AUTOSPHERE
LEVEL 3 / LEVEL 4 AUTONOMOUS VEHICLE INTERFACE

BY

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THESIS

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ABSTRACT

The advancement of Level 3 and Level 4 vehicle autonomy transforms the relationship between the driver and their car. By allowing the vehicle to operate independently without human maneuver, this technology liberates us from steering and places us as decision-makers. Simply stating our desired destination is necessary to set the car in motion.

However, aside from our ambitious vision of the L3 and L4 automation, an effective interface built for future human-vehicle interaction still needs to be explored. Our activities in the car will drastically change, making current modern vehicle interfaces inadequate for the demands of L3 and L4 vehicles. Consequently, there is a need for innovative solutions that align with the demands of these advanced autonomous vehicles.

Auto Sphere, a human-vehicle interface designed for self-driving cars, has been conceived, enabling drivers to deliver commands as decision-makers across various commuting environments effectively. This report covers the background introduction, user study, user test, interface design process, and outcome.

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Chapter 1

Introduction

1.1 Level 3 and Level 4 Vehicle Automation

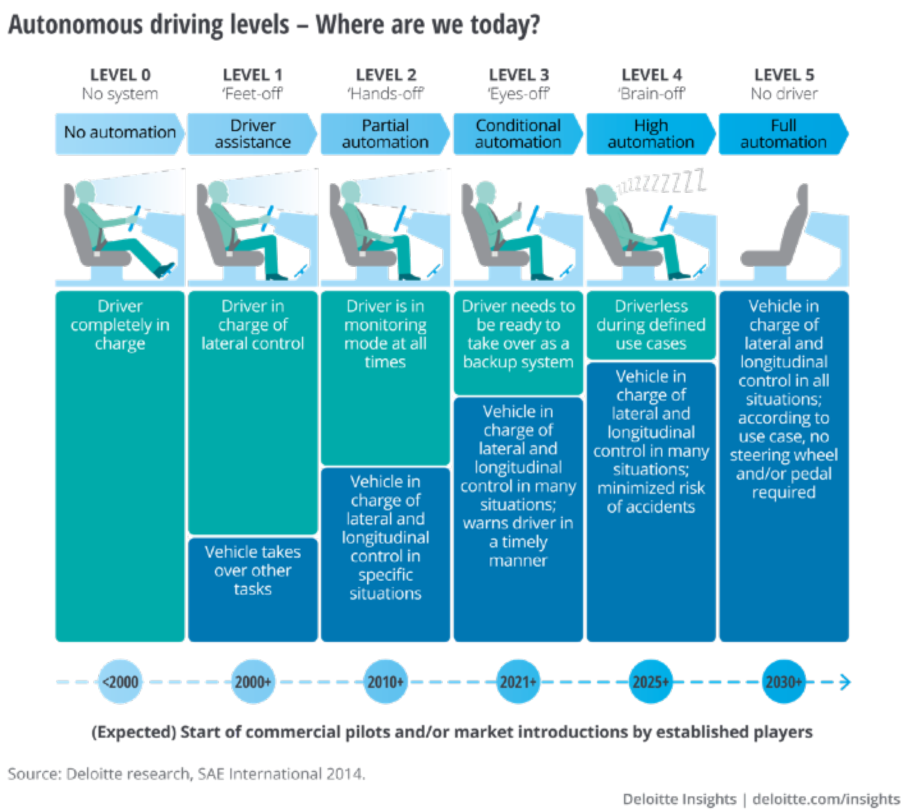


Figure 1.1: Autonomous Driving Level

Autonomous driving, or self-driving, turns manual overriding vehicles into active, intelligent tools. As the Society of Automotive Engineers (SAE) specified in the *SAE J3016 Visual Chart* (2021), autonomous driving includes six levels: from level 0, entirely human-driven, to level 5, fully operated by machine. Most modern vehicles are equipped with level 2 automation, capable of performing particular driving-related tasks (e.g., Lane Centering, Adaptive Cruise Control, Lane Change). Level 2 automation is classified as 'partial automation,' which means the driver is still required to monitor the driving environment and be ready to intervene when needed.

On the other hand, Level 3 and Level 4 automation represent a significant technological leap from Level 2. At Level 3 (Conditional Automation), vehicles can navigate autonomously under certain conditions but require human intervention when faced with unfamiliar situations. Level 4 (High Automation) furthers this autonomy, enabling vehicles to operate independently within predefined environments and conditions.

Recent technological advancements and increased investment from major automakers have reignited the push toward Level 3 implementation. Companies like BMW, Mercedes-Benz, and Honda have announced plans to introduce Level 3 systems in their upcoming models, with the first deployments expected in the next few years.

In summary, contemporary Level 2 self-driving systems still require drivers to engage and supervise constantly. In contrast, Level 3 and Level 4 automation significantly advance, allowing drivers to disengage from driving responsibilities and engage in non-driving-related tasks (NDRTs) under specific, predefined conditions. Implementing higher levels of autonomy will reshape the automotive landscape, offering the potential for enhanced safety, convenience, and efficiency.

1.2 Infotainment System Design Trend

The vehicle's infotainment (information and entertainment) system is an interface platform. It provides drivers with driving-related and non-driving-related information. The infotainment system evolves with contemporary vehicle technologies and users' needs. This evolution can be traced from the traditional physical dashboard, which primarily displayed basic vehicle information, to the modern touchscreen interface. It now offers drivers various functions, including vehicle information, navigation assistance, climate control, music streaming, and access to personalized applications and services.

A significant part of those functions is driving(or riding) safety, which includes speed, vehicle status, and warning since the driver still plays a vital role in safe driving. The emphasis on safety remains prominent as the driver continues to hold substantial responsibility for safe driving. Today's modern vehicle infotainment system is primarily designed for human supervision (as seen in Level 2 automation) and manual driving scenarios.

Compared to the contemporary infotainment system, the future will drastically change with the introduction of L3/L4 automation. Drivers no longer have to intervene in the vehicle's regular automation, as seen in L2 partial automation; their role will revolve around decision-making, and the machine will take most vehicle maneuvers when the condition allows. The freedom of human interference allows the infotainment system to be more versatile, which includes three primary functions: ride-related information display, decision-making input, and entertainment.

1.3 Future Human-Vehicle Interaction

Vehicle Infotainment System evolves with technology progression. At the transitional stage to intelligent vehicles, car manufacturers have launched various concept designs envisioning the future human-vehicle interaction, mainly featuring two key elements: an expanded display area and touchscreen functionality. These designs prioritize digitalizing infotainment displays and reconfiguring vehicle interiors to cater to non-driving-related activities.

Audi skysphere concept[1]C

Figure 1.2: Interior of *Audi skysphere concept[1]C*

The ultra-wide screen moves downward during manual driving and raises upward in autonomous driving with the steering wheel folded back.

Audi grandsphere concept[1]

Figure 1.3: Interior of *Audi grandsphere concept[1]*

Figure 1.4: Interior of *Audi grandsphere concept[1]*

Audi grandsphere concept[1] features a projected screen with the steering wheel hidden behind the screen. A knob and a touchpad are on the door panel for command input.

Mercedes-Benz EQS infotainment system

Three large screens align throughout the whole dashboard. Each display serves its function: Instrument Cluster Display, Central Information Display, and Co-Driver Display.

Figure 1.5: Mercedes-Benz EQS infotainment system

Volkswagen ID Buzz Concept

Figure 1.6: Interior of *Volkswagen ID Buzz Concept*

ID Buzz is a concept EV minivan equipped with swivel chairs. Front seats can be turned 180 to face rear passengers.

Many design approaches for the infotainment system in L3/L4 autonomous vehicles follow a common trend: adopting more extensive, notably wider screens. This expansion in screen size accommodates a wide range of content but also brings the difficulty of managing increasingly various information for drivers. Also, in most concept designs, the primary mode of interaction between humans and the infotainment system remains touch-based. While touchscreen is ubiquitous and user-friendly, touch-based interaction becomes less practical when dealing with extensive and intricate information hierarchies on a large screen that may be out of easy reach. Additionally, the touchscreen's unresponsive and inadequate feedback can cause the driver to feel unsure about whether the system has received and understood their command. This can result in the driver repeatedly attempting the action or losing focus on their primary task.

1.4 Project Goal

An increasing number of vehicle manufacturers are incorporating L2 or L2.5 driving assistance in their production models, and some experimental L3 capabilities are also available to consumers. As previously discussed, drivers will encounter novel forms of automation-related information in the future with the introduction of autonomous driving. This transformation in information dynamics can influence the interaction between humans and vehicles. In light of this, the project introduces a human-vehicle interface accommodating incoming L3/L4 vehicle automation technologies, guided by a human-centric design philosophy.

The report documents the entire design process, encompassing key stages such as problem definition, user research, user testing, ideation, industrial design, interface design, and the resultant outcomes.

Chapter 2

HMI in Autonomous Vehicle

2.1 Our Envision

As demonstrated earlier, vehicle manufacturers have disclosed a glimpse into the near-future L3 vehicles through numerous concept designs. These designs embody a strong aspiration for humans to disengage from active driving responsibilities, allowing the car to assume complete control while we enjoy the journey on the road.

According to vehicle manufacturers, the infotainment systems featured in autonomous-enabled vehicles undergo a noticeable transformation in user interface and content presentation. In autonomous-enabled cars, a substantial portion of driving-related information, traditionally displayed prominently on the infotainment screen, becomes less dominant or disappears altogether. The display area is occupied mainly by visual entertainment and non-driving-related tasks:

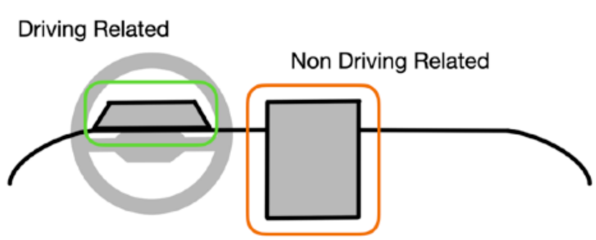


Figure 2.1: Conventional Layout

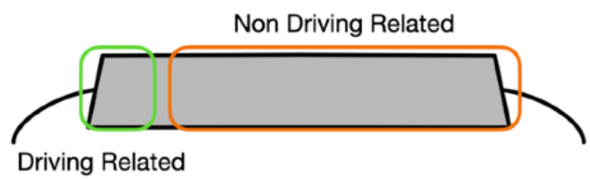


Figure 2.2: Trending Layout

The global automotive digital cockpit market indicates an increasing trend toward digital interfaces in vehicles and shows a growing trend toward digital interfaces in cars, driven by the shift toward more entertainment-centric infotainment systems. Passengers are no longer burdened with constantly monitoring driving-related information or assisting with navigation tasks. Instead, users can immerse themselves in personalized content on the expansive display area throughout their trip. The entertainment-focused interface looks appealing and showcases our vision of the future, where individuals can enter the car, enter the destination, allow the vehicle to drive independently, and enjoy the ride.

However, such a futuristic vision usually overlooks the essential human-centered design practicality and the complexity of real-life usage. When introducing vehicle automation under allowed conditions, one should consider the importance of human involvement and interaction experience. the primary mode of interaction in these systems remains touch-based. Although touchscreens are widely adopted due to their familiarity and user-friendliness, they pose significant issues when dealing with extensive and complex information hierarchies on large screens. For example, reaching different parts of a wide screen can be physically challenging and distracting for drivers. (ALTEN Group, 2020)

Car manufacturers have received numerous complaints about overly digitalized vehicle interfaces. For instance, according to *Autocar,* Volkswagen plans to reintroduce physical buttons on steering wheels due to criticism of their virtual haptic interfaces. Moreover, Tesla's new touch-based gear shift system, which requires drivers to switch gears on a touchscreen, has led to user input confusion and heightened the risk of severe consequences. (Golden, 2021)

These examples underscore the need to balance technological advancements and user-friendly design, ensuring that automation enhances rather than hinders the driving experience.

2.2 Travel’s Unpredictability

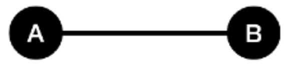


Figure 2.3: Expected scenario

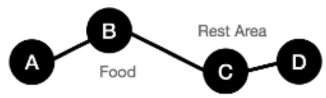


Figure 2.4: Real scenario

Riding a self-driving car seems convenient: moving from point A to point B, with the driver stepping in only when necessary. However, the journey experience can often be more intricate, especially during extended trips - a scenario usually favored by vehicle automation.

Manual driving will be replaced by vehicle automation in many scenarios: daily commuting, inter-city traveling, road-tripping, and tourism. During the riding, we may encounter unplanned or improvising events that lead us to detour or reroute to a new destination, such as taking a meal at a highway oasis or refreshing at a rest area.

The claim that long-haul trips often involve unpredictable events and spontaneous decisions is supported by interviews with five drivers who frequently undertake extended journeys (over 3 hours). The interviews aimed to explore the nature of decision-making and unplanned occurrences during such trips, posing the following questions:

1. *Do you take (at least one) meal during a long-haul trip (road trip, intercity travel, etc.)?*
2. *Which one is more common for you:*
   A. *Pre-set a restaurant or a rest area before the trip starts (Plan the whole trip).*
   B. *Making impromptu decisions depends on real-time conditions.*

3. *Have you ever driven in a national park? If yes, have you ever stopped your car randomly (without planning)?*

The interview result demonstrates the unpredictability of traveling in vehicles:

- All 5 took unplanned rest or meals during the trip.
- In most cases, none are destined to a specific place for rest and meals before trips.
- Four of the five had driven in a national park, and all took unplanned roadside parking.

These findings substantiate the unpredictable nature of long-haul trips through targeted interviews with experienced drivers. Their insights highlight the frequent spontaneous decisions made during travels, suggesting that real-world autonomous vehicle experiences will be more complex than point-to-point journeys. This contradicts the assumptions made by automakers, who often propose autonomous driving as a seamless, predetermined experience.

2.3 Need for a New Interface

Adapting the vehicle's autonomous navigation and dynamic changes is crucial. The trip extends beyond point-to-point transportation. By understanding the complexities of real-world journeys and potential unplanned events, we can develop a safe, efficient, and adaptive autonomous system.

Today's infotainment system in vehicles does an excellent job with conventional navigation. Users can easily input their destinations or search for them before setting off, making the journey's beginning smooth and hassle-free. However, the unpredictability of road travel means that not every decision is pre-planned. The interface might struggle to provide rapid and efficient solutions, especially if they require immediate attention or quick rerouting. Here are three examples:

- You want to pass the front slowly moving truck:

    To overtake a vehicle in front, one typically needs to change lanes, pass slower cars, and then return to the original lane. However, in the current interface, there is no option to instruct the autonomous system to 'overtake the vehicle in front.' In such cases, the driver must assume control and manually execute the overtaking maneuver. An effective interface can maintain the seamless experience that autonomous driving promises. Switching between manual and autonomous modes, especially for a task as common as overtaking, is inconvenient and disorienting for the driver.

- Riding on the highway and the logo sign makes you hungry:

    Eating on the go can often be an impromptu decision influenced by external cues, like highway sign logos. Traditional HVI interfaces, designed primarily for pre-planned routes, sometimes must catch up in these spontaneous scenarios. Instead of offering a quick and intuitive way to navigate these sudden points of interest, they often present a multi-layered approach. Users may have to navigate multiple menus, enter a search query, or pinch and zoom on a digital map to find the desired location. While seemingly minor when stationary, these steps can become increasingly cumbersome for on-the-spot decisions, leading to missed highway exits.

- Touring the national park and plan to stop the car and take a walk:

    While human drivers often find roadside parking intuitive, pinpointing an exact spot for autonomous vehicles can be challenging. Different from specifying a location on the map as a destination-related input, designating a parking location on a digital map can be problematic because it may need more geographical details, especially in rural areas. Also, due to map scaling, users may find difficulty interpreting the real-world spot through a scaled digital representation.

Furthermore, drivers often refer to their chosen parking spots simply as '*that*' spots without providing detailed descriptors as drivers might think, “I’ll park over there” or “That spot looks good.” The challenge remains in converting this vague reference into a language that machines can understand and act upon.

The modern trending human vehicle interface is primarily built on machine automation: manufacturers envision our future as a hand-free, non-guarded. However, as autonomous technology advances, it's vital to remember that driving isn't just about following a mapped route. It's deeply intertwined with the active human desires and the unpredictable nature of road adventures. Research supports the importance of adaptive interfaces for real-world complexities. For instance, an adaptive user interface can evolve through phases of development, gradually becoming more personalized and responsive to the driver's needs based on accumulated data from various sensors and user interactions. This approach ensures the system can present relevant information and controls dynamically, enhancing the user experience and safety (Sun et al., 2018). Consequently, supported by the study from MIT: “*Moreover, we believe that while the shared autonomy approach is counter to the approach taken by most people in automotive industry and robotics research community in the past decade, it nevertheless deserves serious consideration.*” (Fridman, 2018). it’s essential to design human-vehicle interaction interfaces that center around the human experience, ensuring drivers can seamlessly handle any ambiguities or unpredicted scenarios that arise during automated journeys.

Chapter 3

User Research

3.1 Initial User Research

As stated earlier, the project aims to develop an effective and user-friendly interface between humans and vehicles. This tackles the challenge of addressing the ambiguity and unpredictability of human needs during a journey in an automated car. To gain a deeper insight into people's preferences and demands concerning interactions during a vehicle trip and automation, a survey was conducted with 26 participants.

Participants' driving proficiency is segmented into five tiers based on their cumulative years of driving: beginner, intermediate, advanced, expert, and none.

Table 3.1: Number of participants and their driving experience

Driving Experience	Number of people
≤1 year	4
>1 year, ≤3 years	6
>3 year, ≤5 years	5
>5 years	11
No Driver License	1

The survey seeks a primary scope of people's perspectives and anticipation regarding future autonomous vehicles and their interaction, focusing on three main areas:

- Willingness to deploy autonomous driving:

Will you enable vehicle automation?
A. Yes, let the machine take full control
B. Yes, but supervise and intervene
C. Only when road condition is clear
D. Never

Figure 3.1: Question1

This survey section examines participants' acceptance of autonomous vehicles and determines the extent to which they will yield control to these automated systems. Their insights help us better understand the perceived value of this technology and identify potential areas of concern or resistance.

- Infotainment system interaction preference:

Top 3 Expectation of infotainment system:
A. Larger display, more content
B. Display trip related info
C. More effective input instead of touching
D. Smaller display for safety information only
E. Voice command
F. Connect and control with smart phone

Figure 3.2: Question2

These choices reflect the latest design trends that use innovative technologies. Collecting user feedback early in the process will help develop the initial interface. This ensures that it aligns with the drivers' preferences, alleviates their concerns about the user experience, and improves the interface's efficiency and reliability.

- Events during vehicle automation:

What will you do (during vehicle automation)?
A. Relax/Music/Enjoy the scenery
B. Video
C. Social Media
D. View/Plan the trip
E. Work
F. Food

Figure 3.3: Question3

The driving experience will inevitably change as we transition to the automation era. This survey question aims to gather feedback from participants on their envisioned scenarios (specifically non-driving-related tasks). For example, would they use their commute to work to relax or engage in entertainment? Users' in-vehicle events can impact the overall experience, as our posture and position may vary.

The three areas intertwine and provide a comprehensive understanding of the user experience in the context of future autonomous vehicles: our readiness, our anticipation, and our behavior (Non-Driving related tasks that affect the overall interface interaction). The findings from these segments will offer valuable insights into user behavior and expectations and serve as a compass, directing the design and development of more intuitive, user-centric infotainment interfaces in the future.

3.2 Research Result

Quentions1:

Will you enable vehicle automation?

- Yes, let the machine take full control
- Yes, but supervise and intervene
- Only when the road condition is clear
- Never

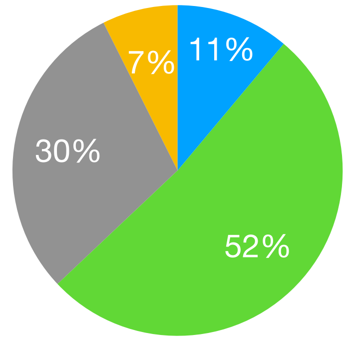


Figure 3.4: Question1 Result

Quention2:

Top Three Expectations of the Infotainment System:

- Larger display, more content
- Display road condition and planned trajectory
- More effective input instead of touching
- Smaller display for safety information only
- Voice command
- Connect and control with a smartphone

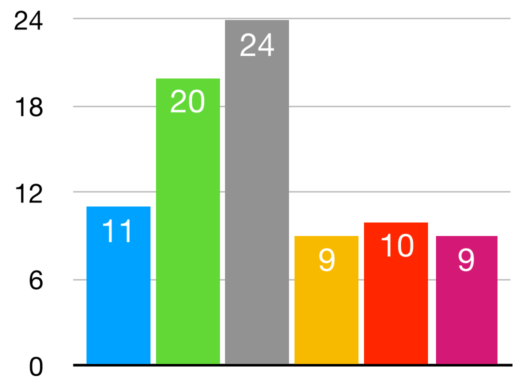


Figure 3.5: Question2 Result

Quention3:

What will you do (during vehicle automation)?

- Relax/Music/Enjoy the scenery.
- Video
- Social Media
- View/Plan the trip
- Work
- Food

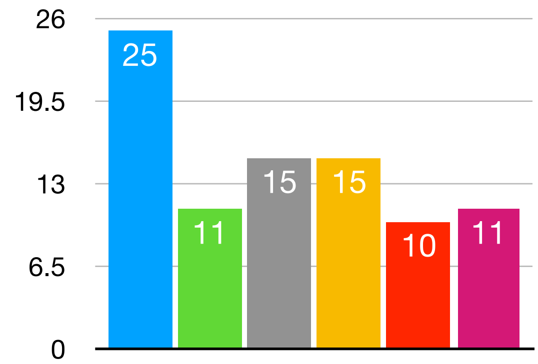


Figure 3.6: Question3 Result

3.3 Result Highlights & Findings

- **Automation information should be accessible to the driver.** (20/26):

In question 2# '*Top Three Expectations of the infotainment system,*' 20 out of 26 participants expressed a desire for the infotainment system to display road conditions and planned trajectories.

Also, the result of question 1#, '*Will you enable vehicle automation,'* indicates that most drivers are willing to embrace the incoming vehicle automation with conservation. Merely 11% of the participants will leave complete control of the machine. In contrast, 82% will either conditionally deploy the self-driving (30%) or supervise the automation (50%). The data underlines the importance of ensuring transparency and access to automation-related information. In autonomous mode, the driver must perceive the system's intention, including the maneuver, its purpose, method, and timing. (Pokam et al., 2019)

These findings underscore the need for transparency and access to automation-related information through infotainment systems. With drivers likely to engage with and oversee vehicle automation regularly, there is a strong demand for real-time details about the automation process to be furnished via these systems.

- **There is a strong need for more effective and clear input than touching.** (24/26)

  The demand for an alternative touchscreen infotainment system interface is high, given the widespread criticism of digitalized interfaces in the current vehicle market. While the digital touchscreen interface is straightforward and intuitive, it needs to improve in handling complex, time-sensitive, or visual-free tasks effectively due to the need for analog interaction and tactile feedback. Incorporating physical controls and haptic feedback alongside the touchscreen could enhance the user experience, allowing drivers to perform certain operations without diverting their visual attention from the road, thereby improving safety and usability.

- **Non-visual tasks, routine tasks, and productivity tasks are all highly anticipated.**

  The options in question3 can be categorized into three scenarios based on the required in-vehicle space to perform the task:

  - **Leaning**:

    Tasks that can be performed relaxed, like listening to music or appreciating the scenery, refrain from demanding the driver's active engagement. Consequently, drivers may refrain from actively interacting with the vehicle or giving it any attention during these activities. Users prefer to lean backward on the seat and stay far away from the vehicle’s dash when performing these tasks.

- **Far-Sitting:**

  Far-sitting refers to a seat's position that sets back from the vehicle's dashboard and is in a sitting posture. This position is well suited for entertainment and productivity activities such as eating, media consumption, and working. Users require a regular stance but extra space in front of them for those tasks.

- **Regular-Sitting:**

  Regular sitting describes a position similar to or identical to what manual driving requires. In an autonomous driving setting, drivers are usually in the common sitting place when interacting with the vehicle, including supervising, controlling transfer, and planning/editing trips, e.g., through the infotainment system.

The result of question 3#, '*What will you do (during vehicle automation),*' shows an even distribution of all kinds of expected tasks except ***Leaning*** tasks (Relax/Music/ Enjoy the scenery), which 24 of 26 participants wish to perform. The outcomes for the other five options are relatively consistent, with an average count of 12.4 and a standard deviation of 2.15. This indicates that there isn't a significant preference variation among these five task choices.

Figure 3.7: Seat position, from left to right: Leaning, Far-Sitting, Regular-Sitting

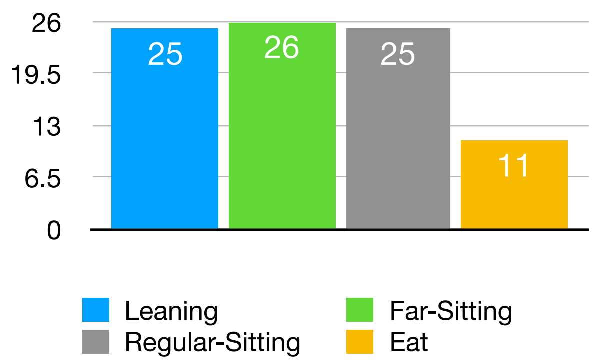


Figure 3.8: Activity Sum

The sum of responses across task types suggests that various functions accommodating different driver positions will prevail in future autonomous vehicles. (Shi & Frey, 2021)

This poses a challenge for designing modern and conceptual infotainment systems: effectively adapting the interface to accommodate these diverse positions and activities. To solve this problem, a new interface approach is necessary.

- **Through all levels of driving experience, most people will not leave complete control of the machine but retain certain control** (24/26):

The chart indicates that most participants lean towards conditional or supervised autonomous driving. This inclination is consistent across all levels of driving experience, underscoring a widespread concern about fully autonomous driving. It suggests that, regardless of how experienced a driver is, a desire remains to retain some control or oversight when letting machines take the wheel.

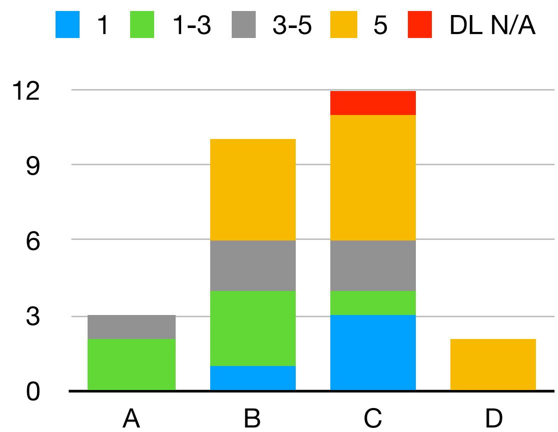


Figure 3.9: Driving experience and willingness to enable vehicle automation

Will you enable vehicle automation?

A. Yes, let the machine take full control

B. Yes, but supervise and intervene

C. Only when road condition is clear

D. Never

Figure 3.10: Question 1

3.4 Other Findings

- **Display size is not a priority in the infotainment system preference**:

Regarding screen size preferences, the data from question 2# indicates a need for more consensus. Eleven participants voted for a 'larger screen,' while nine preferred a 'smaller display for safety information only.' With neither option garnering a majority vote and the counts being relatively close, there does not appear to be a singular, dominant preference for screen size among the participants.

Notably, however, among the 26 participants, 20 voted in favor of options related to screen size. This suggests that although there may not be a unanimous agreement on the precise dimensions, the display size should remain user-friendly for all types of content, regardless of viewing distance.

- **As for now, the headwear AR display device is not widely appreciated by participants**:

The survey includes an optional question to determine participants' acceptance of augmented reality glasses as an alternative to the conventional in-vehicle display:

Of all the participants, only 4% are open to AR headwear devices instead of traditional displays. However, a significant majority, approximately 56%, are unwilling to consider using AR devices. Additionally, less than half of the participants (41%) will use AR glasses as a display extension.

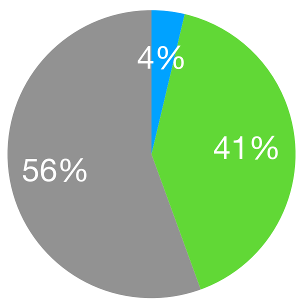


Figure 3.11: Willingness to use AR headwear

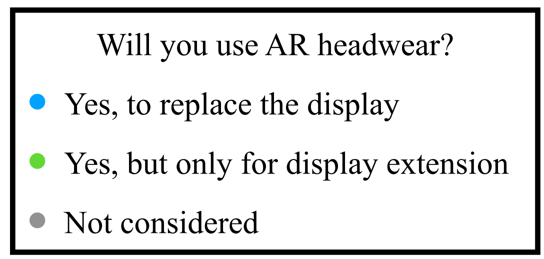


Figure 3.12: Will you use AR headwear?

The data indicates that participants prefer to avoid embracing augmented reality headwear devices for in-vehicle applications. Several reasons could account for this reservation, ranging from a lack of familiarity with AR devices to concerns about their cost-effectiveness and the overall user experience they provide. Though AR has been trending in some sectors, we're still early in this novel technology's commercial application. Considering this, this project will focus on enhancing traditional in-vehicle displays rather than incorporating or replacing them with new information display technology such as Augmented Reality.

3.5 Summary and Conclusion

The preliminary research provides a foundational understanding of the project's value. It directs the project's design approach and paves the way for areas of focus for further study and design process based on the participants' responses. The result highlights information accessibility and transparency in autonomous vehicles since we occasionally supervise and intervene in automation. It also reflects people's disfavor of touching-based interaction and demand for a more effective infotainment interface when the driver does all kinds of tasks. Aside from the emphasized areas suggested by the initial research, it also alludes to aspects that may be less important: display size and display alternative. This project won't advocate for a particular dimension because the survey results don't strongly favor a specific screen size. Instead, it will develop a graphical user interface centered around the user's requirements. Moreover, considering users' challenges and reservations when facing new technology, the project will avoid exploring new display technologies, particularly headwear augmented reality. While self-driving liberates the driver from constant manual control, we still need to access driving-related information and communicate with the automation system. Additionally, the spontaneous driving nature means various unplanned events can arise during a journey, underscoring the need for a solution that addresses unpredictability. As a result, there is a solid demand for an effective interface for driving under vehicle automation.

Chapter 4

Ideation

4.1 Overview

As vehicles evolve to operate more autonomously, the driver's role significantly shifts to an overseer, making critical decisions when needed. The ideation chapter will discuss and document the brainstorming and conceptualization for the human-vehicle interface design. This phase will encompass:

- **Design Principles**: Primary guidelines and criteria that steer the design direction
- **User Behavior Analysis**: Driver's behavior and psychology study
- **Vehicle Behavior Analysis**: Deconstruct the car's movement to align the interface with the operation
- **System Architecture**: Structural framework of the interface system

The ideation process will support the interface design by framing the holistic view of the interface system.

4.2 Design Principles

Based on the preliminary survey, it has been determined that the design principles for the vehicle infotainment system require a more effective human-vehicle interface than just a touchscreen. To truly enhance the driver experience, the system design principles should facilitate convenient driver intervention in vehicle automation for spontaneous needs without regard for seating position.

The interface should promote safe, uncomplicated access by presenting essential trip and vehicle data on a pragmatically sized display within sight at all times. This ensures that critical information is readily accessible and does not require drivers to divert their attention from the road unnecessarily. (Zhang et al., 2021)

Moreover, the interface design should prioritize intuitiveness and optimization for driver ease of use and information accessibility. By blending technological advancement with human-centered principles, an interface can be crafted that keeps the driver informed, engaged, and confident throughout the automated driving experience. (C. Zhang et al., 2020)

4.3 Driver's Intervention

The most fundamental is understanding the driver's intervention for unplanned tasks during a trip or vehicle automation. Where are the unplanned tasks from? Following are some examples to help us take a closer look at the answer:

- Pause the car in a national park to take photos of the stunning scenery.
- Leave for the next highway exit to find some food.

Such stances can be triggered by outside or inside factors: allured by the scenic beauty in the national park (outside factor) or the body's need for hunger (inside factor). The critical foundation is comprehending why a driver intervenes in vehicle automation for unscheduled tasks during a trip. These impromptu interventions originate from two primary sources: external and internal stimuli.

- External Stimuli:

These driving forces originate from the surroundings or external environment, requiring an immediate reaction. They "originate from the environment outside the organism.” (Drew, C., 2023)

- Internal Stimuli:

These stimuli originate from within the organism, such as hunger, thirst, pain, and emotions like fear or happiness. (Drew, C., 2023)

External and internal stimuli can inspire the driver to intervene spontaneously in the automated trip for unplanned stops. Although the inputs driven by two motivations are similar — moving to a new destination, the nature and urgency of the driver's commands can be distinct. For externally stimulated tasks, drivers usually respond instantly since the operational window may be brief. Any delay might result in missing the desired location or moment. On the other hand, when driven by internal stimuli, drivers might exhibit a more measured response. They will follow the conventional trip management method: search for an ideal destination on the map and proceed.

Understanding the complex relationship between these stimuli and driver intervention is crucial. The interventions motivated by these stimuli are often not neatly separable but may be interchangeable or even simultaneous in certain situations. The complexity will shape the adaptability of the human-vehicle interface according to specific scenarios.

4.4 Vehicle’s Movement

Constructing the interface system framework involves analyzing the vehicle's behavior and movement. The term "vehicle's behavior" refers to the various movements of the car that correspond to the driver's input. Categorizing these multiple movements is critical to shaping a seamless interaction workflow between the vehicle and its human operator.

Usually, drivers interrupt their planned trip or take control of the vehicle automation when they need to perform specific actions such as passing the front vehicle, changing lanes to a faster one, rerouting to a new destination, or stopping by the side of the road. Regardless of drivers' motivation, interruption or intervention aims at two types of vehicular movements:

- Destination-Related Movements:

    Destination-related movements are characterized by a vehicle diverging from its pre-planned route to head toward a new objective. Driver's intervention, such as finding a gas station and stopping at the rest area, impacts the overall trip course at a macro level without changing the vehicle's on-road lateral movement.

- Non-Deviated Movements:

    The act of changing the direction or path of motion without deviating from the intended route. This can include straightforward movements (forward and backward) or movements to the side (left or right). The interventions, such as accelerating/decelerating, changing lanes, and overtaking other vehicles, are typically based on these fundamental linear and lateral movements.

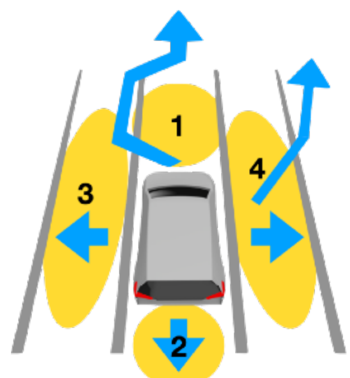


Figure 4.1: Possible vehicle movements on road

Besides the two usual types of movement, one case involves roadside parking between them. Roadside parking, like moving towards a destination, deviates from the planned path, with the parking spot becoming the destination. At the same time, roadside parking remains consistent with the predetermined route by requiring the vehicle to move to the edge of the roadway rather than what destination-related movement does.

To create a flexible, comprehensive interface, the design will incorporate features that can adapt to and handle two types of movements and roadside parking to accommodate this. This will contribute to a flexible and comprehensive human-vehicle interface that better serves the evolving needs of drivers for vehicle automation.

4.5 Driver and Vehicle

In earlier sections, we categorized the driver's interventions as either "externally stimulated" or "internally stimulated," which leads to different levels of urgency based on their motivation. Also, the vehicle's movement is classified into two sections, destination-related and non-deviated, based on whether or not the motion deviates from the planned route, along with one particular case: roadside parking, which lies between the two.

Table 4.1: Matrix of stimuli types and vehile movements

Type	External Stimuli	Internal Stimuli
Destinaton-Related	**Locate the Destination**	**Search for a New Destination**
Non Deviated	**Direct Input Command**	**Direct Input Command**

By organizing the driver's behaviors and the vehicle's movements into a 2x2 matrix, we can understand the required information and interaction for each combination. This structured approach helps systematically identify the different needs that arise based on varying driver behaviors and vehicle responses:

In total, there are four types of intervention and three corresponding driver’s inputs:

- Destination-Related Input by External Stimuli:

Example: Seeing the roadside café makes me crave coffee.

Due to the brief time frame available for rerouting to a new destination, quick responses to external stimuli are essential for the driver. Failure to act promptly could result in missing the intended location or taking a detour. Consequently, a responsive interface is crucial for the driver to locate the desired adjacent destination promptly.

- Destination-Related Input by Internal Stimuli:

Example: Leave for the next rest area to take a stretch.

The driver does not have to act instantly on internal stimuli, such as fatigue, and no new destination is targeted in advance. In this case, the driver will have ample time to search for the desired location through the infotainment system. Since there is no urgent need or time pressure, the interface should seamlessly support the driver's input process without lag or frustration. The goal is for the driver to casually browse options, make selections, and plan the next stop conveniently.

- Non-Deviated Input by External/Internal Stimuli:

Example: Switch to the faster lane due to the slow-moving truck ahead.

Whether the driver reacts to an external stimulus or internal impulse, their input remains identical when the vehicle continues straight ahead without deviating. For instance, when the driver wants to change to a faster lane due to an external factor like a slow-moving truck forward or an internal factor like boredom, the required input is immediate and identical even though the stimuli differ.

To summarize, the human-vehicle interface should support drivers with the following tasks:

- Locate an adjacent destination
- Search for a destination
- Input non-deviated command
- Provide feedback

The proposed classification matrix cannot account for every potential scenario solely based on interpreting the driver's motivation and vehicle motion. For example, if the fuel level reminder warns the driver to find a gas station, an external factor stimulates them to take a non-urgent action: the driver is more likely to utilize the 'Search for a destination' function than 'Locate an adjacent destination.' In this situation, the matrix does not perfectly predict how the driver will use the interface. However, the matrix offers a broad framework for understanding the context behind drivers' interventions for unplanned tasks, making trends and optimal interface design choices more evident. It provides a systematic view of the driver's needs and suitable functionalities for various situations. (Ataya et al., 2021)

4.6 Interaction Workflow

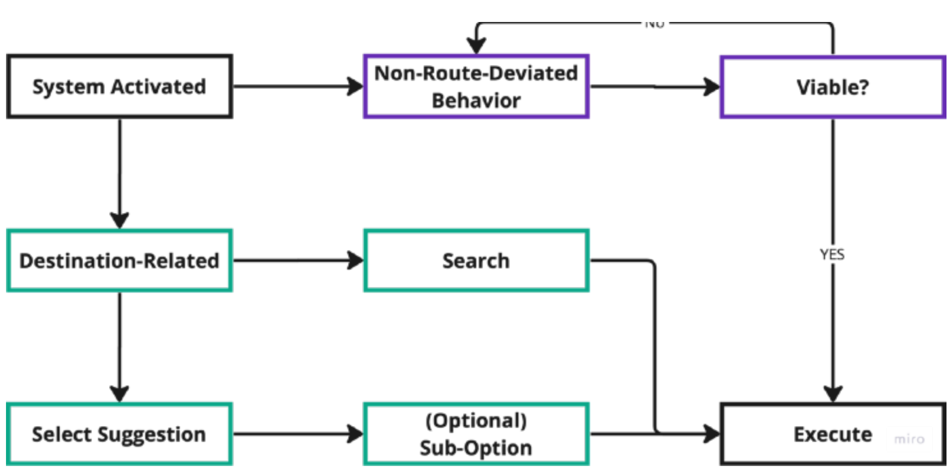


Figure 4.2: Interaction workflow

The infotainment system interface operates dynamically based on the specific command input from the driver:

> For the non-deviated commands, such as lane changing, the system first analyzes the feasibility of executing the requested. It then provides feedback to the operator regarding the viability of the command and current status before taking any action. If not, the driver can input another command or terminate the intervention anytime. For instance, the input will only be executed if sufficient clearance or faster lanes are available to change to. This allows the driver to confirm the system's interpretation and readiness before changing the vehicle's course.
>
> In the case of commands related to destinations, the interface supports two primary functions. First, it can promptly locate nearby points of interest within a reasonable radius of the vehicle's position and present them to the operator to select a new destination, such as the gas station at the upcoming exit. Second, it facilitates direct searches for locations that may be further away, enabling the driver to input a particular destination name or address. This allows the operator to choose a convenient nearby option or search for a specific place they have in mind.

By adapting its functionality for non-deviating maneuvers, destination locating, and other command types, the proposed interface can interpret and respond appropriately to drivers' unplanned tasks. This context-based approach allows it to handle three requests (locate an adjacent destination, search for a new destination, and input a non-deviated command) smoothly and effectively using an input device and an information display.

4.7 System Component and Workflow

To perform the key functions effectively, the interface requires two primary components: an input device and an information display:

The input device should enable users to locate nearby points of interest, conduct searches for specific destinations, and directly input commands and preferences without navigating through complex menus. This input mechanism should be intuitive and easily accessible, allowing seamless interaction.

On the other hand, the information display should present critical data to the driver in a user-friendly visual format. This display should show the user's requested information, such as nearby restaurant locations or navigation routes, and communicate real-time feedback on system status. The information should be organized and presented clearly and concisely, minimizing cognitive load and ensuring the driver can quickly comprehend the displayed data.

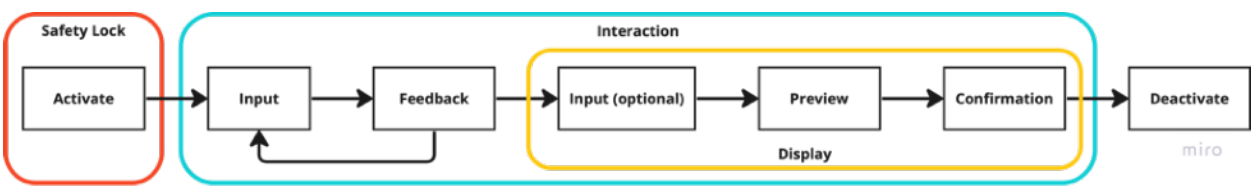


Figure 4.3: Interface System's components and workflow

From activating the interface, the driver will interact with the infotainment system using the input device. The input device is a primary mechanism allowing the driver to intervene in the automation, such as finding a location and passing front vehicles. As the driver inputs commands, the interface provides real-time status updates on execution. If further data is required, like locating the nearby coffee shop, the information display assists by presenting supplemental information such as a map and a suggestion list.

Finally, the interface deactivates after the driver confirms the command to avoid unintentional mis-input.

The input device and information display constitute the core components that enable the interface to effectively support critical functions like searching, commanding, and informing. These two elements allow a clean, straightforward communication conduit between humans and machines. The upcoming design phase will work on the two components individually and then unite them into an integrated system.

Chapter 5

User Interface Experience Research

5.1 Research Subject

The first step in the design process is to research the user interface experience. This chapter will document the research process, including the methods, data collected, and insights obtained. It will also discuss the findings and analyze the research outcomes.

The primary goal of the research is to evaluate and rank the user experience associated with three proposed interaction devices: touchpad, knob, and joystick. These three input modalities are widely accepted and commonly employed in modern automotive and informatics systems, making them suitable candidates for consideration in this project. The research chapter will analyze the findings and synthesize the quantitative and qualitative data to identify the strengths and weaknesses of each interaction device.

Figure 5.1: Touchpad interface

Figure 5.2: Knob interface

Figure 5.3: Joystick interface

5.2 Test Components

A virtual environment simulating a self-driving scenario is built using the Unreal Engine. In this simulation, the car moves on a four-lane road, and participants can change lanes using one of the three input devices being evaluated (touchpad, knob, or joystick), all while experiencing the driving from a first-person perspective.

Figure 5.4: UE5 Simulation

Figure 5.5: First-person view

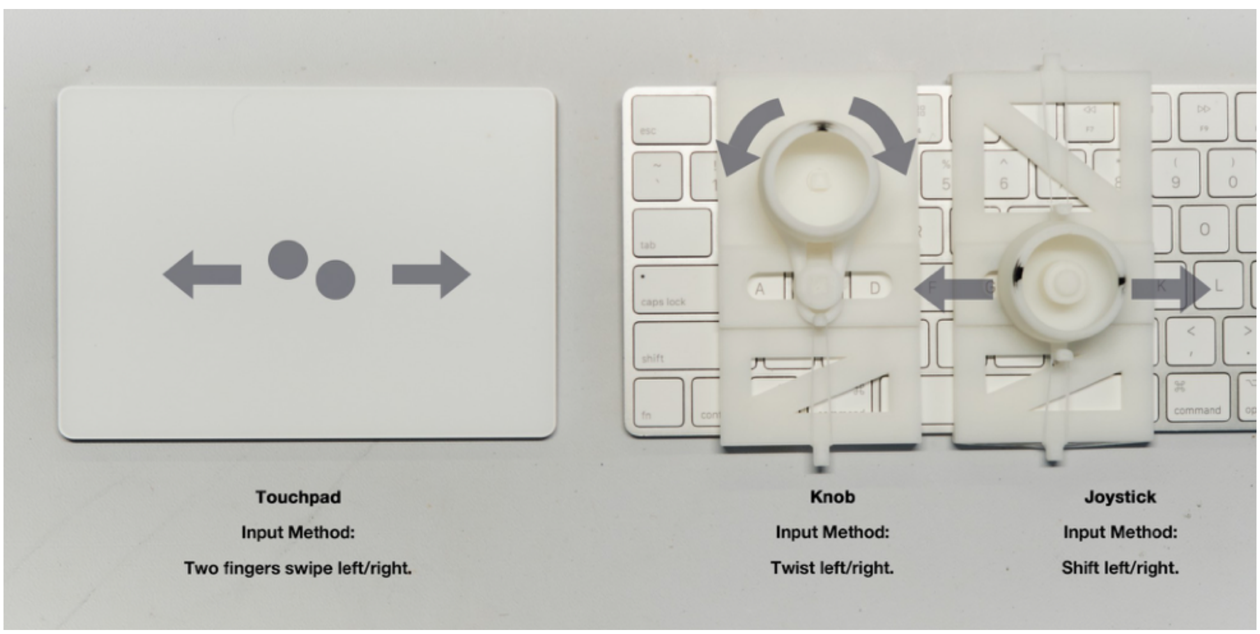


Figure 5.6: Tested input devices

To represent the physical interaction with the knob and joystick interfaces, 3D-printed parts are mounted on a keyboard. These 3D-printed components are designed to integrate with specific keys on the keyboard, allowing the keys to be pressed by twisting the knob or moving the joystick. This mechanism enables participants to experience the tactile feedback of using a knob or joystick interface in realistically. The touchpad input is simulated using a separate touchpad device.

5.3 User Experience Test Design

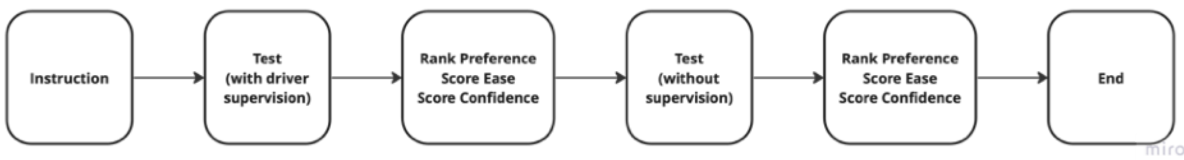


Figure 5.7: User test design

During the test, participants will be asked to use each of the three input devices (touchpad, knob, and joystick in random order) for 30 seconds to switch lanes on the four-lane road in the simulation. The testing process will consist of two cycles:

1. **Supervised Cycle**: In this cycle, participants must watch the road conditions during the test. This means they can visually confirm that their lane change commands are correctly executed by observing the vehicle's movements in the simulation.
2. **Unsupervised Cycle**: In this cycle, supervision is not mandatory. Participants can watch the road or engage in non-driving-related tasks during the test. This means visual confirmation of command execution is not guaranteed, mimicking real-world scenarios where a driver's attention may be diverted.

To replicate the unpredictability of events during an actual trip, lane change commands will be given three times every 30 seconds in a random order and with varying intervals.

The test aims to evaluate the usability and effectiveness of each input device under different conditions by incorporating both supervised and unsupervised cycles. The supervised cycle assesses the device's performance when the user actively monitors the road. In contrast, the unsupervised cycle simulates scenarios where the user's attention may be divided or focused on other tasks.

The randomization of lane change commands and intervals further enhances the realism of the testing environment, as it introduces an element of unpredictability that mirrors the dynamic nature of real-world driving scenarios.

Figure 5.8: Supervised Cycle

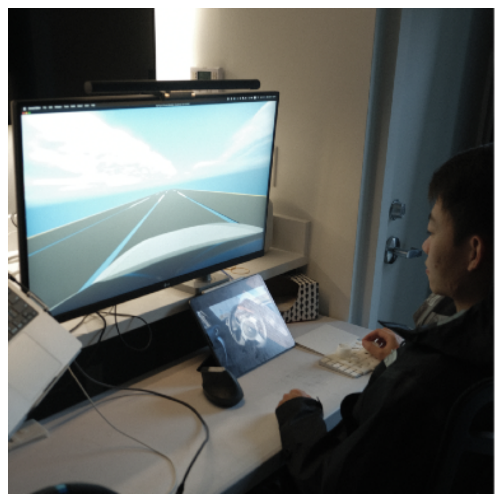


Figure 5.9: Unsupervised Cycle

5.4 Quantitative Evaluation

After each test cycle (supervised and unsupervised), participants will be asked to provide two separate scores on a scale of 1 to 5 for each input device (touchpad, knob, and joystick):

1. **Ease of Use Score**: This score reflects the participant's assessment of how easy it was to familiarize themselves with and use the input device during the test cycle. It measures the

device's intuitiveness and the ease with which participants could operate it effectively. It provides insights into each input device's inherent usability and learnability.

2. **Confidence Score**: This score represents the participant's confidence level in the clarity of the input feedback provided by the device, especially during the unsupervised condition. It reflects the participant's perception of the input device's standalone reliability, independent of other peripheral sensory feedback, such as visually sensing or watching the vehicle's movements in the simulation.

After scoring each device separately for ease of use and confidence, participants will be asked to rank the three input devices (touchpad, knob, and joystick) in order of their overall preference.

The charts presented above display the ranking and scoring results for the three input devices (touchpad, knob, and joystick) by six individual participants across both supervised and unsupervised test cycles. The standard deviations for ease of use and confidence scores have also been calculated and presented. These standard deviation values indicate how consistent or variable the participants' experiences were across the six participants for each input device.

A lower standard deviation implies that the participants' ratings were more consistent, suggesting a higher level of agreement in their perceptions of the input device's ease of use and input feedback confidence. Conversely, a higher standard deviation indicates a broader spread in the participants' ratings, indicating more significant variability in their individual experiences and perceptions of the input device's usability and feedback reliability.

5.5 Data Analysis

Figure 5.10: Test results visualization

From the data visualization above, the joystick outperforms the other two input modalities in all evaluation sections:

- Ease of Use

Joystick consistently shows a high rating across six participants in supervised and unsupervised conditions, with an average score of 4.83 and a standard deviation of 0.37

when supervised and an average of 4.66 with a standard deviation of 0.47 when unsupervised. This is the highest rating and least varied among the three options.

Table 5.1: Supervised - Ease rating

No.	Joystick	Knob	Touchpad
1	5	3	4
2	5	3	1
3	5	3	5
4	5	2	4
5	4	4	2
6	5	4	2
AVG	4.83	3.17	3.33
SD	0.37	0.69	1.41
R	1	2	4

Figure 5.2: Unsupervised - Ease Rating

No.	Joystick	Knob	Touchpad
1	5	2	4
2	5	4	2
3	5	3	4
4	4	2	5
5	4	2	4
6	5	4	2
AVG	4.67	2.83	3.5
SD	0.45	0.90	1.12
R	1	2	3

The knob’s average score is lower than the touchpad in both supervised and unsupervised conditions but has less consistency than the touchpad.

Participants experienced inconsistent perceived ease of use with the knob, which may be attributed to varying perceptions of the rotation direction. The lack of visual confirmation in unsupervised test conditions exacerbates this inconsistency.

Two of the six participants believed that turning the knob counterclockwise meant to 'switch to the right lane.’ The other four participants believed that turning it clockwise indicated the same command. This confusion was more evident in the unsupervised condition, as the average score decreased from 3.17 to 2.83, and the standard deviation increased from 0.69 to 0.90.

The touchpad input device exhibited the highest variability in user ratings, with scores ranging from the highest of 5 to the lowest of 1 in the supervised condition and from 5 to 2 in the unsupervised condition. This wide range of scores suggests that different participants perceived the touchpad's usability and reliability differently.

Compared to the knob input device, the touchpad was generally considered easier to use due to its straightforward interaction: swiping right or left to change lanes. This simple gesture did not produce the same level of confusion as the knob, where participants had differing perceptions of the rotation direction mapping.

However, the touchpad was prone to mis-inputs, whereas the knob and the joystick were not. Occasionally, the system would fail to respond to the participant's input on the touchpad. Through observation, these mis-inputs were caused by misalignment between the participant's posture and the touchpad's orientation. When participants' bodies were slightly rotated to the right or left, their gestures on the touchpad were translated into sloped swipes rather than distinct right or left swipes, leading to input errors.

- Input Confidence:

The confidence rating results, which measure the clarity of input feedback provided by each device, prove the joystick's superiority among the three input options tested.

Table 5.3: Supervised - Confidence Rating

No.	Joystick	Knob	Touchpad
1	5	2	5
2	4	5	1
3	5	5	2
4	5	3	1
5	4	3	1
6	5	4	3
AVG	4.67	3.67	2.17
SD	0.47	1.11	1.46
R	1	3	4

Table 5.4: Unsupervised - Confidence Rating

No.	Joystick	Knob	Touchpad
1	5	3	4
2	5	4	1
3	5	5	2
4	4	2	3
5	4	1	3
6	5	4	2
AVG	4.67	3.17	2.5
SD	0.47	1.34	0.96
R	1	4	3

Participants gave the joystick the highest average confidence scores in supervised and unsupervised conditions, indicating they most trusted its input feedback. The joystick received an average score of 4.67 in supervised and unsupervised conditions, which is the highest compared to other options. It was also the most consistent, with a standard deviation 0.47 in both scenarios. These consistently high confidence ratings and minimal variability across participants and test conditions show that the joystick is the most reliable and trustworthy option for users operating under vehicle automation.

The knob's confidence scores fall in between the joystick's and the touchpad's. Averages 3.67 when supervised and 3.17 when unsupervised. This mediocre performance can be attributed to the confusion surrounding mapping clockwise and counterclockwise rotation directions to lane change commands. The confidence score further dropped when the supervising was absent.

The touchpad still performs the worst and has the lowest confidence score: 2.17 under supervision and 2.5 without supervision. Interestingly, the average confidence score increased in the second test cycle, as the testers were aware of and avoided the potential input errors due to position misalignment in the first test cycle. However, this awareness remained the same as the touchpad's ranking relative to the other options, further reinforcing the need for more confidence associated with touchpad use.

A common criticism of touch-based gesture interfaces is the absence of physical feedback. Notably, the touchpad tested in this study has a tactile motor that generates strong vibrations upon receiving input. Despite this feature, the user experience evaluation remained unaffected. Interviews and observations revealed the inadequacy of such feedback compared to the joystick and the knob. The vibration is only perceptible when the finger touches the pad. In contrast, in a typical and natural swipe gesture, the finger often leaves the touchpad during the final stage of the gesture's trajectory. Consequently, testers may only receive clear feedback if their hand remains on the touchpad throughout the gesture.

During the two test cycles, both the knob and the touchpad received ratings of 3 or higher, indicating a significant range of user confidence and satisfaction. On the other hand, the joystick maintained a consistent rating of 1 across both cycles, demonstrating its reliability and consistency among the test group.

• Overall ranking

Table 5.5: Supervised - Ranking

No.	1st	2nd	3rd
1	Joystick	Touchpad	Knob
2	Joystick	Knob	Touchpad
3	Joystick	Knob	Touchpad
4	Joystick	Touchpad	Knob
5	Joystick	Touchpad	Knob
6	Joystick	Knob	Touchpad

Table 5.6: Unsupervised - Ranking

No.	1st	2nd	3rd
1	Joystick	Touchpad	Knob
2	Joystick	Knob	Touchpad
3	Joystick	Touchpad	Knob
4	Touchpad	Joystick	Knob
5	Joystick	Touchpad	Knob
6	Joystick	Knob	Touchpad

According to the ranking results, the joystick is the most preferred input method for vehicle automation among the participants in both supervised and unsupervised conditions. In the supervised conditions, all six participants ranked the joystick as their top choice, while in unsupervised conditions, five out of six participants ranked it as their top choice. The ranking indicates that the joystick is the No.1 choice for both circumstances in the test group.

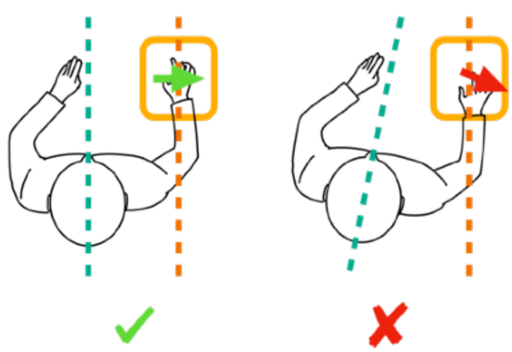


Figure 5.11: Gesture misalignment

An interesting observation was made while evaluating the input devices in the unsupervised condition. Participant 4# gave a higher score (5) to the touchpad over the joystick (4) when rating the ease of use in the unsupervised cycle. This participant was the only one who preferred the touchpad over the joystick. In an interview, the participant explained that the swipe interaction on the touchpad was more intuitive and faster than the joystick's analog input, especially for non-driving related tasks. This finding highlights the importance of a friendly, intuitive, and effective interface that can be easily accessible.

5.6 Conclusion

The interface experience research evaluated the users' preference among the three input modalities: joystick, knob, and trackpad. Throughout the quantitative analysis, qualitative observation, and interviews, the research concluded that the joystick interface outperforms the other two devices from the learning cost, intuitiveness, clarity of feedback, and users' trust. The joystick is the most optimal option for users to control and change vehicle automation.

While each input device has advantages and disadvantages, the joystick consistently received the highest ratings across all evaluations, with the most consistent scoring distribution (lowest standard deviation). The knob, though, is also an analog input device as the joystick; it sometimes confuses direction mapping, with users struggling to determine whether clockwise or counterclockwise rotation would achieve the desired input. Additionally, half of the six participants found the knob less comfortable compared to the other two options.

Despite being the most ubiquitous input device in daily life, the trackpad did not perform as well in the test. Although it scored higher than the knob in the ease of use evaluation, it still fell behind the joystick and exhibited the least consistency in participants' scoring. This suggests a potential risk in user acceptance when implementing large-scale touch-based interactions. The poor feedback quality made the touchpad the least favorable option regarding user confidence and trustworthiness. The unresponsive nature and inadequate feedback from touchscreens can lead to user frustration. Also spotted in other research, drivers may feel uncertain whether their input has been registered, potentially causing repeated attempts to execute commands and diverting their attention from driving tasks. This problem is exacerbated in autonomous vehicles, where drivers might still need to monitor the system's performance and intervene if necessary. (Čegovnik et al., 2020). The virtual interface posed a risk of potential input errors, as it was observed that the system might not execute users' inputs if their orientation was misaligned with the touchpad.

The research emphasizes the significance of creating a seamless, intuitive, and user-friendly experience for drivers, particularly when they are involved in non-driving-related tasks (NDRTs). It aligns with the research and recommendation that "*Auditory and/or tactile displays should complement visual information and be used to help reorient driver attention in critical situations. Sustained attention to HMI should not be required in time-critical situations*" (Mehrotra, S., 2021).

Despite the joystick's superior performance, the interface should be seamlessly integrated into the vehicle's infotainment system to provide a practical and discreet user experience.

Automation interfaces can optimize user satisfaction, trust, and overall experience by prioritizing user-centric design principles and addressing these considerations.

Chapter 6

User Need and Design Criteria

6.1 Overview

Upon determining the subject's form and progressing to the detailed investigation stage, defining the interface needed to help physicalize the subject is crucial. This chapter will cover the decision-making process, including the subject deconstruction, user needs analysis, and final summary.

6.2 Two Types of Automation Intervene

Based on previous user research and workflow studies, the controller should allow users to input two types of commands for vehicle automation: non-deviated commands for movement that does not change the destination and deviated commands for changing the destination. Examining each command type and its respective requirements helps to gain a more accurate and thorough understanding of the design requirements for the interface.

Non-deviated:

Non-deviated vehicle maneuvers include switching lanes, passing front vehicles, roadside parking, etc. These are everyday tasks we perform daily. These maneuvers involve the car staying on its planned route while the driver indicates their intention using turn signals and steers the wheel to make minor adjustments. In the context of autonomous vehicles And autonomous cars, translating these non-deviated inputs is relatively straightforward. The driver or passenger can input the desired command, like in a manually driven vehicle, and the autonomous system executes the rest of the vehicle maneuver.

Deviated:

Searching for, locating, and setting a new destination using a car's infotainment system is expected. However, doing so can be an unsatisfactory experience as accessing the full functionality of the navigation map while driving can be unsafe and divert the driver's attention away from the road. Technology companies and automakers limit drivers' access to the map's advanced features during driving to reduce this risk, relying on voice input for location searches to minimize distraction. However, this limited interaction often results in an unsatisfactory user experience due to several factors. For example, inconsistent voice interpretation accuracy may be erratic, especially in noisy environments or with uncommon place names. Additionally, the user interface (UI) may be simplified with reduced displayed content, making it difficult for drivers to confirm the system’s understanding of their destination input. Limiting the user's input to the system can also lead to the map failing to locate a desired destination.

Fortunately, self-driving technology opens up new navigation user interface (UI) design possibilities. With the reduced safety burden on the driver and a larger display area available, self-driving cars can offer an improved user experience and increased efficiency in finding desired destinations accurately and quickly.

A combination of traditional HVI design principles and forward-thinking approaches is required to incorporate standard and unconventional instructions into autonomous vehicles.

6.3 Commands Breakdown

Table 6.1: Commands Breakdown

Command Type	Command	Change Driving Status?	Timely Command?
Non-Deviated	**Regular On-road Change**	**No**	**Yes**
	Road Side Park	**Yes**	**Yes**
Deviated	**Locating Adjunct Destination**	**No**	**Yes**
	Search A Destination	**No**	**No**

Non-Deviated, Regular On-road Change:

As discussed in Chapter 4.4, "Vehicle's Movement," and Chapter 6.2, "Two Types of Automation Intervene," it is common for vehicles to make regular on-road maneuvers such as changing lanes, slowing down, or passing other cars. These maneuvers are usually simple and involve basic actions such as activating the turn signal and moving the car. Mapping these routine on-road maneuvers to the vehicle's automation interface is relatively straightforward.

Non-Deviated, Road Side Park:

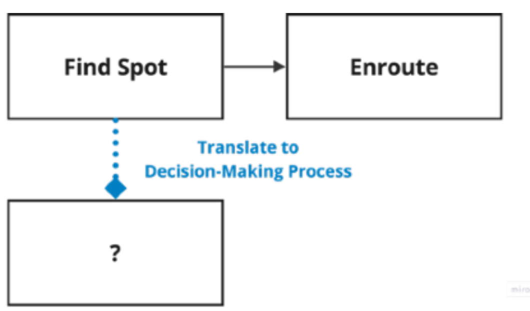


Figure 6.1

Roadside parking is an exception to the typical pattern of uninterrupted driving. While the vehicle remains on the planned route, it ceases driving, requiring users to choose a parking spot manually in certain situations. Such behavior can be spontaneous during a road trip while dropping off, picking up people, or in emergencies. Therefore, they require an efficient method to specify the parking location.

The problem lies in how users can communicate with the system when designating a parking spot on a digital map. Unlike specifying a destination by selecting a location on the map, establishing a parking spot can be challenging due to the lack of geographical details provided by the map, especially in rural areas. Additionally, due to scaling issues, users may need help interpreting the real-world location on a digital map.

The optimal solution eliminates the need for translation instead of relying on a descriptive approach to determining the location. Augmented Reality (AR) technology enables users to choose a parking spot using real-life references. When in roadside parking mode, a more extensive always-display section allows users to select the parking location through an AR preview window.

Deviated, Locating Adjunct Destination:

Diverting to an unplanned destination is a common occurrence during driving. In manual driving, the driver can instantly navigate to the location without communicating with the car's infotainment system. However, with automated vehicles, the challenge lies in efficiently finding and setting a new destination. The current Human-Vehicle Interface (HVI) is slow and limited in its ability to serve this purpose effectively and promptly. This is problematic since drivers have a limited time to make such changes. To avoid missing their destination and having to take a detour or switch to manual driving, drivers need a new interface that allows them to quickly and easily locate nearby locations.

6.4 Design Guideline

The interface should allow users to promptly change the vehicle's movement, adjust its condition, and set a new destination. As discussed in Chapter 4, the system should allow users to input movement commands, view nearby options, and designate a parking spot alongside other essential interactions. To bring this concept to life, the following interactions and functions are necessary:

1. **Activator**: A mechanism to engage the system anytime inside the vehicle, ensuring users can initiate interactions whenever needed.
2. **Direction Indicator**: A method for users to specify the desired direction of the vehicle's movement, enabling them to communicate their intentions to the system effectively.
3. **Option Selector**: An intuitive way for users to explore and choose from available options, such as potential destinations or parking spots, facilitating quick decision-making.
4. **Manual Override**: A failsafe method for users to override the system and end the autonomous operation, guaranteeing that the driver maintains ultimate control over the vehicle when necessary.

All components must be integrated into a joystick-style input device with the corresponding graphical user interface. The proposed interface will provide users with a seamless and efficient method for controlling the vehicle's movement, adapting to changing circumstances, and inputting new destinations on the trip. This adaptability is crucial for ensuring an intuitive and smooth user experience in autonomous vehicles.

Chapter 7

Industrial Design - Joystick

7.1 Overview

In the previous chapter, it is concluded that the joystick analog input device is the most effective option for testers to intervene and change vehicle automation. Building upon these findings, this chapter will document several critical stages in the industrial design process of the joystick-style interface, including ideation, development, iterations, CMF, and outcome.

Note that the linear documentation does not represent the design progression. As mentioned in Chapter 4.7, *System Component and Workflow*, the interface consists of two major parts: the input device and the information display. These two components are interconnected and cyclically undergo iterative refinements, with each part informing and influencing the design of the other.

7.2 Concept and Evaluation

As discussed in *Chapter 6.4, Design Guideline*, the joystick, as the primary input device, should work with the GUI to enable the driver to input commands, including initiate, execute, and terminate. As indicated in the chart, the driver is expected to operate the joystick for:

Table 7.1: Commend stage and operation

Command Stage	Operation
Initation	Activation
Execution	Indicate Direction
	Select Option
Termination	Confrim Execution
	Cancle Ongoing Task

1. **Initiation:**

A safety mechanism to activate the system to initiate a job: "*Systems should be designed to minimize or prevent unintentional actions (e.g., accidental activation or deactivation of the system)*" (Mehrotra, S., 2021)

2. Execution:

Indicate a direction for non-deviated movement

Select an option to assign a new destination

Select a spot for roadside parking

3. Termination:

Confirm a task

Cancel a task during the vehicle's movement (non-deviated task).

From the requirement, several ideas are conjured:

- **Concept A, Touch-Capacitive Thin Joystick:**

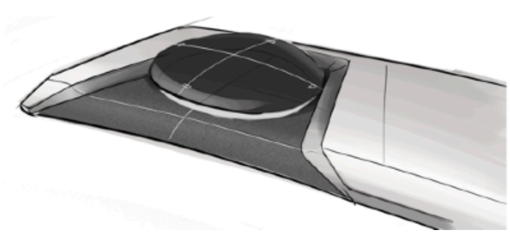


Figure 7.1: Concept A

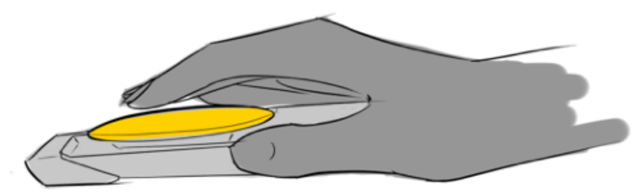


Figure 7.2: Concept A

The joystick is a large, thin, circular pad that is touch-capacitive. Users can rest their palms behind the joystick and move it with their fingers. The built-in touchpad on the joystick allows users to input other commands, such as select and confirm.

- **Concept B, Control Panel with Touchpad:**

The joystick serves as a standalone input device for orientation indication only. A touchpad/touchscreen is in front of the joystick for other input.

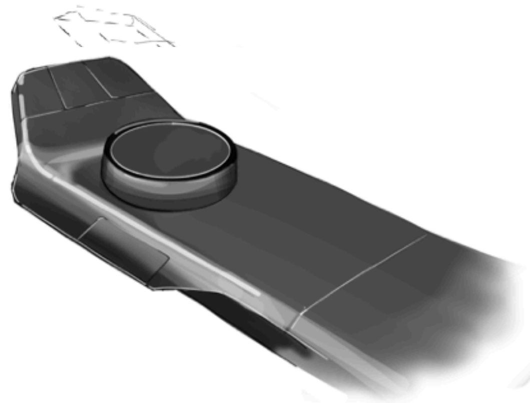


Figure 7.3: Concept C

- Concept C, Control Panel with Analog Input:

Similar to concept B, however, the touchpad/touchscreen in front of the joystick is replaced by analog interfaces, such as physical buttons or scroll wheels for selection and confirmation replace the touchpad/touchscreen in front of the joystick.

All three concepts share a similar idea: let the joystick be the input device for the most crucial job - pointing the intended direction for the vehicle’s motion change and adjunct locations. Users can use other input methods that are easily accessible and integrated into the joystick or around it on the control panel.

Each concept has its pros and cons, from aesthetics to functionality. Concept A has the most integrated design. The thin, circular shape is sleek, non-obtrusive and can easily blend into the car’s interior with a futuristic look. At the same time, Concept B and Concept C incorporate extended interfaces, which may result in a less streamlined look compared to Concept A. Nonetheless, Concept A's low-profile design makes it more susceptible to input errors. Placing analog input and digital interface on the same control level increases the likelihood of user confusion and misinput. It demands that users interact with the interface using carefully measured force; otherwise, they may inadvertently move the joystick or fail to actuate it. A potential solution involves restricting the interface workflow by locking the joystick after direction indication and exclusively enabling the touchpad interface. However, this approach may constrain the user's freedom in navigating the interface and potentially introduce additional complications in user experience and information architecture. An alternative approach is to implement a locking mechanism, allowing joystick movement only when unlocked. This solution shares similarities with Concept B and Concept C, with Concept A separating the joystick and touchpad virtually through a lock, while Concept B and Concept C physically split the two components.

Table 7.2

Concept	Pro	Con	Solution
A	Sleek Looking	Overly-Integrated Interface Casues Confusion	Virtually Split Two Interfaces By a Lock
B	Seperated Secondary Analog Interface Promises the Input Accurancy	Less Interaction Flexbility than Touchpad Provides	Concept C
C	Touch-Based Input Provides the Most Versatility	Prone to Input Error	Poentially Negotiable for Unimportant Jobs

The difference between Concept B and Concept C mainly falls into the secondary interface: analog input versus virtual input. As *Chapter 5, User Interface Experience Research indicates*, analog interface outperforms touch-based input in ease of use and confidence. However, the touchpad provides more flexibility and freedom in the interaction. Gestures and touch are potentially faster than analog buttons, and safety concerns are not as prominent as the primary input device for prompt orientation indication the joystick requires. Also, Concept C can fit a display to enhance the information presentation.

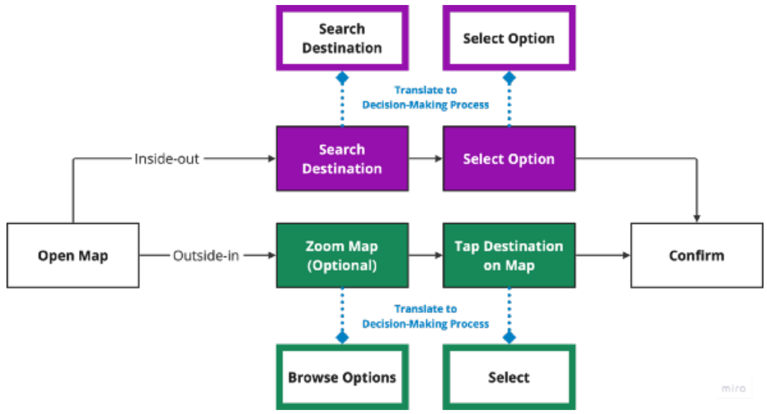


Figure 7.4: Workflow of locating a new destination

Concept A is the most visually appealing choice, with its integrated interface simplifying the control panel. However, an additional mechanism is required to clarify the interface and prevent unintended inputs. On the other hand, Concept B and Concept C offer complementary strengths: Concept B prioritizes input accuracy, ensuring accurate communication, while Concept C emphasizes versatility, providing users greater flexibility in various situations. The critical consideration is determining whether users will benefit more from a straightforward, focused interface or a more adaptable system that accommodates a broader range of user needs. The decision between simplicity or flexibility should be guided by a deep understanding of the users' goals, behaviors, and expectations within the vehicle's automation.

7.3 Supplemental Interface - Scroll Wheel

It's crucial to determine the user requirement while changing the vehicle automation to determine the detailed interface or control panel layout. While commanding non-deviated movements such as changing the lane can be as simple as a single swivel on the joystick, finding an adjunct location or setting a parking spot can be another story. Users may go through multiple

UI hierarchies to find the desired option. The UI layout will be further explored in the subsequent GUI design chapter. To streamline the workflow, the system should actively provide destination options based on geography and the map or passively through the user's manual search.

Typically, manual location searches occur when the destination change is not urgent, allowing the user to reroute to another spot later. However, when the need to change the destination arises suddenly, alternatives to manual searching may be more appropriate. In such cases, drivers often zoom in on the map and directly pin the desired location. To streamline this process and eliminate the need for zooming, dragging, and spotting, the interface will present options based on the user's desired orientation, enabling them to select the destination from a list. If the intended location is not readily available, it is likely far from the user's current position and can be found through manual searching. By combining auto-prompted options with manual search functionality, the interface ensures that users can effectively navigate to their desired destination without missing their intended target, even in situations requiring swift decision-making and adaptability. Thus, a scroll wheel is ideal as the supplemental secondary interface for selecting an option and confirming. The analog input ensures input accuracy and scrolling input guarantees the speed on a 2-D liner interface.

Like the computer mouse, the scroll wheel is integrated into the front side of the joystick for the best ergonomics. Users may find it hard to reach if the joystick is separated in front of it unless it is low enough to provide enough clearance for accessibility. Lowering the joystick presents another issue – difficulty in manipulating it effectively. As illustrated in Concept A, a low-profile design results in limited space for the user's finger to grasp the joystick securely.

Consequently, users are forced to move the joystick by pressing their finger on the top, relying solely on friction rather than having a firm hold.

7.4 Concept Iteration

Figure 7.5: 3D printed design iteration

The final controller concept merges Concepts A, B, and C in *Chapter 7.2, Concept and Evaluation*. Inspired by Concept A, additional interfaces are integrated into the joystick, enhancing accessibility and promoting a more ergonomic interaction. Like Concept B, the controller incorporates a secondary analog input device and a scroll wheel on the front side of the joystick, facilitating intuitive selection and confirmation of operations. Finally, drawing from Concept C, an adaptive function key is placed on the controller, accompanied by a small display. This dynamic button switches functionality based on the current task, such as canceling a job during movement changes or initiating a destination search when browsing nearby locations.

- **Concept Version 1**

As depicted above, the initial design features a sleek, oval droplet shape when viewed from the top, creating an intimate and organic feel. The streamlined-cut sides of the controller

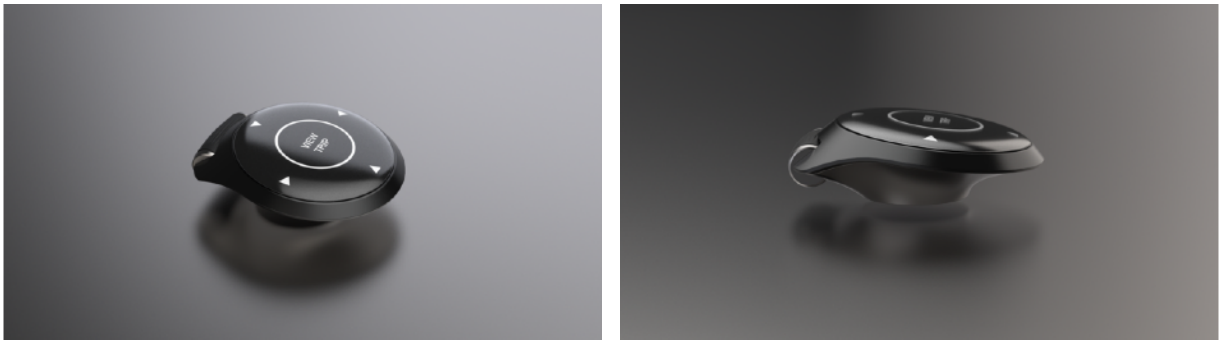


Figure 7.6: Concept V1

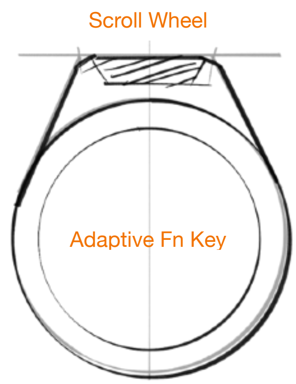


Figure 7.7: Concept V1

contribute to its thin, fluid, and dynamic appearance, creating a harmonious and visually appealing form. The function button's display is beneath a curved bulge glass, seamlessly blending into the overall design and maintaining a cohesive aesthetic.

However, the sleek, thin-looking results in awful ergonomics. The edge is too sharp to be comfortably held in hand, leaving no room for an activation button. A thicker profile replaces the streamlining cut to address the issue and provide better palm support. It also gives space for an activation button on the left side, which is easily accessible with the thumb.

- **Concept Version 2**

Figure 7.8: Concept V2

The second major iteration of concept version 1.0 kept the original shape but had some proportional changes. The joystick got thicker for better comfort and longer to position the scroll wheel further, improving ergonomics. It also has an updated design language. The joystick maintains its droplet shape but now has two hard ridges on top, extending from the scroll wheel to the tail, with an adaptive function key sitting between the ridges, concentric with the joystick's contour. Version 2.0 has a clearer layout divided by the two ridges, with a curved, streamlined top surface similar to version 1.0. While the cut-out on the side profile in version 1.0 emphasizes the fluid design language, the ridge lines in version 2.0 are more visually straightforward, highlighting the visual language on the top surface.

Version 2.0 also undergoes serval iterations with tweaked height, length, width, and proportion. Each iteration is 3D printed and evaluated. While the interface layout (integration of the joystick and the scroll wheel) shows no difficulty in learning, the form still needs to be improved for comfort and ergonomics. Although Version 2.0 offers a more secure grip than the initial concept, the droplet shape still challenges comfort. The long, thin design allows users to hold the controller only from two sides, which proves problematic for passing and decelerating commands (moving forward and backward). Consequently, users may feel unsure, as the controller risks slipping out. While this issue can be mitigated by grasping the thinner frontal portion of the controller more tightly, doing so leads to discomfort and fails to alleviate psychological concerns completely.

- **Concept Version 3**

Concept 3 departed the old droplet shape and replaced it with a thick, cubic form with soft edges and curved surfaces —the new shape results from the loft between two opposite trapezoids. This new shape is derived from the lofted transition between two opposing trapezoids. The naturally bent surface between the top and bottom planes provides a

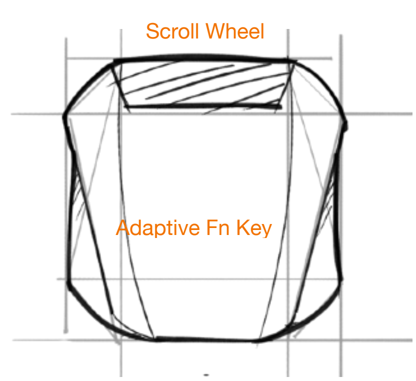


Figure 7.9: Concept V3

comfortable resting place for the user's thumb, conveniently housing the activation button. The top surface is more boldly extruded, and the bottom is trimmed to create a smooth, dynamic shape that fits naturally and securely in the palm, allowing for comfortable use. The design retains the ‘two ridge’ element on the top surface for fluid and streamed visual language and indicates the interface layout.

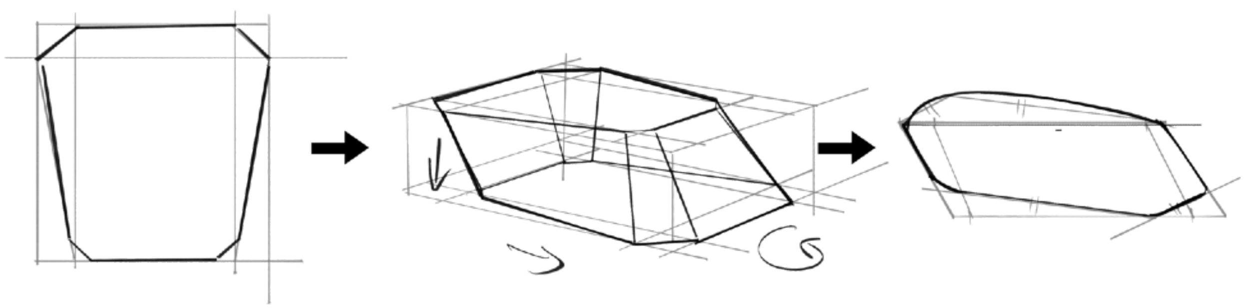


Figure 7.10: Concept V3

Moreover, the cubic form allows ample front and top space for a scroll wheel and a function key. Users can hold the controller more securely and comfortably, and a wider scroll wheel allows them to select options more easily. Although version 3 sacrifices some of its predecessor's streamlined and organic unity, it provides the best comfort and is the most user-friendly among the three iterations.

7.5 CMF Design

Color, material, and finish (CMF) design is the crucial next phase following the three size adjustment stages of the final concept version 3. CMF is an essential stage in the joystick controller design. The design needs to guarantee the aesthetic, manufacture validity, and production cost at the same time. The CMF design follows the established language of fluid and organic while informative.

- **CMF Iteration 1**

The initial CMF design prioritizes streamlining the side profile and enhancing the clarity of the interface. The joystick features a sandwich structure, with black covers on the top and bottom and a main frame in the middle that wraps around the cubic form, providing support for all internal components. The support frame extends from the front top to the tail bottom, creating a dynamic visual language.

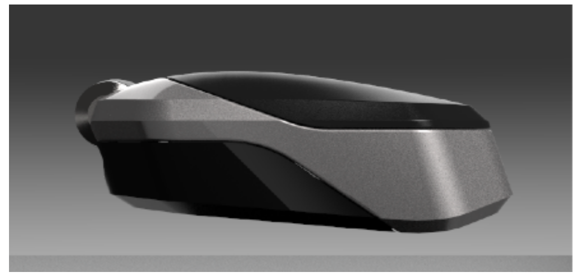


Figure 7.11: CMF iteration1

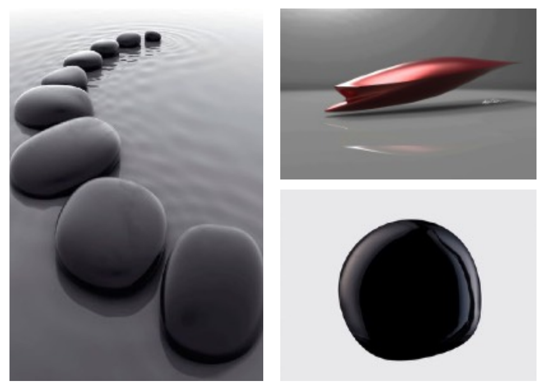


Figure 7.12: Mood Board Interation 1 and 2

The CMF design lays out the interface from the top view. The main frame, which wraps from top to bottom, splits to indicate the scroll wheel and function button, ensuring intuitive user interaction. An elegantly fading LED indicator seamlessly integrates into the function key, creating a subtle yet lively "breathing" effect. This gentle illumination contributes to the overall dynamic, organic, and cohesive design language.

To further enhance the user experience, the top part of the joystick is coated with a matte metallic black finish. The matte texture provides a smooth yet secure grip and is resistant to oil and stains, ensuring the controller maintains its clean appearance over time. The modestly reflective metallic finish subtly highlights the "two ridge" element, emphasizing the streamlined design and adding a touch of sophistication to the overall aesthetic.

- **CMF Iteration 2**

The second iteration comprises four variations that build upon the revisions made in the initial iteration. The fading-effect indicator has been replaced with one or two more straightforward and more prominent lighting bars. This updated design simplifies the production process by eliminating the need for a fading mask on the button, instead positioning the indicator separately from the function button. This change streamlines manufacturing and gives the user a more apparent and straightforward indication.

Figure 7.13: Design Language of Interation 2

Each variation in this iteration explores different combinations of LED indicator placements. The indicators are strategically located along the top surface's centerline, on the joystick’s tail part, or combined. These placements are evaluated based on visibility and visual appeal, ensuring the user can easily perceive the indicators.

Also, along with the polished white finish in iteration 1, another three materials are tested in iteration 2, including rough iron texture, matte metallic grey, and recycled plastic, which is cold white with blue particles blended.

- **CMF Iteration 3**

Iteration 3 introduces a fresh design approach that departs from the aesthetic established in the previous iterations. While the earlier designs embraced an organic, classic, and dynamic appearance, characterized by the metallic, fluid-shaped main frame extending from the front top to the tail bottom, the new design embraces a more minimalist and unified aesthetic by simplifying the sandwich structure:

Figure 7.14: Design Language of Interation 1 and 2

Figure 7.15: Design Language of Interation 3

Under the new visual language, the top panel merges into one black plate with a long LED indicator splitting across the front part of the panel. The larger LED is more eye-catching and naturally divides the scroll wheel and the function key. It is visually cleaner because of fewer visual elements and results in a flushed mid-frame structure for easier production and assembly.

- **CMF Iteration 3+**

More detailed changes were applied to the third major iteration, it includes:

- Replace the function key's display with a low-res OLED panel for a lower cost.
- Tested different assemblies with respective joint lines (including dummy lines) and CMF to evaluate visual expression.
- Tested different finishes, including warm, ceramic-like plastic, pure white gloss paint, anodized metallic black, recycled plastic, and warm silver:

Total three rounds of CMF evaluation were conducted to determine the final design (next page).

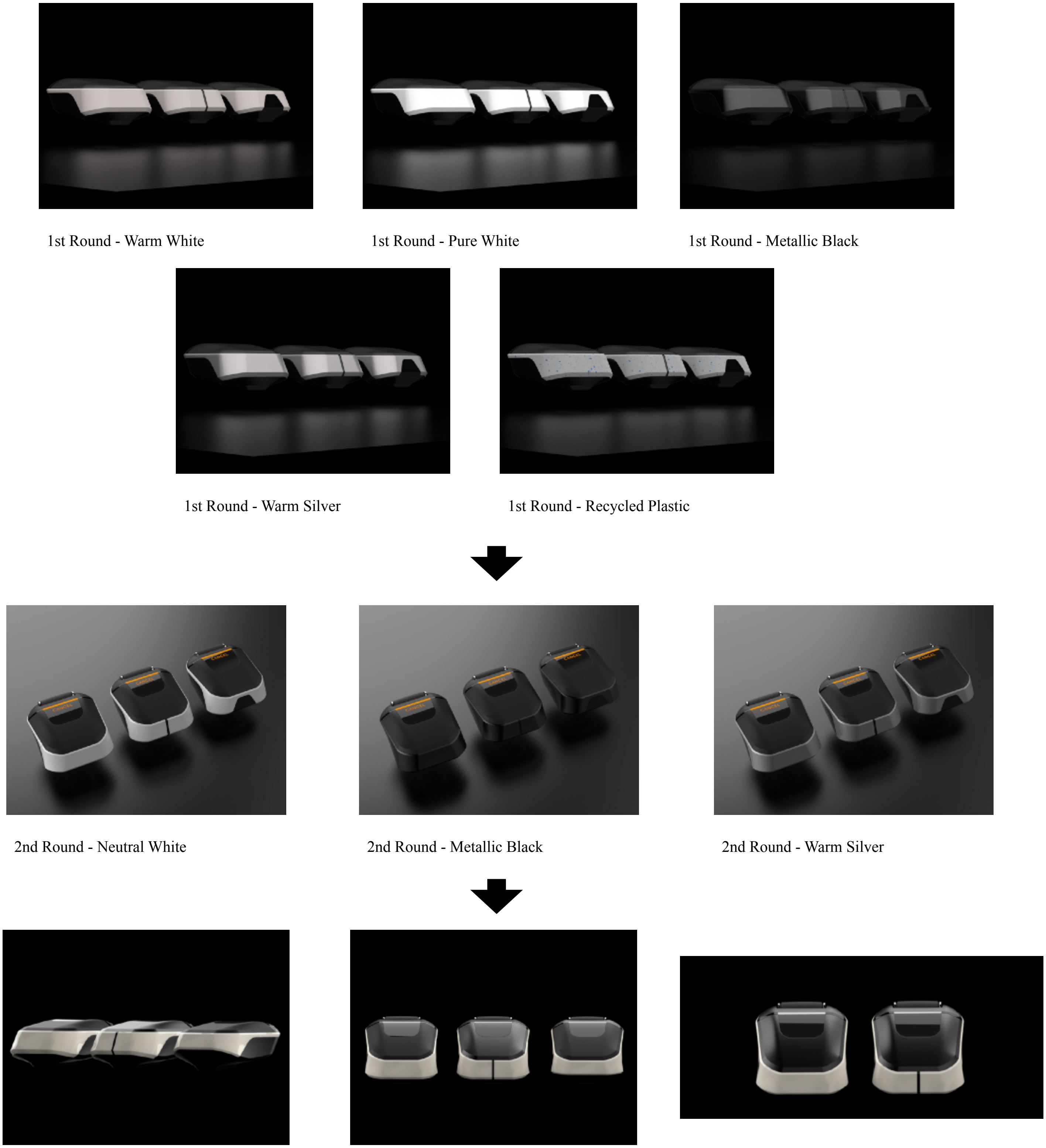


Figure 7.16: Three rounds of CMF Evaluation

7.6 Final Design

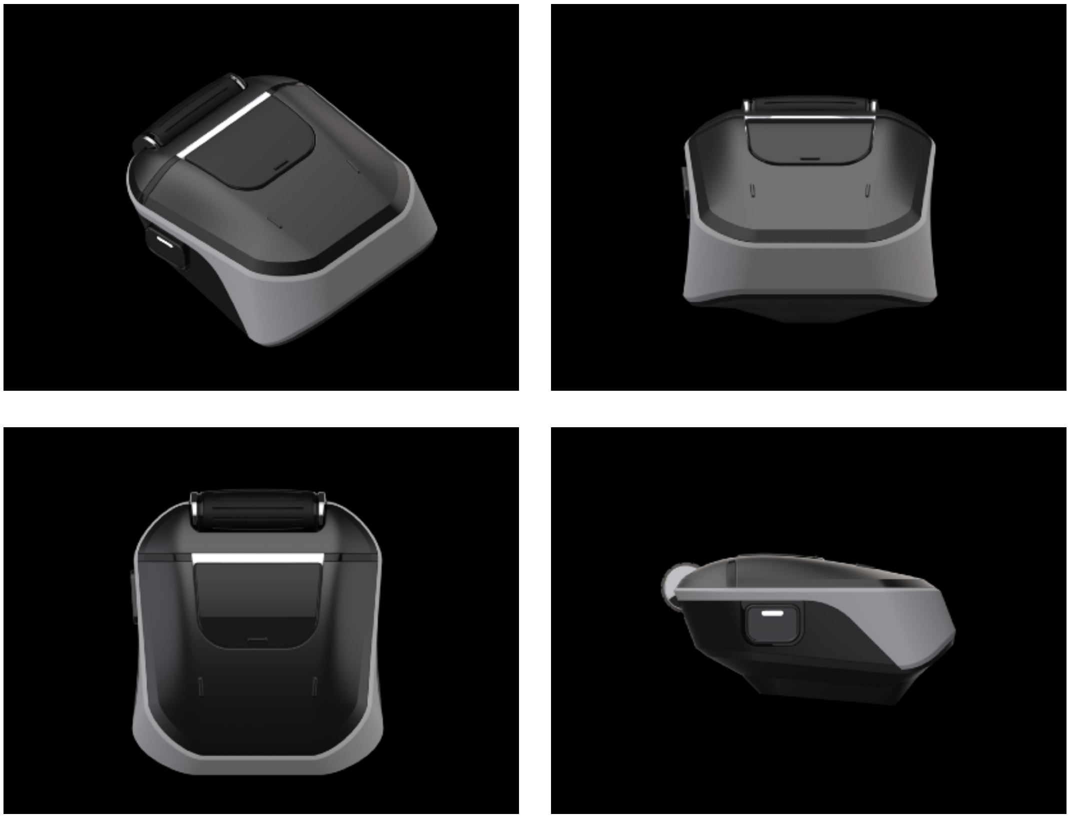


Figure 7.17: Final Design

- **Design Language**

Figure 7.18: Final Design, Side View

The final design features a simple, elegant joystick with a user-friendly interface layout. Derived from CMF Iteration #3, it maintains the minimalist design language, characterized by dynamic, streamlined lines that define the entire form. The sandwich structure visually divides the device into three distinct parts: the top interface, the middle palm rest, and the bottom unlock button.

Figure 7.19: Final Design, Top View

A long, large scroll wheel is positioned on the front top panel, ensuring easy access for the user. Two budged, curved ridges gently flow from two sides of the scroll wheel towards the tail of the panel, sculpting a smooth, organic, yet firm top surface. The change of light and shadow across this surface at different angles creates a tidy, clean, yet dynamic aesthetic.

Despite multiple stages of form and CMF design iteration, the outcome still aligns with the original intention. Two simple lines shape the side profile for a visually speedy, thin appearance while keeping a thick form to maximize comfort. The top panel is a united black surface that extends the two ridges from top to end, powerfully underscores the organic design language through the fluid and smooth reflection with the help of lighting and shading. The scroll wheel and the function key harmoniously rest between the two ridges, which is visually cohesive and functionally intuitive.The scroll wheel and function key harmoniously rest between two ridges, offering a coherent and intuitive design.

- **Components and Function**

The controller is versatile, highly integrated, and fits comfortably in your palm. Users can easily input trip-related commands and interact with the infotainment system:

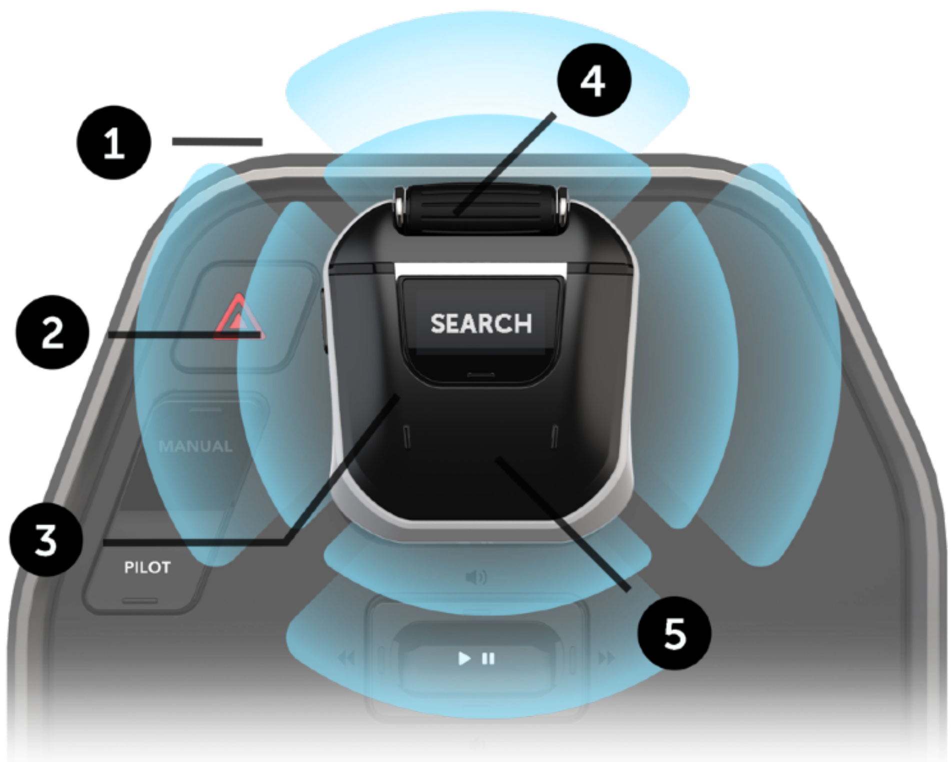


Figure 7.20: Controller components

1. **Activation Button:** When the activation button is not pressed, the joystick remains fixed, allowing users to control the regular infotainment system with the scroller wheel and the function key without worrying about inputting trip-related commands by error.

2. **Two-Travel-Stops Joystick:** Joystick mode is activated after the fingerprint lock is pressed. The joystick features two travel stops:

   • **First travel stage** by pushing the joystick to the first stop: instant vehicle behaviors that do not deviate from the planned route, such as changing lanes, decelerating, overtaking, etc.

   • **Second travel stage** by pushing the joystick further to the second stop: instant instructions for changing the destination.

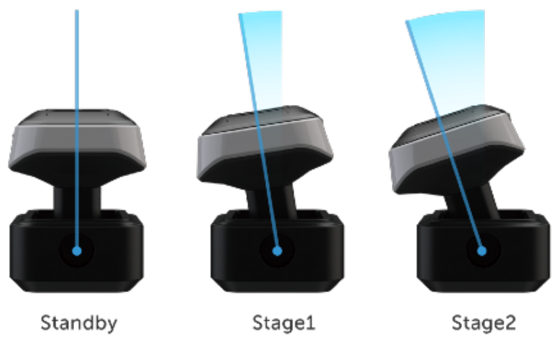


Figure 7.21: Travel Stages

3. **Adaptive Function Key:** The adaptive function key allows users to input conditional shortcuts or commands. For example:

Figure 7.22 Search for adjunct destination, or music and video.

Figure 7.23: Cancel a progressing movement input such as overtake.

Figure 7.24: Long press to swtich between jobs through app dock

4. **Scroll Wheel:** Easily navigate to options with the scroll wheel. Scroll the wheel to select, and then press the wheel to confirm.

5. **Touch Capacitive Pad:** The pad is comfortably shaped and curved. Users can wipe left/right with the palm to go back/forward without adjusting the hand's position.

Chapter 8

Graphical User Interface

8.1 Overview

The graphical user interface (GUI) is the other part of the vehicle automation control interface. Based on previous research in Chapter 4, Chapter 6, and Chapter 7, the GUI is set to support users with the following tasks:

- Locate a new/adjunct location
- Input non-deviated moving commands
- Provide visual feedback

This chapter aims to provide a comprehensive overview of the GUI components and design process. The linear documentation does not accurately represent the design process, as the joystick and GUI are highly intertwined. Both components were designed in parallel rather than sequentially.

8.2 GUI Layout

- **Layout Structure**

The layout of the center screen should accommodate the driving-related content and the non-driving-related content in a balanced manner. The current automakers have done an excellent job in the subject:

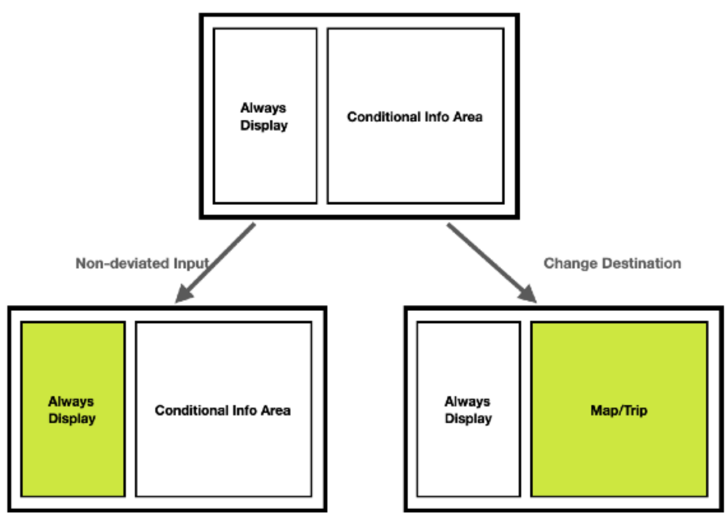


Figure 8.1: UI Layout

Like most automakers, the center screen in modern vehicles is divided into two distinct display areas: always-on and conditional content. The always-display section presents information that must be constantly visible to the driver, ensuring that critical data is always accessible. This section typically includes the following elements:

1. Road condition viewport for manual driving and automation change
2. Trip-related info, including time, route, or destination
3. Ongoing tasks include system status and media playing

In contrast, the conditional section is designed to exhibit information that is not necessary to display at all times and is primarily based on user input. This section adapts to the driver's specific needs and preferences, displaying relevant content when required. Common examples of information shown in the conditional section include:

1. Map/Trip for editing the trip
2. Entertainment Content

In most cases, the conditional section occupies a more significant portion of the screen to accommodate a broader range of information and provide a more detailed view of the selected content. However, the size and layout of both the always-on and conditional sections can be adjusted based on the specific input and the driver's preferences. This adaptability ensures that the most relevant information is prominently displayed.

- **Interface Component:**

Figure 8.2: UI components

Three interface areas are shown in the rendering above:

6. **Road Condition and Comand Preview**: Users can safely and efficiently execute quick commands while staying informed about road conditions. The interface provides a preview of the instant command. A widget at the top of the window indicates execution status, providing immediate feedback to the user.
7. **Apps/Task Area**: Components are laid out, and users can easily navigate with the scroll wheel. Long-press the Fn key and roll out the app dock to switch between jobs.
8. **Comfort Control**: Comfort control is separated from the main display. Users can easily read the info and control it anytime. Two physical knobs and buttons enable fast

adjustment and shortcuts. Note that this project's design subjects exclude the comfort control interface.

8.3 Interface Breakdown

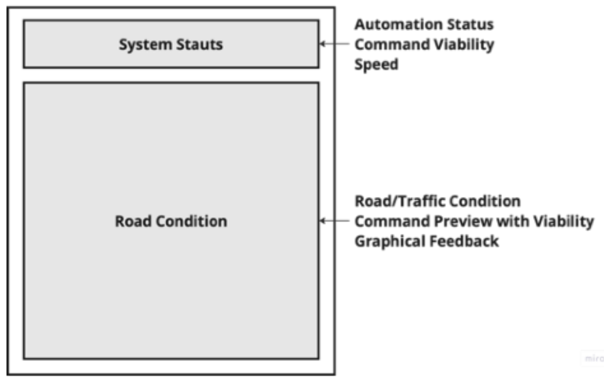


Figure 8.3: Interface breakdown

The GUI must accommodate different input commands under a unified visual language and similar information architecture to maximize the user experience by minimizing the learning cost and workflow difference between the two types of command:

- **Non-Deviate Input**

For non-deviating inputs that require immediate execution, users often need instant access to road information to make decisions. In such cases, finding new destinations is unnecessary, as the focus is on navigating the current route safely and efficiently. To accommodate this need, the always-display section of the interface is designed to provide crucial information related to road conditions and input previews.

The vehicle's user interface (UI) comprises system status and road condition. The system status area displays a controller icon representing the driver's vehicle involvement. As recommended by the research published by AAA: "*System status (e.g., on, off, activation, deactivation/disengagement, availability) should be presented clearly and continuously. In doing* *so, display elements for a common system should be grouped together.*" The icon on the left represents the current driving mode ('A' means 'Auto-Driving Mode' as shown in the image). The controller icon changes when the driver activates the vehicle automation by pressing the activation key.

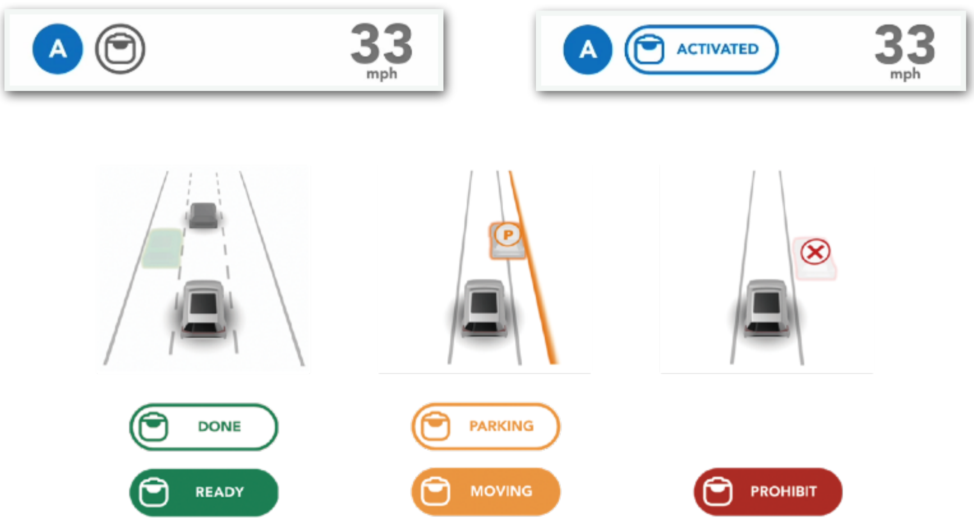


Figure 8.4: Components and widgets

As indicated in the image above, the interface provides a view of traffic conditions and a preview of the input. A semi-transparent vehicle model with color glowing indicated the non-deviated inputs or the driver's intention. Three colors represent the validity of the input:

- Green: Feasible movement without additional input needed, like switching to a faster lane when the clearance is promised
- Organe: Attention needed and further operation required. For example, the indicator will turn to a flashing, solid-filled orange when the vehicle executes the command, or it will turn orange-stroked, indicating further input (spot parking location) is required for the roadside parking command.
- Red: Unfeasible vehicle motion, such as travel out of the lane

- **Roadside Parking**

As *Chapter 6.3 Commands Breakdown* mentions, roadside parking is an exception to the regular pattern of uninterrupted driving. While the vehicle remains on the planned route, it ceases driving, requiring users to choose a parking spot manually in certain situations. Unlike specifying a location on the map as a destination-related input, it can be challenging to designate a parking spot on the digital map because:

1. The map sometimes contains insufficient geographical details, especially in rural areas.
2. Due to map scaling, users may find difficulty interpreting the real-world spot through a scaled digital representation.

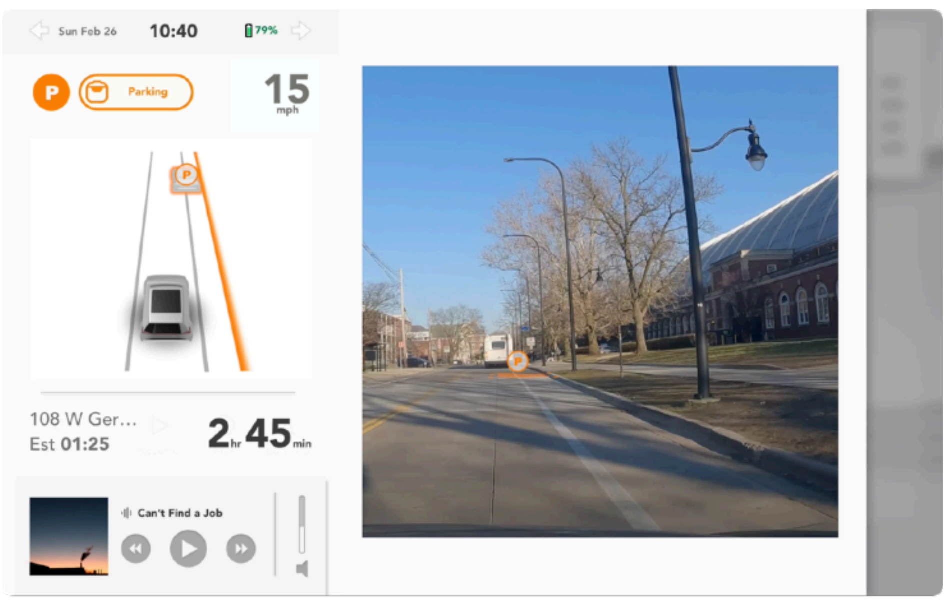


Figure 8.5: AR viewport

The solution is to use Augmented Reality to assign a parking stop with UI overlaying on the real world. Upon entering the roadside parking mode, the always-display section will expand, the indicator will turn orange, and the system will wait for the user's further input. Users can view the traffic condition and use the scroll wheel to move the desired spot back and forth. The parking spot's move-to-assign design also contributes to the scroll wheel design in *Chapter 7.3 Supplemental Interface - Scroll Wheel.*

- **Deviated Input**

As discussed in Chapter 7.3, Supplemental Interface - Scroll Wheel, the type of stimulus significantly influences a user's navigation behavior. Users tend to select it directly on the map when they are already familiar with the area or when the destination is within their immediate vicinity. In such cases, the interface prioritizes displaying nearby points of interest and allows users to quickly select using the scroll wheel. By presenting relevant information and allowing users to interact with the map directly, the system can streamline the process and minimize the need for extensive searching or manual input.

On the other hand, when the destination is located further away and sufficient time is available, users are more likely to engage in proactive searching. This behavior is especially common when users are unfamiliar with the area or when the destination is not immediately visible on the map. Nevertheless, geographical factors also restrict the selection of workflows. For instance, if the screen size or map scale limits the location options, users may search for the destination instead of browsing the map.

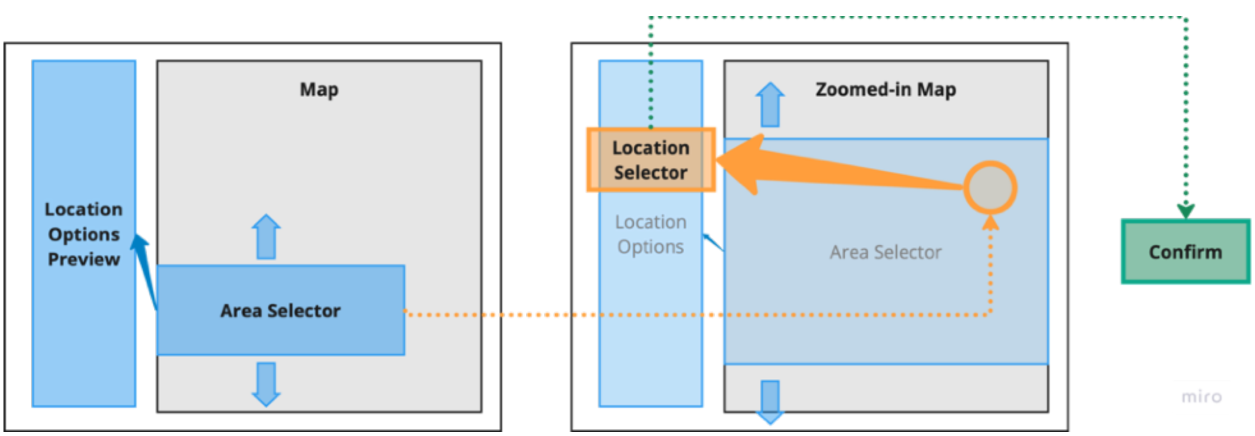


Figure 8.6: Interface workflow for deviated inputs

Users can scroll the selector forward or backward to choose areas in front of or already passed. The interface employs a two-step design that follows a hierarchical approach, transitioning from a zoomed-out to a zoomed-in view to facilitate the rapid selection of new adjunct destinations. The first step involves an area selector that dynamically adapts to the direction in which the joystick is shifted. When the joystick is moved to the right, the area selector covers locations on the right side of the vehicle's current position. Conversely, when the joystick is moved to the left, the selector focuses on locations to the left. Once users have selected the desired location, they will choose the appropriate sub-option (if applicable) to confirm the new destination. This hierarchical approach ensures that users can make precise and informed decisions while maintaining a streamlined and efficient navigation experience, and all of these inputs can be executed using a single scroll wheel.

Figure 8.7: Search button

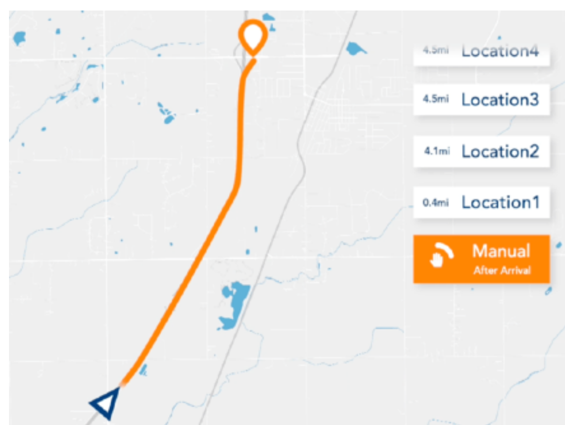


Figure 8.8: Option of overtaking control

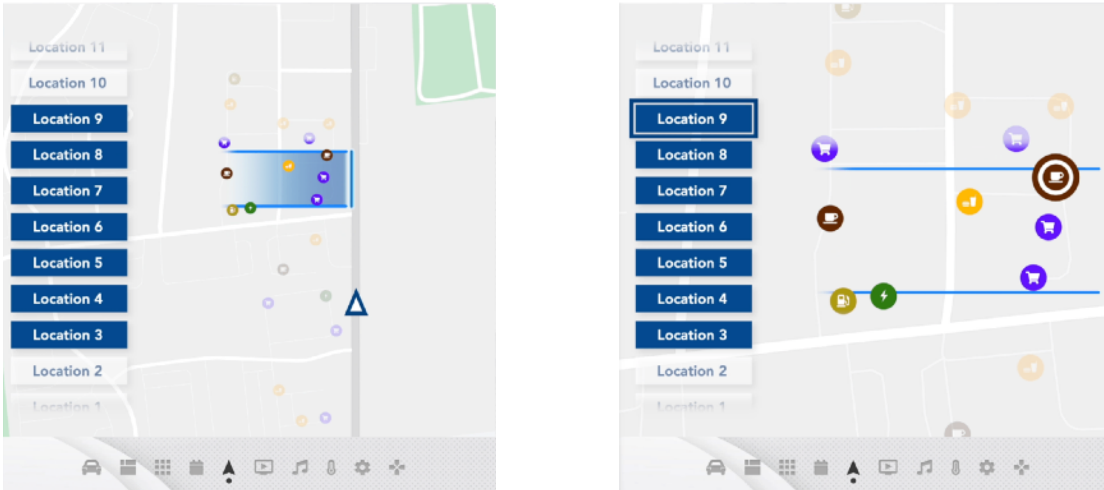


Figure 8.9: In urban/suburban areas, the area selector directly covers options on the right or left.

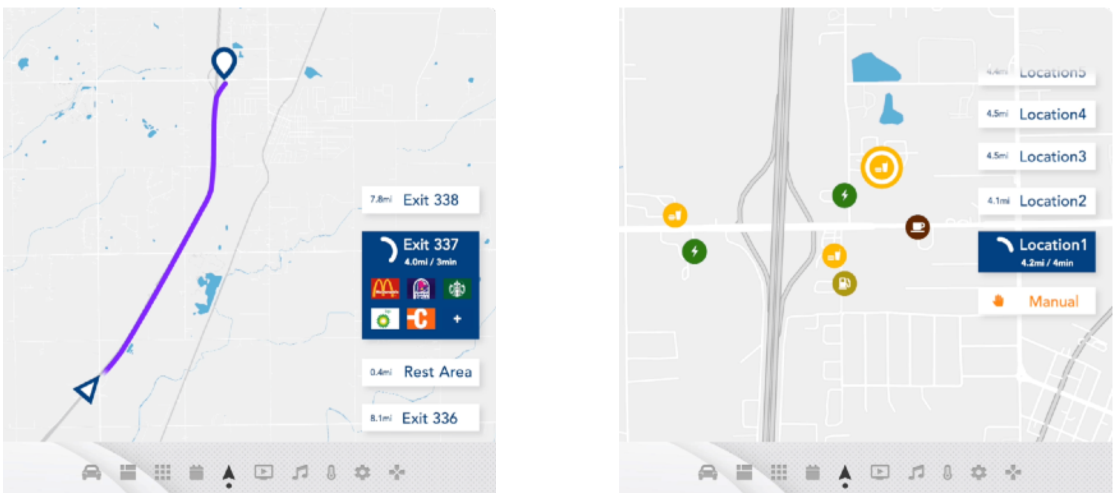


Figure 8.10: When the vehicle is on highway, the area selector is based on Exits.

Chapter 9

Final Outcome

9.1 Final Design Overview

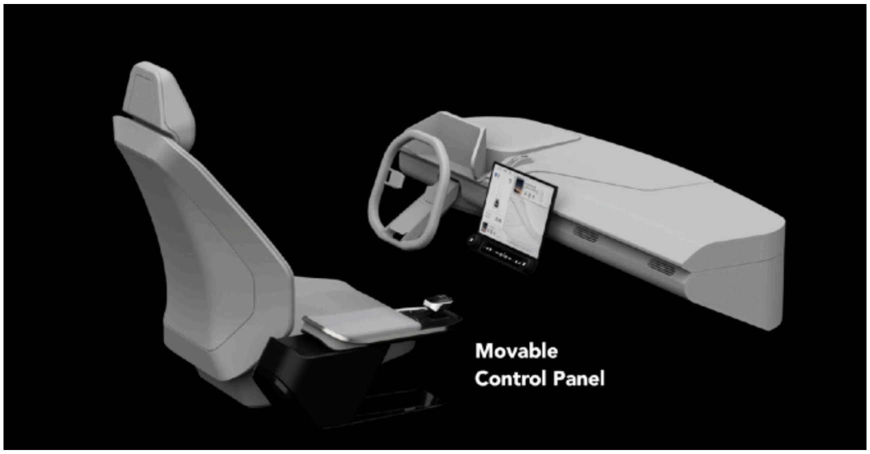


Figure 9.1: Movable control panel

Figure 9.2: Peripheral interface

The project outcome, '*Auto Sphere*,' features a control panel and an information display. The control panel is mounted on the armrest and moves with the seat position, ensuring the driver can access the interface anytime. Besides the joystick controller, the final design includes a peripheral interface for general tasks, including media control, a driving mode switch, and an emergency button. While not part of the original intent, the peripheral interface demonstrates the joystick controller's adaptability within a broader vehicle interior.

9.2 Interface Demo

Table 9.1: Roadside park

Step1: Press the activation button to unlock the joystick. The controller icon on the display will turn from grey to blue and show 'ACTIVATED'.	
Step 2: Move the joystick towards the orientation of the desired parking spot until it reaches the joystick's first travel stage. In the preview of the car's movement, the vehicle will turn red, and the indicator widget will display the word 'PROHIBITED' because no other lane is available.	 

Table 9.1: Roadside park (Contin.)

Step 3: Move the joystick again to the joystick's second travel stop. The system will enter roadside parking mode with a spot selector overlayed on the AR viewport. The indicator will turn orange-stroked, waiting for further instruction from the driver.	 
Step 4: Move the spot selector back and forth with the scroll wheel to assign the parking spot, then press the scroll to confirm.	 
Upon confirmation, the car will travel to (as the indicator showing 'MOVING') and stop at (as the indicator showing 'DONE') the desired spot.	

Table 9.2: Lane Switch

Step 1: Unlock the joystick	
Step 2: Move the joystick towards the orientation of the desired lane until it reaches the joystick's first travel stage. In the preview of the car's movement, the vehicle will turn green, and the indicator widget will display the word 'READY' if the clearance is allowed to switch lanes.	
Step 3: The car will automatically change the lane. The preview and the indicator will turn orange, notifying the driver to be attention. Driver can also cancel the command and return to the original lane by pressing the CANCEL (as displayed on the adaptive function key) anytime during the movement.	

Table 9.3: Reroute on highway

Step 1: Unlock the joystick	
Step 2: Move the joystick to the second stop stage; the interface will show the exits ahead along the route.	 

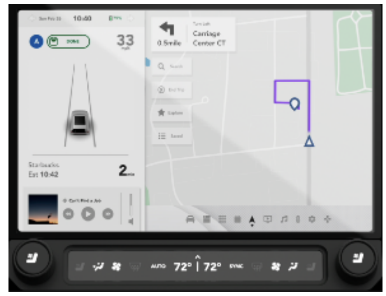
Table 9.3: Reroute on highway (Contin.)

Step 3: Select the Exit using the scroll wheel	
Step 4: The driver can select the point of interest (if applicable) and search by pressing the adaptive Fn key. The driver can also take over the driving after exiting the highway.	 
Step 5: Upon confirmation from the driver, the vehicle will reroute to the new destination or hand over the control to the driver after reaching the exit.	

Table 9.4: Reroute in urban

Step 1: Unlock the joystick.	
Step 2: Move the joystick to the second stop stage on the right/ left, depending on the orientation of the point of interest. The interface will display the available options on the assigned side.	 
Step 3: Move the area selector with the scroll wheel to confirm and zoom in on the covered area.	
Step 4 (Optional): The driver can adjust the covered area on the UI by scrolling while pressing and holding the scroll wheel.	 

Table 9.4: Reroute in urban (Contin.)

Step 5: After zooming in the area, the driver can select the destination in the list on the left. The driver can always search for the destination by pressing the SEARCH anytime during the workflow if the desired destination is not listed.	

- **Other Operation**

Figure 9.3: Other Operation

Chapter 10

Conclusion

The report documents the progression of the design project ‘Auto Sphere.’ It started with the background introduction of future vehicle automation and the automaker’s current effort to change the future vehicle’s infotainment system to embrace the future. However, when people are excited and waiting for the self-driving technology to be delivered, something is missed in the automakers’ concept models: the interaction between humans and the car during vehicle automation. A trip in a car is not always smooth or linear, as people often interrupt their driving with unplanned tasks such as resting or grabbing food.

‘Auto Sphere’ aims to address the communication between the driver and the self-driving car for those unplanned tasks during the trip. With study and research on driver behavior and vehicle behavior, a system workflow is conjured to adopt various communication between the driver and the car under different circumstances. A user experience study was conducted and evaluated quantitatively and qualitatively to materialize the system, and an interface including a joystick-style controller and a graphical user interface was proposed.

The 'Auto Sphere' project outcome results from extensive design iteration, balancing functionality and efficiency. The final design includes the elegant, versatile, intuitive joystick controller, cohesive information architecture, thoughtful widgets, and graphical interface. This human-centered approach embodies a beautifully designed system that allows drivers to smoothly communicate with their vehicle and input commands like lane changes, roadside parking, and rerouting while enabling them to easily control and customize L3/L4 automation.

The streamlined decision-making process delivers a seamless, user-friendly experience under most conditions, with an aesthetically pleasing and intuitive analog controller and GUI.

However, further research and experimentation must be conducted to explore a similar subject. In 2023, innovative technologies such as Large Language Models (LLM) and Spatial Computing were introduced to the general public, making it easier for us to communicate with machines using natural language. This could result in a significant change in the study's findings in *Chapter 3, User Research*. The survey participants may show a higher acceptance rate for 'Voice Commanding' and 'Augmented Reality.'

Despite these advancements, Auto Sphere's value should be addressed, as intuitive and effective interaction will always be a priority in design goals. The project's focus on human-centered interaction-driven design principles ensures it remains relevant and adaptable to evolving user needs and preferences. Future iterations of the project could incorporate emerging technologies while maintaining the core focus on usability and user experience.

In conclusion, Auto Sphere offers a well-designed, user-friendly solution for driver-vehicle interaction in automotive interface design. As technology advances, the project's foundations in human-centered design will serve as a solid basis for further exploration and improvement, ensuring that it remains at the forefront of innovative and intuitive automotive interfaces.

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