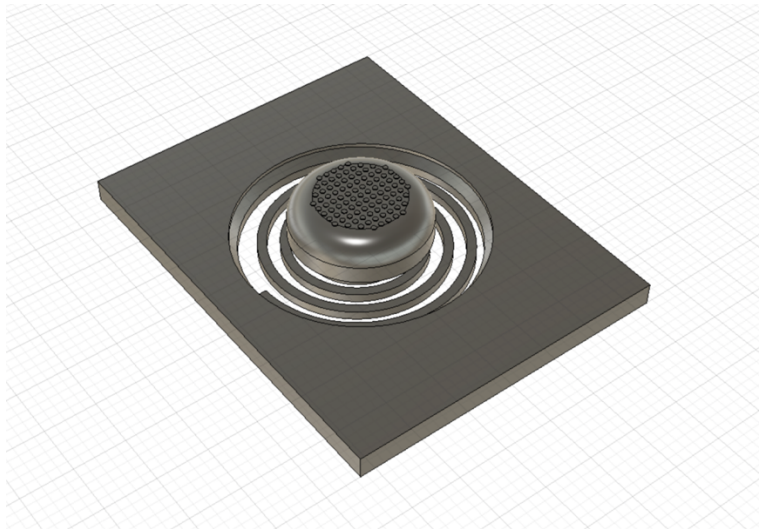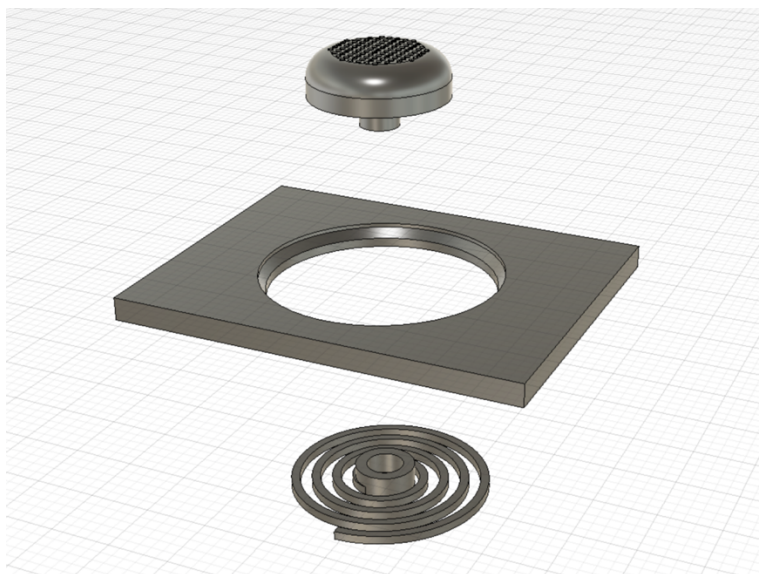

Figure 47: Joystick

Figure 48: Joystick exploded view

3.7.3. Foam and Other Prototype With/Without 3d Print

Some large, not too fine parts, such as the button on the armrest, would take up too much time through 3d printing, so it can be made by using foam and other common materials. Through the conductive marker/pen, the designer should draw a line which links the side of the material in contact with the touch screen, and the button. A remote link is achieved. This way is fast and flexible. By covering the non-button areas with adhesive tape, accidental touching can be avoided.

3.7.4. Bridge Software Ready

According to Chapter 2, the principle of how capacitive screen works, the normal 3D printing filaments and prototyping materials are not capable of interacting with the touch screen. Thus some special methods are needed to make the approach of this thesis feasible.

3.7.4.1. Conductive Filament

By adding metal powder to the filament, the originally non-conductive 3D printed workpiece is turned into a good conductor. This allows the 3-D printing element to interact with the touch screen. However, this approach also has its limitations. For instance, if the whole prototype is printed with this material, there will false touches. Therefore, it is better to print only the parts that are in contact with the fingers.

3.7.4.2 Conductive fabric

The conductive fabric can be cut into small strips and wrapped around the area where it is needed to become a good conductor. Ordinary 3D printed buttons can interact with the touch interface after being wrapped with conductive fabric.

3.7.4.3 Conductive Marker/Pen

Like a marker, the conductive pen leaves a conductive line on the object. This method is more flexible than conductive fabric. The conductivity is achieved by connecting the two sides of the button with the pen. When using this method, it is important to make sure that the model has enough space to draw on the lines. It is also important that the surface of the object is as plain as possible; too many edges can make it difficult to use the pen.

3.7.4.4 Ground Connection

In the case of a button, for example, when both sides of the button are conductive and connected, there is no need for a ground connection. The body's electric field will react directly with the touch screen. However, if only the side of the button that touches the touch screen is conductive, a ground connection is required to provide an electric field for the button. Generally speaking, the electric field can be formed when the conductive material is in contact with a metal object. The metal case of the touch screen can be an excellent place for connecting to the ground wire.

3.8 Bridge Software

Bridge software allows users to customize a variety of different interactions and their positions on a touch screen device (phone, tablet, etc.) as well have the ability to set a hotkey for each interaction. It allows the user to add one or more external devices to the computer through a certain connection to the computer (Figure 49). Any software with these features can be adapted to the prototype testing approach of this thesis. Different software has slightly different types and amounts of interactions, so users may choose different software according to the practical application.
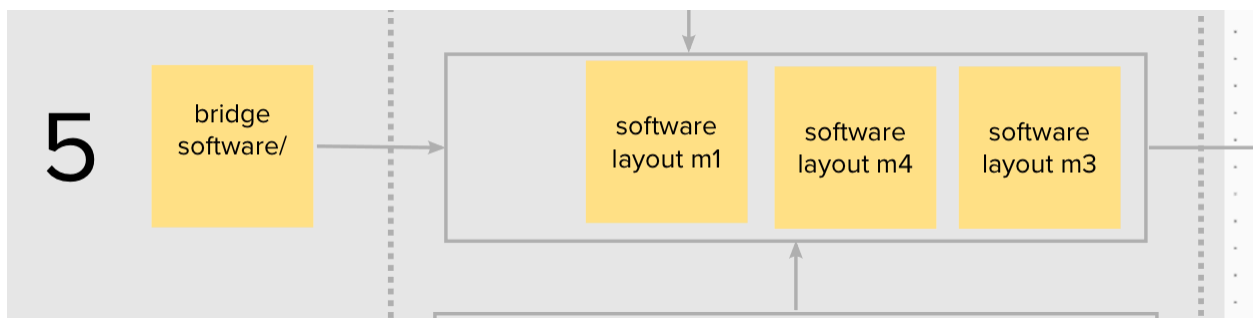

Figure 49: Step5 details

3.8.1 Prepare

Depending on the usage requirements, the corresponding software needs to be set up to adapt to the previously completed physical interaction interface mockup.

3.8.1.1 Create Layout Accordingly to the Physical Mockup

Depending on the position of the different elements in the prototype, corresponding virtual actions need to be mapped out in the software to ensure that their contact points are in reach of the touch screen. Some software supports audio feedback, which can be used to verify

that the positions of the elements correspond to each other without problems. Then the user should save the template.

3.8.1.2 Assign Hotkey to the Layout

Once it is ensured that each interactive element is correctly recognized by the touch screen, the designer should remove the mockup and set the hotkey for each action on the touchscreen. These settings need to be consistent with the hotkey settings later in the UI design software. The process can be tedious, but it can be solved with a trick. Once a template is completed and the hotkey is set, the designer can copy the template and move or change the interaction according for the next set of mockups. This way most of the hotkey setup steps can be skipped.

3.8.2 Connect to PC/Mac

The connection method is not limited to Bluetooth, Wi-Fi or wired connection. Each software has its own method of connection to the PC/Mac, which can be found in the manual of each software.

3.8.3 Test the Hotkey Assignment

After the connection is done, it is similar to a new keyboard-like device connected to the computer. One can test whether the connected hotkey has faithfully restored the previous settings by either testing through a keyboard testing website, or simply opening a notepad and checking it out by cross-referencing the key.

3.9 Testing and Evaluation of The Different Models

After setting up the touch screen and the software on the computer, the designer should place the interactive interface in the location where it needs to be tested. Then the test is ready to start, and step 6 is finished (Figure 50).
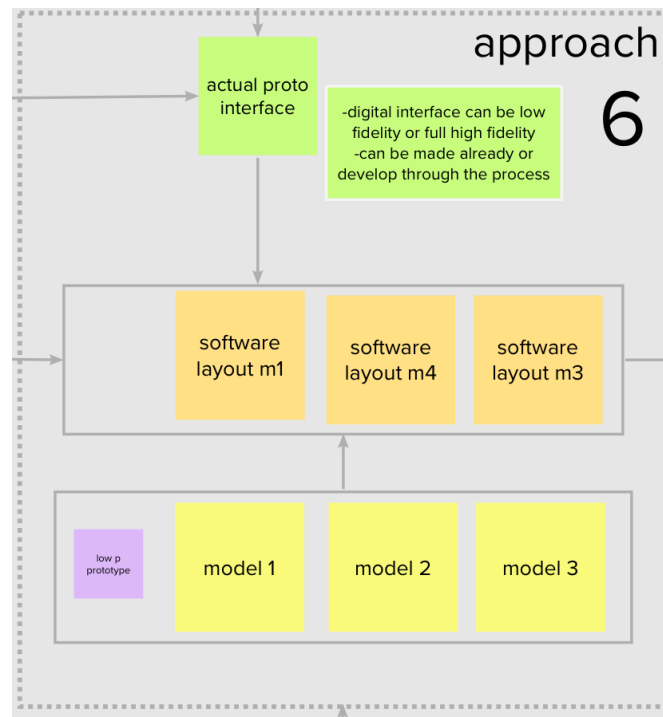

Figure 50: Step 6 details

3.9.1 Methods that Can be Used

There are many specific testing methods, as mentioned in Chapter 2. The more commonly used methods are observation and checklist methods. Depending on the requirements and testing purposes, various evaluation methods need to be adopted. The focus of this thesis on prototype approach is not focused on the specific evaluation process and format, but rather on providing a new approach to testing that allows for the rapid creation of multiple prototypes and

the ability to quickly switch between prototypes to increase test samples. Different users can evaluate different prototypes based on their existing testing processes and criteria.

3.9.2 Evaluate Testing Outcome

Testing can often find problems and directions to solve them. Repeated testing is needed in specific situations (Figure 51).
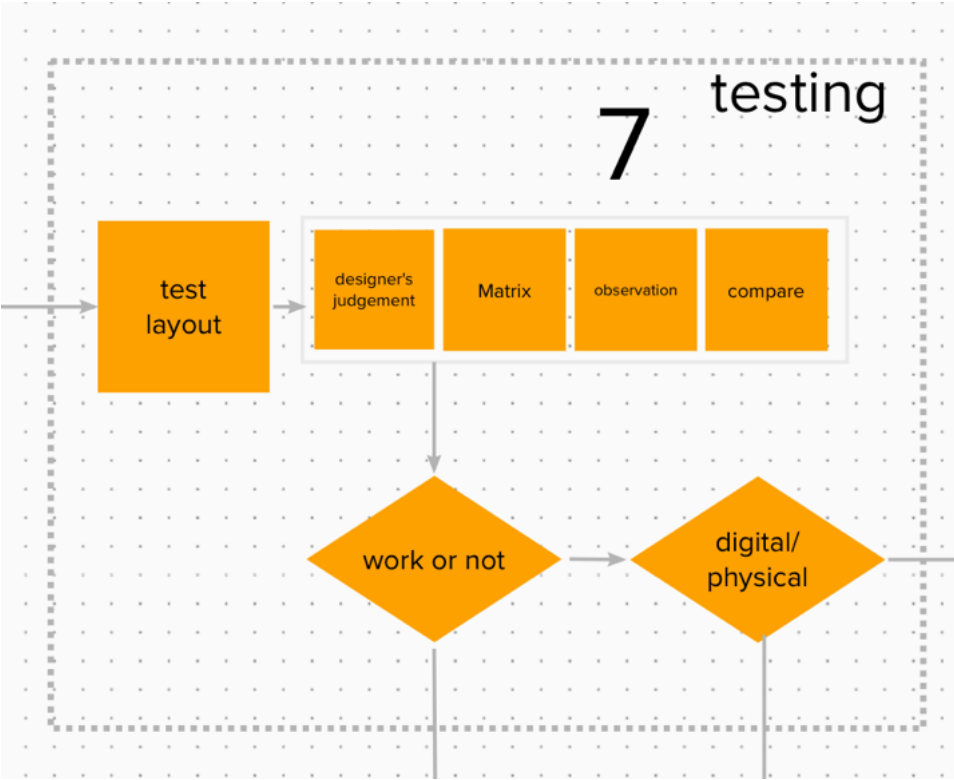

Figure 51: Step 7 Details

3.9.2.1 Good Layout

If a particular prototype stands out, then that prototype can be used as the basis for the next step. However, it is worth being aware that testing usually requires repetition, and if a prototype is perfect in a single test, either the design is very excellent, or the testing methods used are not sufficient to identify potential problems. The reality is often the second one. Multiple tests and multiple approaches are important to test and evaluate.

3.9.2.2 Digital Problem and Route Back

When the UI design leads to a prototype that is not tested as expected, the UI should be revised in reverse. For the case where there is no modification permission for the UI, it should be the same as the case in which the physical interaction interface design causes the prototype's testing to fail to meet the expected goals.

3.9.2.3 Physical Problem and Route Back

When the physical interaction interface design leads to a situation where the testing of the prototype does not achieve the desired goal, the designer can resolve the issue by modifying specific interaction elements, or by recreating one or more interaction mockups, and combining them with the previous tests until satisfactory results are obtained.

Chapter 4: Application

For the sake of application, this chapter focuses on the creation of an in-car screen control panel using the methods and approaches presented in Chapter 3 to simulate real-world situations.
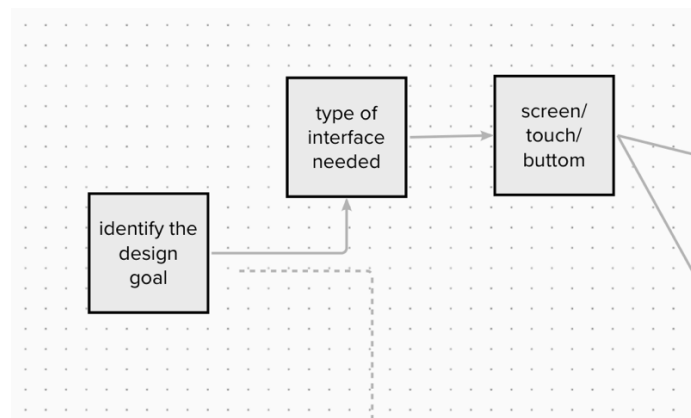
4.1 Application of Method: Step 1 - Definition of Brief

Figure 52: Steps for definition of brief

4.1.1. Identify the Design Goals

In this particular case for a tesla model 3, a large touch screen is located in the center dashboard of the vehicle, which allows different menu selections and controlling certain automobile features. Such as climate controls, seating adjustment, radio control, entertainment system, etc., see Figure 53. In addition to the touch screen, an additional set of redundant control panels are typically desired for different usage conditions, like controlling the touch screen on a bumpy road. It needs to be tested whether this extra control interface is sufficient to improve the user experience and to make the vehicle's human-machine interaction more efficient. If it is

feasible to enhance the efficiency, then what is the optimal control form as well as the position (Figure 52).

Figure 53: Project vehicle's interior (Korosec, 2019)

Specifically, the effort here will be simulate the control of the vehicle's air conditioning system during driving, including but not limited to air conditioning temperature, volume of the air flow, defrosting the windshield, heating the rear view window, etc.

4.1.2 Type of the Interface is Needed

Besides the touch orientated touchscreen, the form of the redundant control panel is not restricted. It can be electronic touch-based controller or physical control interface. In addition to

the above, in order to better evaluate the influence of different operational approaches on the driver, the interface will integrate a variety of different control methods, including buttons, knobs, toggles, sliders, etc., where appropriate

4.1.3 Screen/touch/button

The location of the control panel is also flexible, it can be on the lower side of the touch screen, or away from the touch screen, beyond the Eye-level view. Based on the foregoing information, it can be determined that this system is suitable for the proposed methodology. The digital interface and the physical control interface need to be tested as a package in order to find the most appropriate design. In this section, three different positions will be used for the simulation as shown in the figure 54. Directly below the screen, next to the armrest panel, and on the steering wheel.
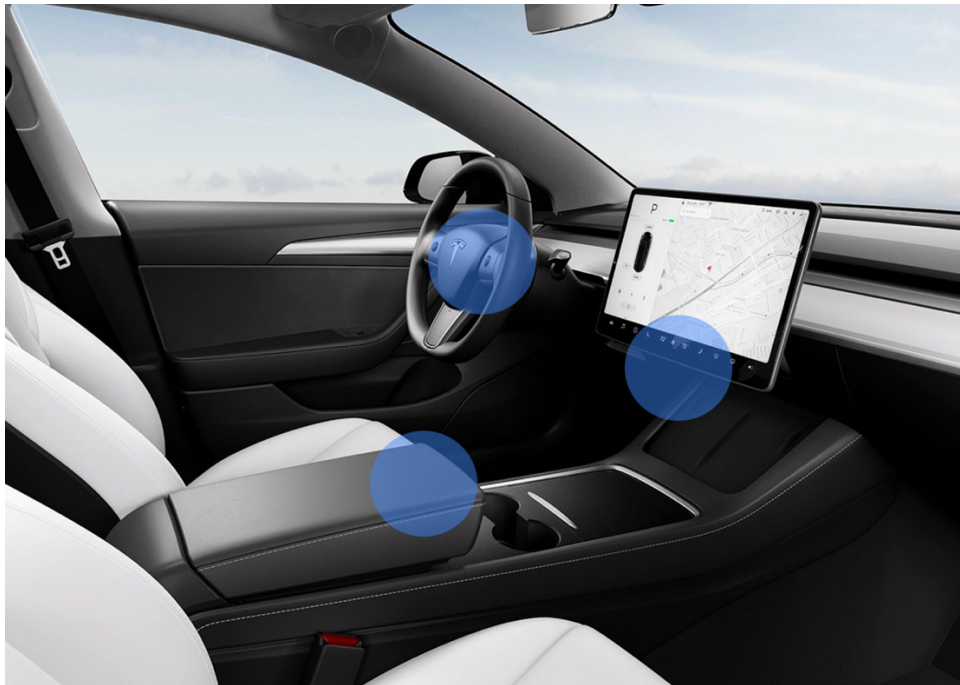

Figure 54: Project vehicle's interior and three different position for the control interface

4.2 Application of Method: Step 2 – UI design

In this case, the design of the UI is already done, so it can be applied directly to the test (Figure 55). However, it still needs to be optimized to become a prototype that bridge software can manipulate.
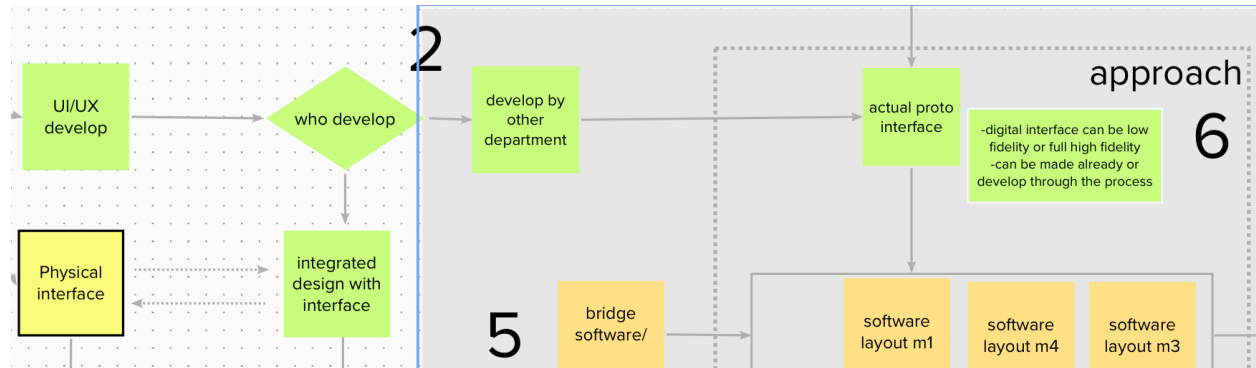

Figure 55: UI design process

4.2.1 Who Will Develops UI

In this case, the touch-based UI interface has been designed in advance and can be used directly for testing the prototype. In this case, the touch-based UI interface has been designed in advance and can be used directly for testing the prototype. Although different departments are responsible for the UI design, the industrial designers can still provide timely feedback on problems encountered and potential solutions. This will be beneficial for the whole project.

4.2.2 Developed by Other Department

In this case, the existing UI has been completed, and the designer can design the corresponding control element according to the pattern of the existing UI (Figure 56, 57).
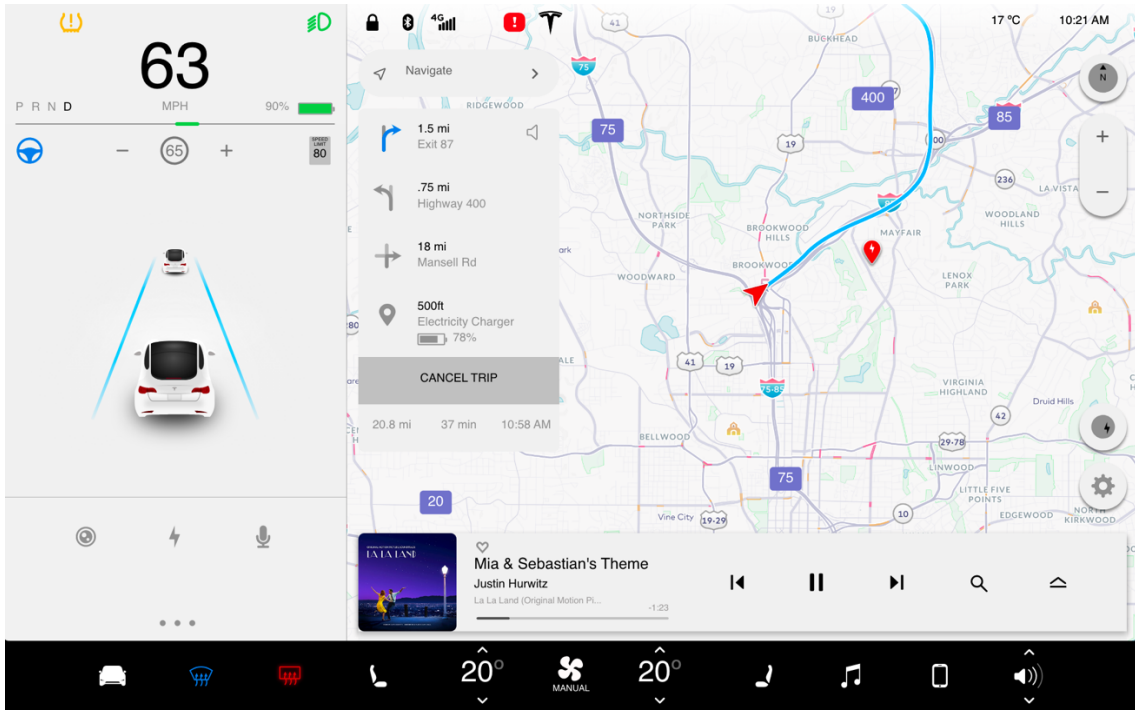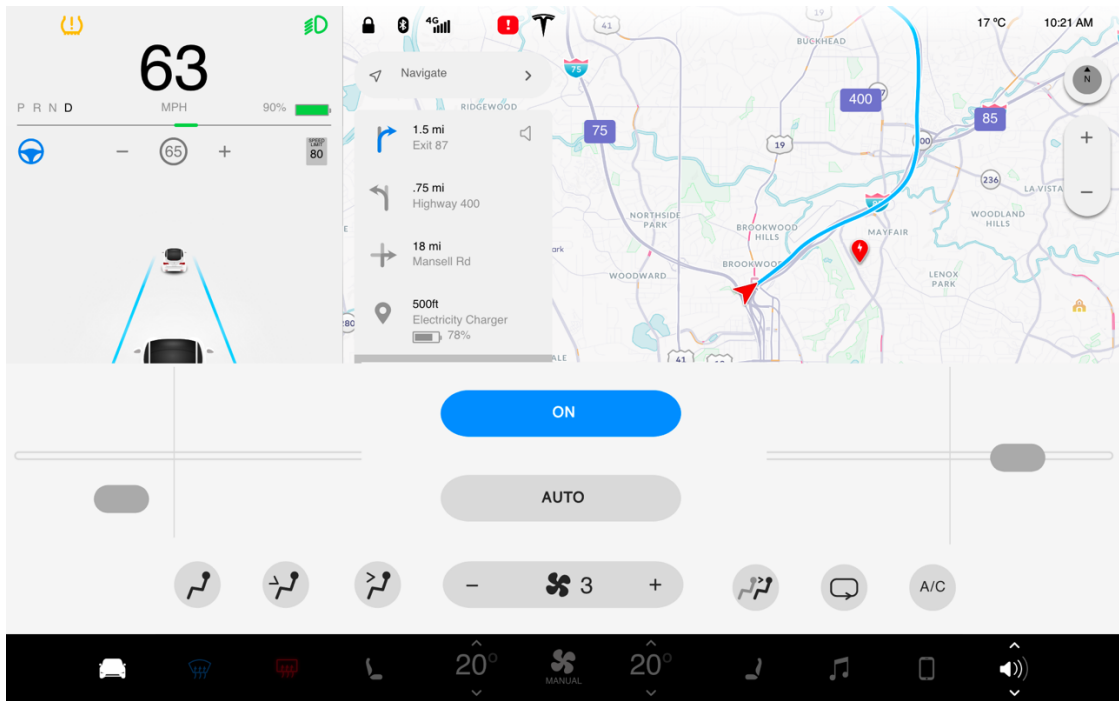
Figure 56: UI for the main screen

Figure 57: Climate control UI detail

4.2.3 Actual Prototype Interface

As mentioned before, it is not enough to only have a working prototype of UI, in order to make the UI and the mockup work together afterwards, it is necessary to set the corresponding hotkey for each demo step. Take adobe Xd as an example, the normal prototype test is implemented by mouse click and swipe, as shown in the Figure 58.

Figure 58: Adobe Xd prototype page and links

On top of that, set the hotkey corresponding to the bridge software, for example, to map specific numbers, by clicking the desire link and assign a specific hotkey to it by selecting the tab on the right of the page (Figure 59). The specific steps will be explained in detail in the following sections. After this, the UI prototype is ready to be successfully interacted with through the mockup.
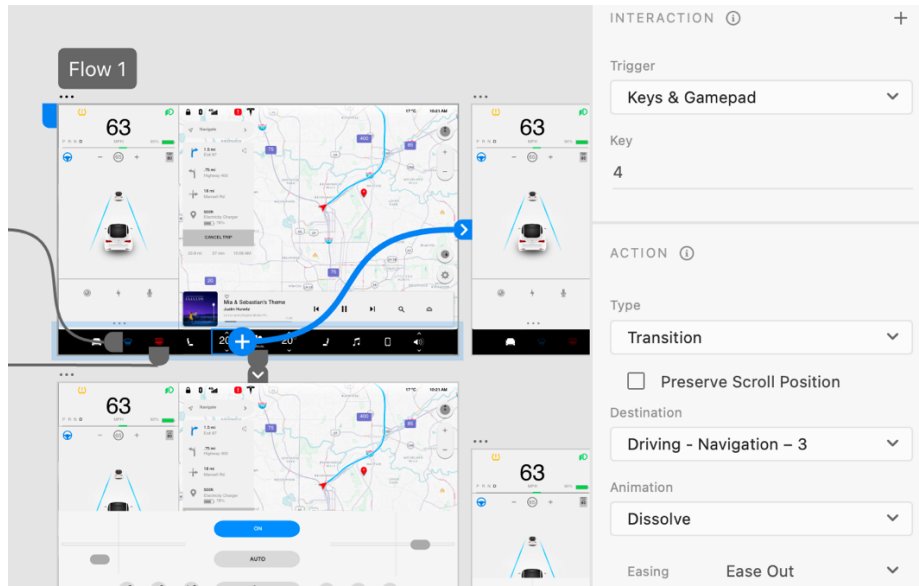
Figure 59: Assigning hotkey number 4 to the link.
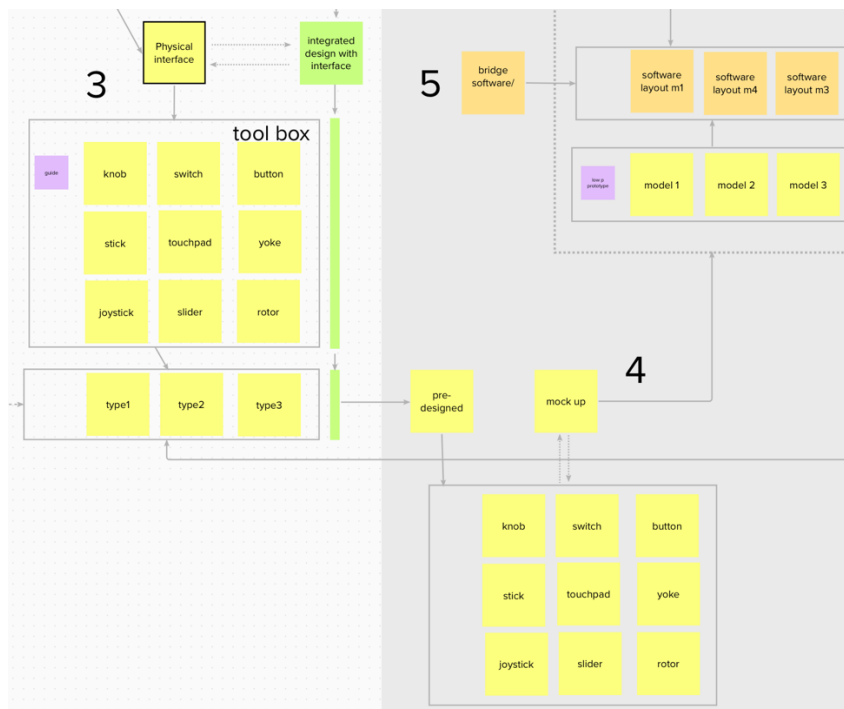
4.3 Physical Interface

Figure 60: Physical mockup process

In this section, specific physical control interfaces will be designed and created. The design is carried out by selecting different control elements. After the general design direction is completed, the control panel will be printed out through 3d printing, and then the printed parts will be able to interact with the touch screen through the various methods mentioned in the previous sections (Figure 60).

4.3.1 Utilizing tool box to create Type1, Type 2 and Type 3

This process utilizes the strengths and weaknesses of the different controls mentioned in the previous chapters, combined with the designer's own experience and knowledge to create a suitable control interface. In this process, ideation sketching is involved, refining the most feasible options worth testing in the sketch. The final selection was type1 for the screen, type2 for the armrest, and type3 for the steering wheel (Figure 61).
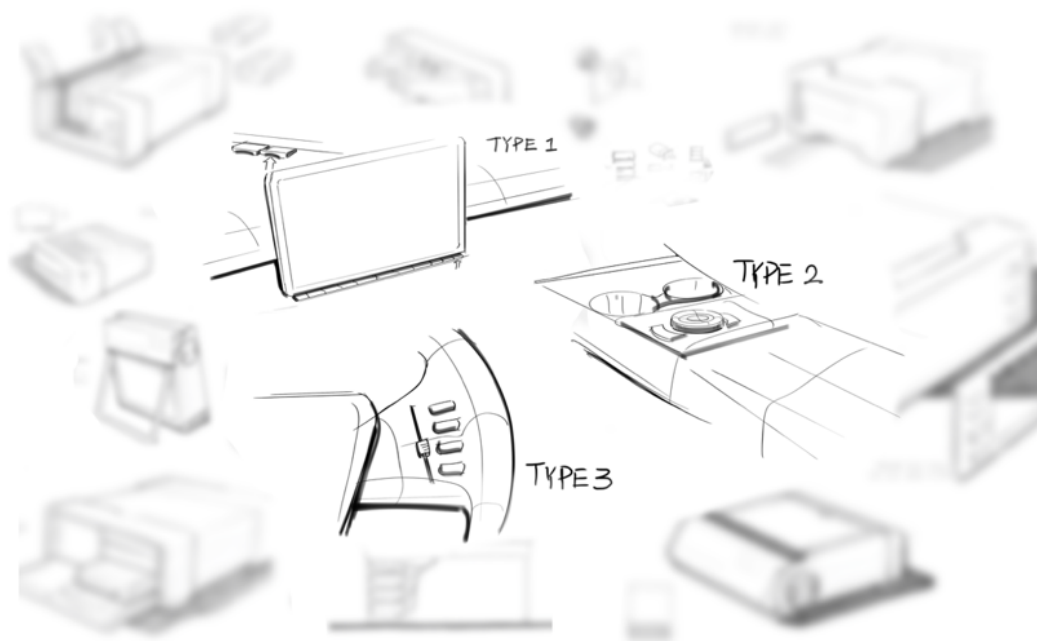

Figure 61: Sketch ideation to type 1-3

Type1 will use a row of buttons at the bottom of the touch screen, which corresponds to the lowest row of buttons on the UI, and is available for selection by the corresponding position. It adds a tactical operation approach without affecting the original aesthetics.

Type2 adds a set of control panel with knobs and buttons next to the armrest compartment. The knob selects the different control menus and the buttons for confirmation and return. With a set of simple control logic, the user can operate blindly.

Type3 adds four buttons to the steering wheel to select different control units and use the slider to quickly adjust to the desired target setting.

The three different operation methods all allow for controlling the air conditioning system without touching the touch screen.

4.3.2 Creating CAD model and mockup

3d modeling replicates the essence of the sketch, while faithfully reproducing of different means of operation, at the same time, 3d printing allows ideas to be easily and quickly transformed into parts that can interact with the touch screen (Figure 62-65).
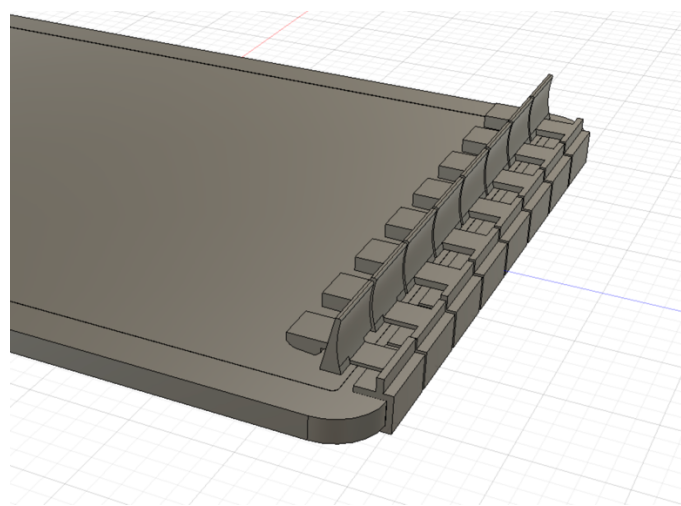

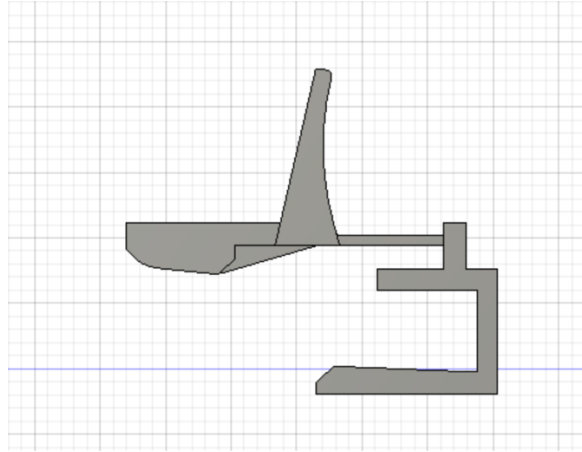Figure 62: Type 1 3d model

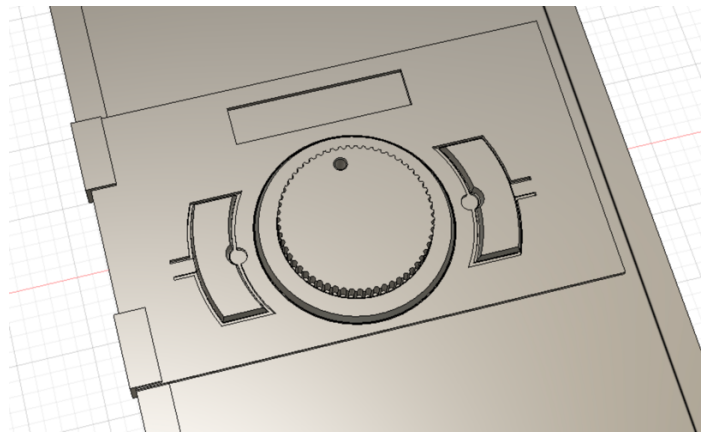Figure 63: Type 1 3d model side view

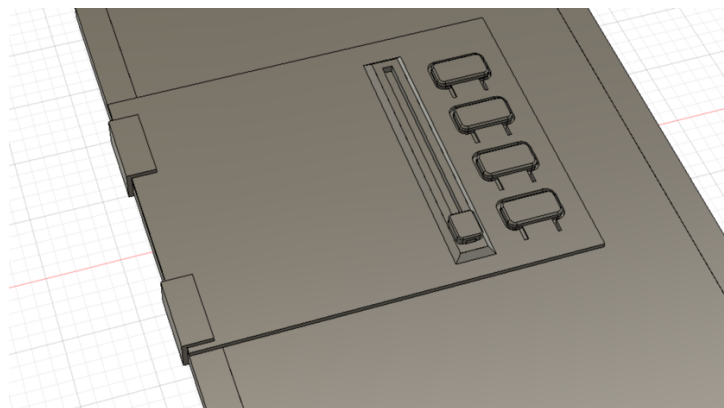Figure 64: Type 2 3d model with rotor and buttons

Figure 65: Type 3 3d model with buttons and slider

In this step, the models focus on the operating experience, allowing them to simulate interaction with the way the design operates. After that, the mockup can be made quickly using 3d printing as shown in figure 66 to 68.
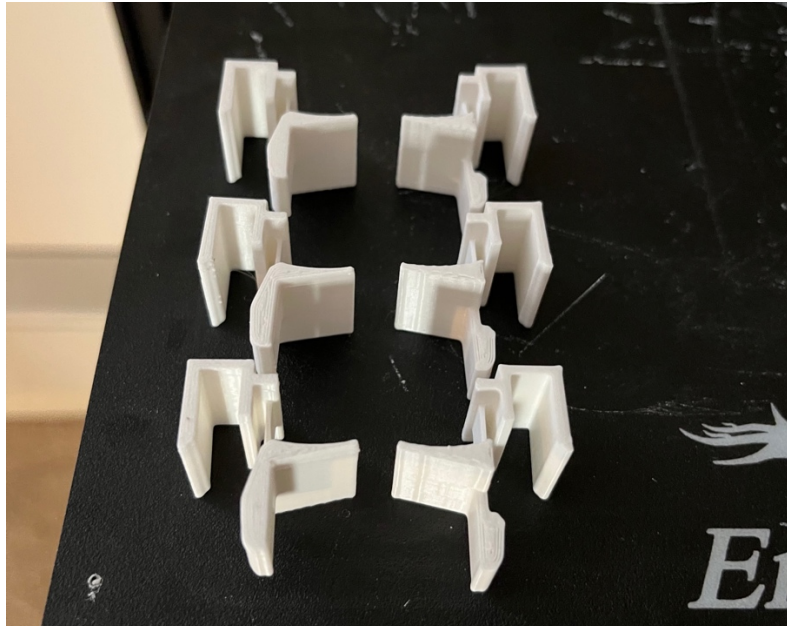

Figure 66: Type 1 3d printed mode
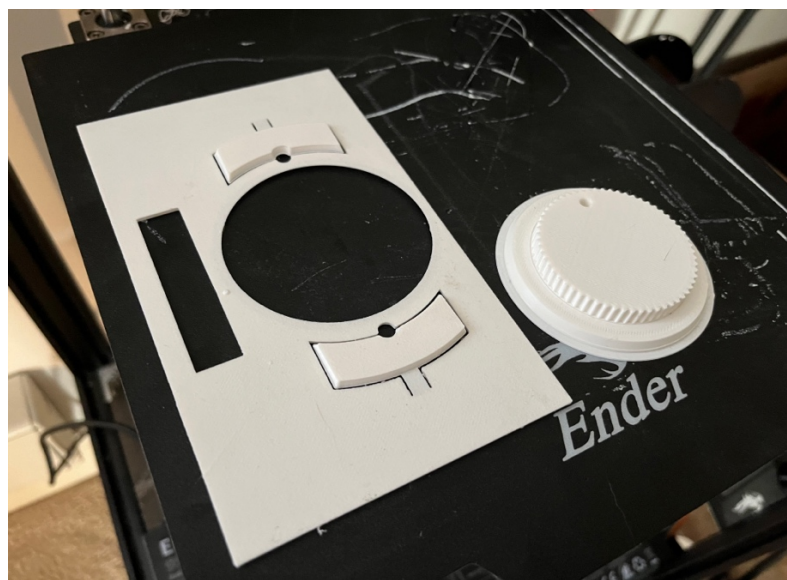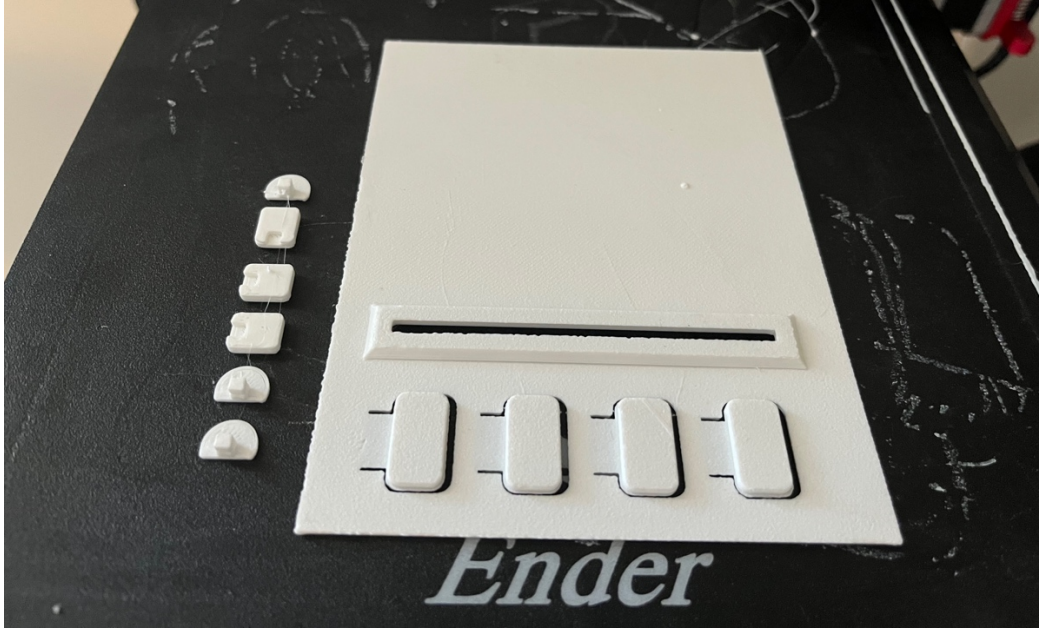

Figure 67: Type 2 3d printed model

Figure 68: Type 3 3d printed model

4.3.3 Make Model Touchscreen Ready

The conductive fabric used here can be cut into small strips and wrapped around the area where it is needed to become a good conductor both contacting finger and touchscreen. Ordinary 3D printed buttons can interact with the touch interface after being wrapped with conductive fabric as shown in Figure 69, Figure 70 and Figure 71. Without this, the capacitive touch-screen will not respond.
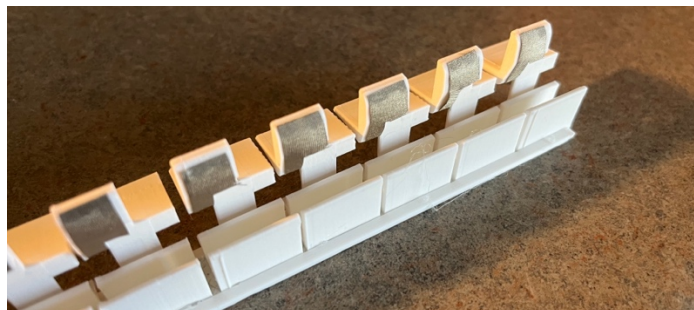

Figure 69: Type 1 3d printed model wrapped with conductive fabric
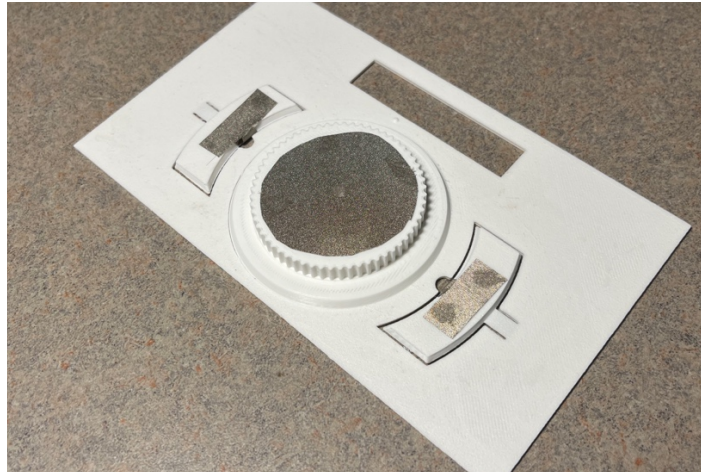
Figure 70: Type 2 3d printed model wrapped with conductive fabric

Figure 71: Type 3 3d printed model wrapped with conductive fabric

4.4 Bridge Software Layout

The software used in this case is Custom ControlPad (CCP) for iPad. This software allows creating button layouts that correspond to mockups (Figures 72-76) Use this software to create the corresponding layout and add the corresponding hotkeys. After connecting to a computer on the same Wi-Fi, the mockup can be controlled on adobe Xd and tested.

Figure 72: Type 1 bridge software layout
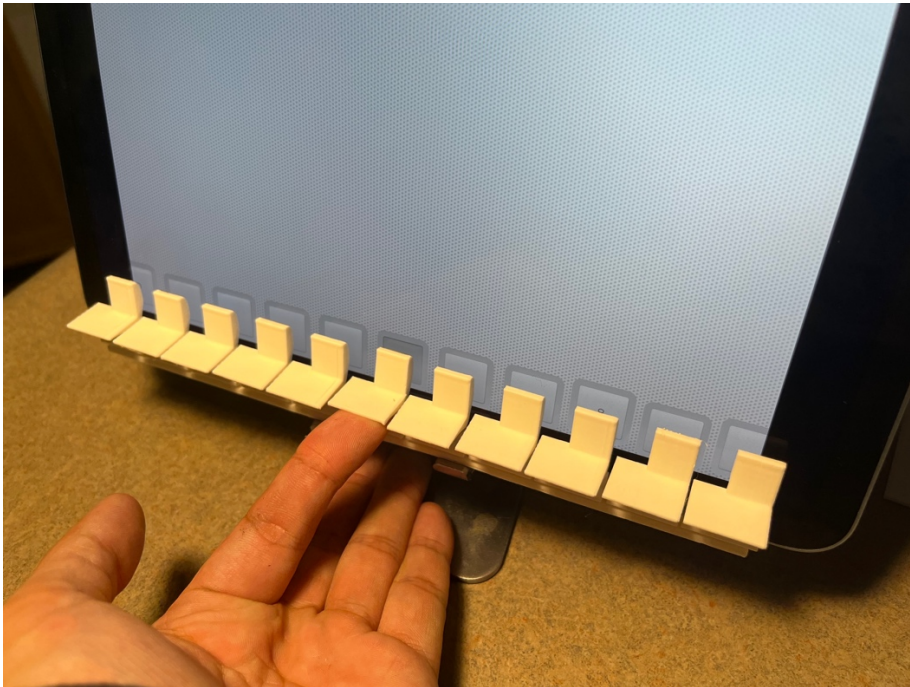
Figure 73: Type 1 bridge software layout corresponding physical mockup layout
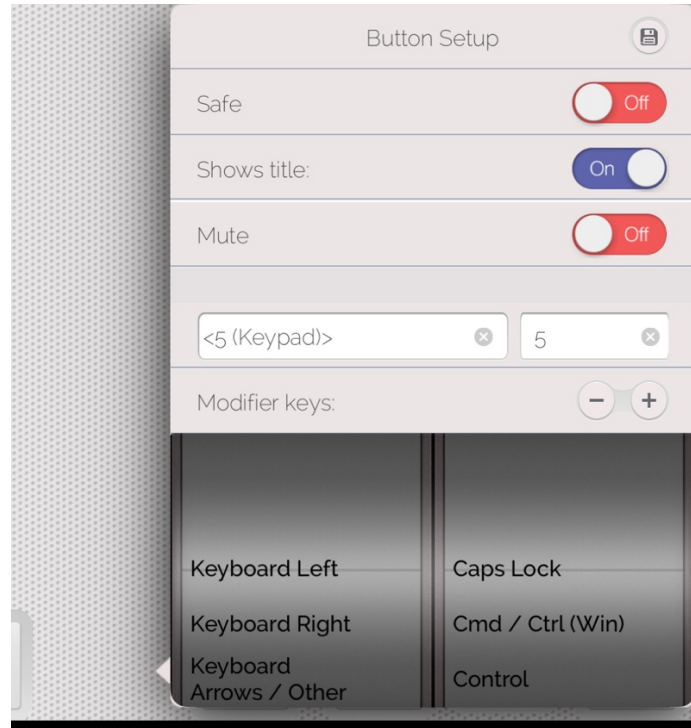
Figure 74: Type 1 bridge software corresponding hotkey setting
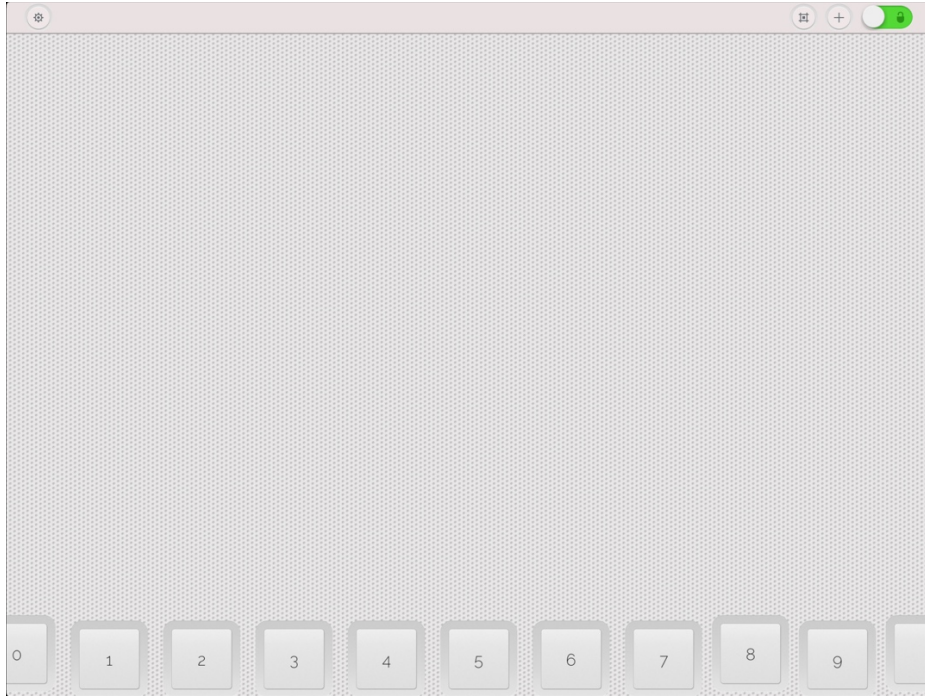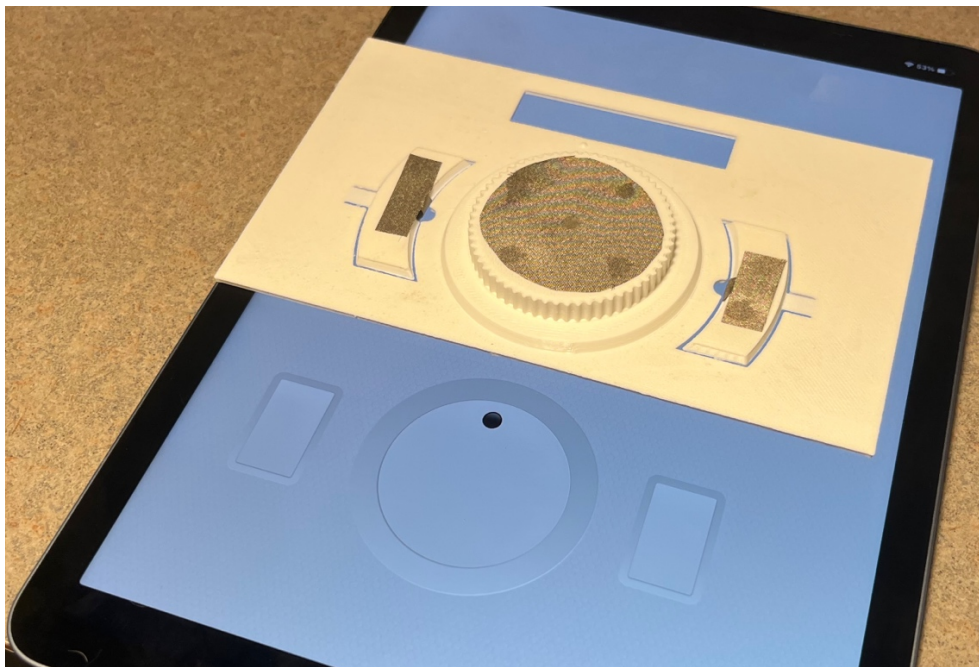

Figure 75: Type 2 bridge software layout corresponding physical mockup layout
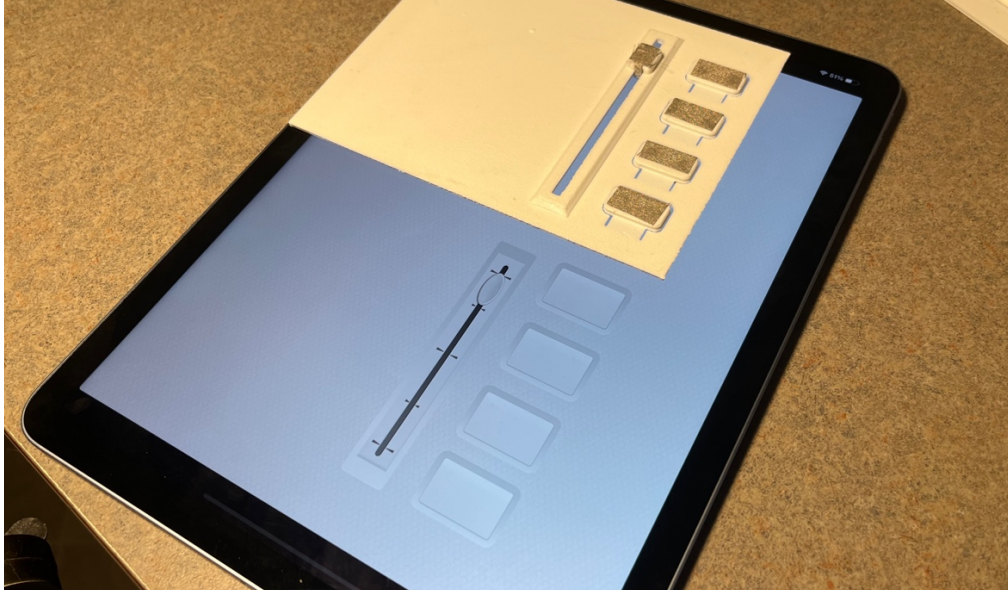
Figure 76: Type 3 bridge software layout corresponding physical mockup layout

4.5 Combine UI, Bridge Software and Mockup

When all three elements are ready, it is time to combine them as a functional prototype (Figure 77). The mockup is overlaid on the corresponding layout on the iPad, the iPad is connected to the computer, and the CCP software on the iPad is connected to Adobe Xd.

After that, place the iPad or the corresponding control module on the test location according to demand, and the test can be started.
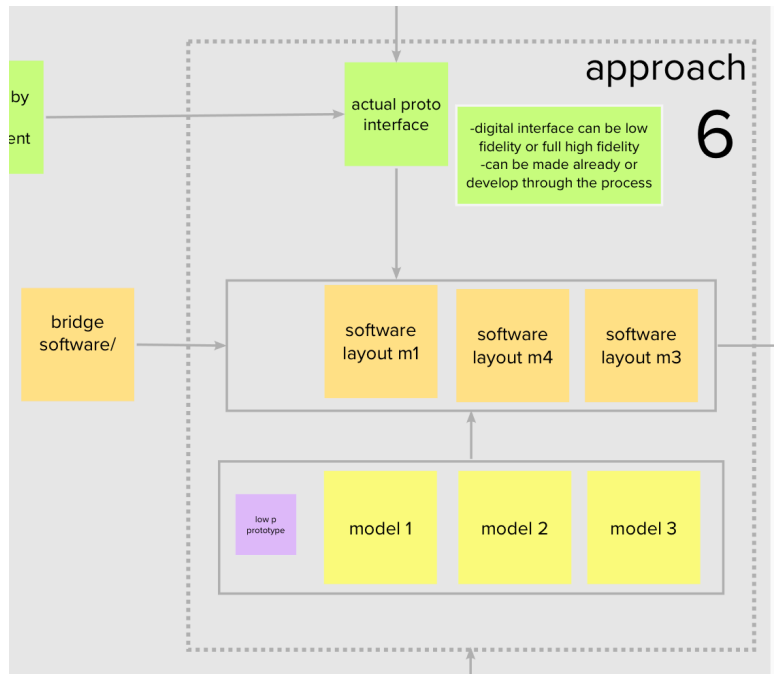
Figure 77: Bridge software process

4.6 Testing Setup

As a rapid test, the setup conditions do not have to be perfect, as long as they meet the test conditions.

4.6.1 Type 1 Setup

In the type1 test, the control panel/iPad was hidden behind the display and only the buttons were exposed (Figure 78). The display shows the UI prototype in Adobe Xd. By controlling the physical buttons on the iPad, the interaction with the UI on the monitor was tested. The air conditioning system of the car can be controlled by pushing the button, including controlling the air flow, adjusting the air flow direction, adjusting the temperature, defrosting the windshield, etc. (Figure 79).

Figure 78: Set-up for type 1 testing
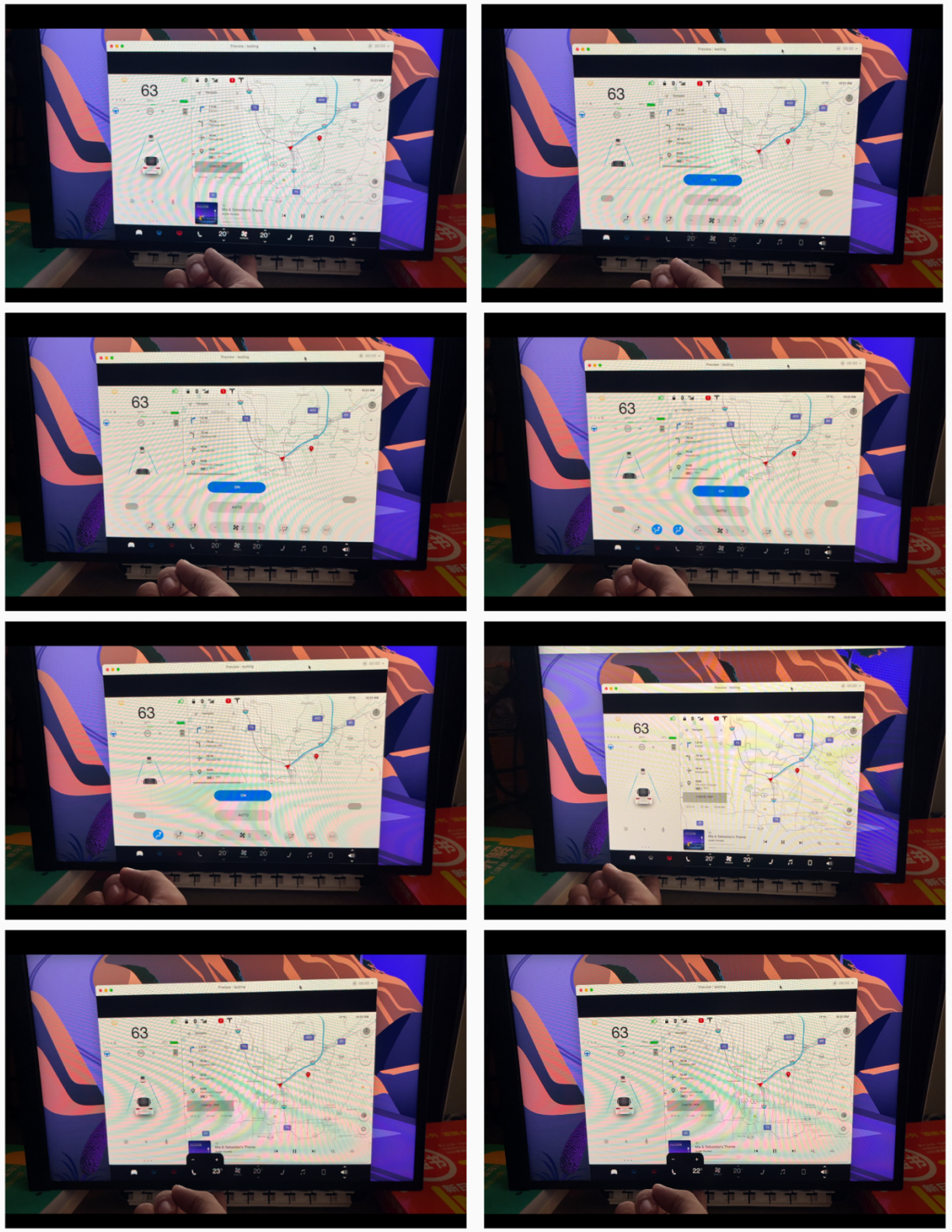
Figure 79: Type 1 prototype controlling the climate setting

4.6.2 Type 2 Setup

The type 2 setup uses a computer to simulate the touch screen in the car, and places the

control unit in a position that simulates the armrest (Figure 80).
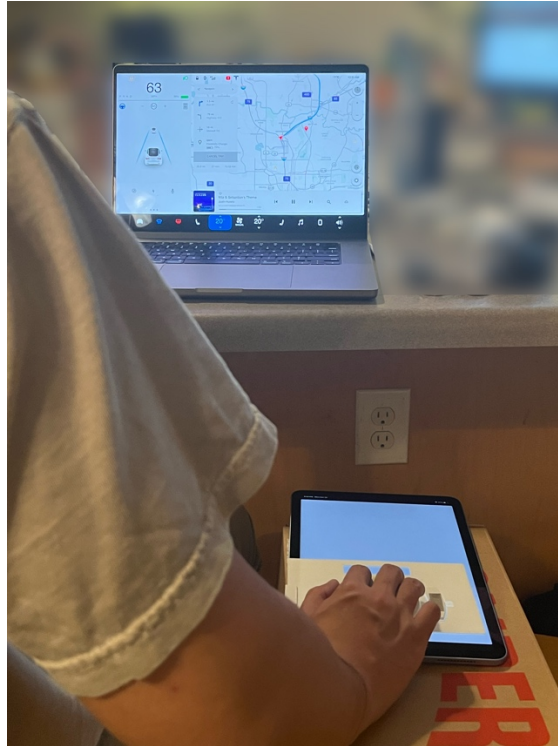
Figure 80: Set-up for type 2 testing

Use of the knob to move the blue highlight in the screen, and then confirm with the left

button after moving to the desired position. Return with the right button.

4.6.3 Type 3 Setup

Attach the iPad to an object that simulates a steering wheel. The buttons on the steering

wheel are accessed by using the thumbs. The four buttons on the steering wheel correspond to

temperature, air volume, wind angle and windshield defrost. After selection, the selected content

is adjusted via a slider to control the car's climate system (Figure 81).

Figure 81: Set-up for type 3 testing

4.6.4 Testing Result

The test methods and results are subjective and are not be the focus of this thesis. This thesis focuses more on the tools and how rapid the testing methods can be made. The results will depend on the actual situation.

Application Summary

Through the practical use of the three example tests, it can be found that all the tools used are familiar to industrial designers. From sketching to 3d modeling, to 3d printing. These test tools do not require in depth cooperation of other departments and can be designed and manufactured quickly and tested effectively. These steps are simpler and faster than the traditional testing process, and more importantly, this approach tests both the UI and its operational aspects at the same time.

Chapter 5: Conclusion

Conclusion

With the evidence in Chapter 2, a simple and effective prototyping method is needed. In Chapter 3, the prototyping process is described in detail, as well as how to combine digital and physical interfaces for testing. Through the practical examples in Chapter 4, three different physical interfaces are quickly created and combined with the developed UI interfaces. All three prototypes were able to control the air conditioning system of the vehicle under test. This is where testers can perform tests and simulations.

Compared to a traditional electronic prototyping approach, this new prototyping approach combine digital and physical interfaces, allowing them to be tested simultaneously. At the same time, the new approach is easier and more convenient to create. By using materials and technologies that designers are familiar with, it is possible to minimize lengthy multi-departmental collaborative work upfront and increase efficiency.

Further Research

The focus of this thesis is to demonstrate that a new approach to prototyping is feasible. However, there are still many considerations that need to be investigated further.

The bridge software involved in the thesis was not designed specifically to produce this type of prototype. Many features are not ideally adapted to the designer's need for interaction. In the future, modifying this software or developing software tools that are more appropriate to the prototype approach of this thesis can further improve the speed and effectiveness of the approach to prototyping within this thesis.

In addition, there is room for improvement in the design of the physical interaction unit involved in the thesis. This thesis only provides a design concept, and does not go into depth on the aspect of the unit. The specific structures, such as the thickness of multiple prints, how the parts are assembled, the specific parameters of the print, etc., require some level of expert knowledge. The knowledge base of these things varies from person to person, and some designers may be more comfortable using this thesis than others. In the future, a platform, or set of algorithms, that can collect and share different parts designed by different designers would greatly enrich the possibilities of this method. It would help designers to create prototypes better.

Andersen, K. W. (2022, July 7). *What is a Stylus? Types of Stylus & Stylus Pens Explained*. National Pen. Retrieved September 26, 2022, from https://www.pens.com/blog/what-is-a-stylus/

App Store. (2013, December 22). *CCP Custom Control Pad Lite*. Retrieved September 26, 2022, from https://apps.apple.com/us/app/ccp-custom-control-pad-lite/id782526884

Benne, J. (2021, August 21). *Elgato Stream Deck MK.2 Review: A Streamer's Best Friend*. Tom's Hardware. Retrieved September 26, 2022, from https://www.tomshardware.com/reviews/elgato-stream-deck-mk2

Beruscha, F., Krautter, W., Lahmer, A., & Pauly, M. (2017). *An evaluation of the influence of haptic feedback on gaze behavior during in-car interaction with touch screens*. 2017 IEEE World Haptics Conference (WHC), World Haptics Conference (WHC), 2017 IEEE, 201–206. https://doi-org.spot.lib.auburn.edu/10.1109/WHC.2017.7989901

Boy, G. A. (2020, January 27). *Human–Systems Integration: From Virtual to Tangible* (1st ed.). CRC Press.

Boyl, B. (2019). *Interaction for designers:How to make things people love*. Routledge.

Burns, M. (2020, December 2). *TechCrunch is part of the Yahoo family of brands*. Retrieved September 26, 2022, from https://techcrunch.com/2020/12/02/im-obsessed-with-the-ford-mustang-mach-e-physical-touchscreen-volume-knob/

CAD CROWD. (2020, July 7). *How Industrial Designers and Engineering Services Have Influenced the Product Design World*. Cad Crowd. Retrieved September 20, 2022, from

https://www.cadcrowd.com/blog/how-industrial-designers-and-engineering-services-have-influenced-the-product-design-world/

Campbell, M. (2013, February 19). *Apple awarded patent for more accurate haptic feedback system*. AppleInsider. Retrieved September 13, 2022, from https://appleinsider.com/articles/13/02/19/apple-awarded-patent-for-more-accurate-haptic-feedback-system

Celusnak, B. M. *Teaching the iPhone with Voiceover Accessibility to People with Visual Impairments. Journal of Visual Impairment & Blindness.* 2016;110(5):369-372. Accessed November 26, 2020. https://search-ebscohost-com.spot.lib.auburn.edu/login.aspx?direct=true&db=eric&AN=EJ1114771&site=eds-live&scope=site

Dobry, W. (2017, September 28). *Future UI Design Without Buttons*. Toptal Design Blog. Retrieved September 21, 2022, from https://www.toptal.com/designers/ui/future-ui-design-without-buttons

Dreyfuss, H. (2012). *Designing for people*. New York: Allworth Press.

Engineering Product Design. (2022, March 18). *What is Rapid Prototyping, prototyping techniques, benefits and limitations*. Retrieved September 25, 2022, from https://engineeringproductdesign.com/knowledge-base/rapid-prototyping-techniques/

Feldberg, I. (2021, December 21). *How Designers and Engineers Can Collaborate More Closely*. Built in San Francisco. Retrieved September 20, 2022, from https://www.builtinsf.com/2021/12/21/designer-engineer-collaboration

Ferris, T. K., Suh, Y., & Miles, J. J. (2015). *Investigating the Roles of Touchscreen and Physical Control Interface Characteristics on Driver Distraction and Multitasking Performance.* University of Michigan, Texas A&M Transportation Institute College Station.

Fieldscale. (2019, March 1). *Why don't touch screens work with gloves on?* Retrieved September 26, 2022, from https://fieldscale.com/blog/touch-screens-with-gloves-on/

Hallgrimsson, B. (2012, October 3). *Prototyping and Modelmaking for Product Design (Portfolio Skills)*. Laurence King Publishing.

Hallgrimsson, B. (2019). *Prototyping and modelmaking for product design* (Second edition.). Laurence King Publishing.

HMI Guide. (n.d.). Retrieved September 21, 2022, from https://www.anaheimautomation.com/manuals/forms/hmi-guide.php#sthash.2McqS5xo.dpbs

Ichida, T., & Voigt, E. C. (1996). *Product design review: A method for error-free product development*. Productivity Press

Kelley, T., & Littman, J. (2001). *The art of innovation: Lessons in creativity from IDEO, America's leading design firm* (1st ed.). Currency/Doubleday.

Kern, D., & Pfleging, B. (2013). Supporting interaction through haptic feedback in automotive user interfaces. *Interactions: New Visions of Human-Computer Interaction*, *20*(2), 16–21. https://doi.org/10.1145/2427076.2427081

Komlofske, A. (2021, December 13). *How to Make Design and Engineer Collaboration a Walk in the Park*. Built in Seattle. Retrieved September 20, 2022, from https://www.builtinseattle.com/2021/12/13/how-make-design-and-engineer-collaboration-walk-park

Korosec, K. (2019, August 31). *Tesla's model 3 interior (even the steering wheel) is now 100%*
leather-free. TechCrunch. Retrieved November 27, 2022, from
https://techcrunch.com/2019/08/31/teslas-model-3-interior-even-the-steering-wheel-is-
now-100-leather

Kroemer, K., & Grandjean, E. (1997). *Fitting the task to the man: A textbook of occupational*
ergonomics. London: Taylor & Francis.

Liu, G., Oman, z, Spiessens, D., Lane, E., Lipson, B., & L, wil. (2021, July 14). *Making Design,*
Product & Engineering Collaboration work. YouTube. Retrieved September 20, 2022, from
https://www.youtube.com/watch?v=8bliweLN8C4

Lovejoy, B. (2020, June 15). *Slide-to-unlock patent battles continue – this time Apple on the*
other side. 9to5Mac. Retrieved September 26, 2022, from
https://9to5mac.com/2020/06/15/slide-to-unlock-patent/

Löwgren, J. & Stolterman, E. (2004*). Thoughtful interaction design : a design perspective on*
*information technology.*MIT Press.

Maeda, J. (2006). *The laws of simplicity*. MIT Press

Mahadi, A. (2020, October). *An Overview of Capacitive Touchscreen Display Technology*.
Research Gate.

Margiene, A., & Ramanauskaite, S. (2019). *Trends and Challenges of Multimodal User*
Interfaces. 2019 Open Conference of Electrical, Electronic and Information Sciences
(EStream), Electrical, Electronic and Information Sciences (EStream), 2019 Open
Conference Of, 1–5. https://doi-org.spot.lib.auburn.edu/10.1109/eStream.2019.8732156

Marston, H. (2022, August 16). *How to Fix Touchscreen too Sensitive? Here Are 6 Fixes*.

    Retrieved September 26, 2022, from https://www.imyfone.com/ios-13/touchscreen-too-

    sensitive-on-ios-13-here-are-6-fixes/

Moggridge B. (2007). Designing interactions. MIT Press.

Pheasant, S. (1996). *Bodyspace: Anthrome- try, ergonomics, and design of work*. London: Taylor

    & Francis.

Piller, F., Ihl, C., & Steiner, F. (2010). Embedded Toolkits for User Co-Design: A Technology

    Acceptance Study of Product Adaptability in the Usage Stage. 2010 43rd Hawaii

    International Conference on System Sciences, System Sciences (HICSS), 2010 43rd Hawaii

    International Conference On, 1–10. https://doi-

    org.spot.lib.auburn.edu/10.1109/HICSS.2010.178

 Apple. "Pointing devices - Inputs - Human Interface Guidelines - Design - Apple Developer."

    (n.d.). Retrieved September 26, 2022, from https://developer.apple.com/macos/force-touch/

Reid, D. (2019, October 17). *The World Is Our Interface – The Evolution of UI Design*. Toptal

    Design Blog. Retrieved September 21, 2022, from

    https://www.toptal.com/designers/ui/touch-the-world-is-our-interface

Schmidtke, H. (1974). Ergonomie, Band2. Munich: Hanser

Sorathia, K. (2015, November 9). *Gestures of Touch Screen*. D'Source. Retrieved September 26,

    2022, from https://www.dsource.in/course/touch-screen-gestures/gestures-touch-screen

Stodart, L. (2021, October 29). *Best Microsoft deal: Grab the Surface Dial or Precision Mouse

    on sale*. Mashable. Retrieved September 26, 2022, from https://mashable.com/deals/march-

    4-microsoft-surface-dial-precision-mouse

Suh, Y., & Ferris, T. K. (2016). *The Impacts of Touchscreen and Physical Control Interface Characteristics on Driver Distraction and Attention Management*. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 60(1), 1519-1519. doi:10.1177/1541931213601348

Tao, D., Zeng, J., Liu, K., & Qu, X. (2021). *Effects of control-to-display gain and operation precision requirement on touchscreen operations in vibration environments.* Applied Ergonomics, 91. https://doi-org.spot.lib.auburn.edu/10.1016/j.apergo.2020.103293

tdxlabs. (2017, July 15). *Elgato Stream Deck - What is inside?* Imgur. Retrieved September 26, 2022, from https://imgur.com/gallery/XyKiL

Tesla On-Screen Wiper Controls Ruled Illegal In Germany. (2020). Benzinga.Com.

Tesla starts testing rain-sensing wipers for Model S, X and 3. (2018). Auto Business News (ABN).

Jayathilaka, D., (2020, August 7). *UI & UX Responsive Sketch Pad for Wireframing and Prototyping: Responsive Sketching Notebook for UI and UX Designers*. Independently published.

Van Zon, N. C. M., Borst, C., Pool, D. M., & van Paassen, M. M. (2020). *Touchscreens for Aircraft Navigation Tasks: Comparing Accuracy and Throughput of Three Flight Deck Interfaces Using Fitts' Law.* Human Factors, 62(6), 897–908. https://doi.org/10.1177/0018720819862146

Van Zon, N. C. M., Borst, C., Pool, D. M., & van Paassen, M. M. (2020). *Touchscreens for Aircraft Navigation Tasks: Comparing Accuracy and Throughput of Three Flight Deck Interfaces Using Fitts' Law.* Human Factors, 62(6), 897–908. https://doi.org/10.1177/0018720819862146

What does the new Mercedes-AMG® Performance Steering Wheel look like? (2018, April 30).

Mercedes-Benz of Scottsdale. Retrieved September 26, 2022, from

https://www.mbscottsdale.com/blog/what-does-the-new-mercedes-amg-performance-

steering-wheel-look-like/

What is a graphical user interface (GUI)? (2020, September 14). IONOS Digital Guide.

Retrieved September 21, 2022, from https://www.ionos.com/digitalguide/websites/web-

development/what-is-a-gui/

Yu, F., Pasinelli, M., & Brem, A. (2017, November 27). Prototyping in theory and in practice: A

study of the similarities and differences between engineers and designers. *Creativity and*

Innovation Management, *27*(2), 121–132. https://doi.org/10.1111/caim.12242

Appendix A: The Graphic of The Approach