Investigating Futuristic In-Car User Interfaces

Steer By Wireless

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Acknowledgements

Thank you to Dmitrijs Dmintrenko for allowing me to work under his supervision and produce this project. Without his proposal to research car user interface and experience, I would not be completing this project on one of my great passions.

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Introduction

This project aimed to prove that a potential new steering interface using a touchscreen and modern controls is beneficial for drivers and can produce safe driving outcomes. I wanted to show that not only could security be provided, but also how much people would be willing to use new driving interfaces over traditional apparatus.

Primary Objectives:

- Assess the feasibility of using a wireless interface to interact with vehicles.
- Create a proof-of-concept interface allowing users to interact with a driving simulator.
- Conduct a test with the prototype in a driving simulation
- Gather feedback on user interactions with the wireless touchscreen interface.
- Interview at least 10 participants to gather feedback on what they like and dislike about the interface
- Investigate the requirements that would be needed to implement this in a modern vehicle, if feasible
- Identify the pros and cons of using a single intuitive interface and how people enjoy interacting with their vehicles.
- Learn about the driving experience and why people may oppose a new form of control.

Scope and background studies

The traditional driving apparatus has remained unchanged since the' advent in 1886. This lack of significant innovation has resulted in a cluttered driving environment, with many controls and interfaces persisting for over a century. In the 21st century, drivers increasingly prioritise comfort and ease of use (Zhou, X., Lai, D. and Chen, Q., 2019), suggesting that simplifying these systems could make the user experience accessible to more people with a potential solution - adopting touchscreens. As society moves into the digital age, the widespread use of smartphones and tablets has made touchscreens a familiar and easy-to-access technology for all modern users.

The study by Large, D.R., Banks, V., Burnett, G. and Margaritis, N. (2017) explores innovative approaches to vehicle control, specifically investigating a joystick as an alternative input method for steering, to enhance the driving experience by introducing a fun but easy to use driving method. The authors aimed to identify steering with a joystick could effectively replace traditional steering wheels, potentially simplifying the vehicle cabin and improving user experience. Their findings show that joystick steering not only provided similar control accuracy but was also incredbly enjoyable and easy to use, providing credibility of the potential of alternative interfaces such as touchscreen or joystick controls for future vehicle designs. This research provides a strong foundation for future studies exploring alternative driving interactions, making the case that unique steering methods positively influence driver acceptance and usability.

Other vehicles and modes of transport have already begun innovation on the use of touchscreen controls for movement, allowing for intuitive and simple-to-use yet pervasive control (Rabhi, Y., Mrabet, M., Fnaiech, F., Gorce, P., Miri, I. and Dziri, C., 2018). Controls used in wheelchairs, such as directional touchpads, could easily be adapted for automotive use. Touch gestures transforming into movement in wheelchairs offer a precedent for vehicle control in daily life. This adaptation would allow for the same level of intuitive control, veering away from traditional steering wheels. Rabhi, Y., Mrabet, M., Fnaiech, F., Gorce, P., Miri, I. and Dziri, C., 2018, also noted that after practice, users were faster and more precise with the touchscreens, suggesting a potential for improved driver reaction times and control accuracy in cars. This highlights the potential for a learning curve that, once mastered, could significantly enhance road safety.

For years, cars have used touch screens as information and control methods. Older car models used knobs and switches to control radios, navigation, and other peripheral functions, but near the start of the 2010s, more cars began adopting touchscreen and digital controls. Initial models of this technology were slower and had worse displays. Still, as recently as 2019, significant innovations have emerged, such as Tesla’s large touch screens, which allow for high clarity and quick touch processing (Brown, T., Marshall, D. and Lerner, N., 2019). Tesla's screens go beyond infotainment and non-critical interactions; they integrate vehicle comfort functions, such as climate control and driving mode selection, into a central touchscreen. This shows a shift towards touchscreen driver interfaces, potentially reducing cognitive load and the vehicle cabin clutter. Furthermore, Apple CarPlay, which syncs with Apple phones to control car functions, is another great example of integrating familiar mobile interfaces (and touch screens) into the automotive environment. This builds off existing user familiarity, reducing the learning curve mentioned before for drivers. However, the reliance on touchscreens, a technology already taking up a lot of our lives, raises concerns about distraction, requiring careful consideration of interface design and safety features.

It is also important to note that touchscreens have already been researched within high-stakes operational environments. Research by (Li, W.C., Liang, Y.H., Korek, W.T. and Lin, J.J., 2022) has explored the use of touchscreens as interfaces in flight operations, investigating human-computer interaction in this high-stakes context, showing that with careful design and testing, touchscreens can be viable control mechanisms even under significant stress. This research proves that touchscreens are viable within high-stakes environments where precision is of utmost importance, such as driving. While flight and road driving dynamics differ, the principles of human-computer interaction and the need for reliable control interfaces are similar. This work also provides a counterargument, showing that touchscreens can be used in highly stressful situations. However, more research on the differences between flight and road driving regarding touchscreen usability needs to be done.

However, the implementation of touchscreens in automotive control has its challenges. One significant obstacle is the impact of road-induced vibrations on touchscreen usability. (Bashar I. Ahmad, Patrick M. Langdon, Simon J. Godsill, Robert Hardy, Lee Skrypchuk, and Richard Donkor. 2015.) highlighted that vibrations can lead to errors in touch input, particularly in control scenarios. This highlights the need to develop robust vibration mitigation strategies to ensure reliable and safe operation. Additionally, the integration of touchscreens must adhere to established principles and standards for vehicle design, ensuring that driver comfort and situational awareness are maintained.

Furthermore, the transition to touchscreen interfaces raises questions about the balance between automation and manual control. As vehicles become increasingly automated, the role of the driver is evolving. Research in Human-Computer Interaction (HCI) (As taught at the University of Sussex 2024) emphasises the importance of maintaining driver engagement and situational awareness, even in highly automated environments. When designed effectively, touchscreen interfaces can provide drivers with seamless access to information and control, enhancing their ability to monitor and take control when necessary. This requires a deep understanding of cognitive load, affordance, and feedback mechanisms, which are crucial considerations in designing intuitive and safe automotive interfaces.

The move towards steer-by-wire technology also presents an opportunity to reimagine the driver interface. Steer-by-wire systems eliminate the mechanical connection between the steering wheel and the wheels, allowing for greater flexibility in steering system design. This opens up possibilities for customisable touchscreen interfaces that can adapt to different driving conditions and driver preferences. In conjunction with advanced driver-assistance systems (ADAS), steer-by-wire and touchscreen interfaces can contribute to a more seamless and intuitive driving experience.

Motivations

This project represents an opportunity to explore how human-computer interaction (HCI) principles can be applied to automotive design. While traditional steering mechanisms have remained largely unchanged, the shift toward digital interfaces and automation presents an exciting challenge: how can we design an interface that feels intuitive and natural while maintaining the precision and control required for driving?

My motivation stems from an interest in user interface (UI) design and its role in shaping user experiences. I am also fascinated with modern vehicles and the evolving technology that we use in them. Many touchscreen interfaces in cars today focus on infotainment rather than core driving functions. I aim to investigate whether a touchscreen-based steering mechanism could be as reliable and efficient as traditional controls. Understanding how users interact with novel control systems and what makes an interface feel "natural" is crucial to this project.

Additionally, this project is an opportunity to develop practical prototyping and user testing skills. Creating an interface that balances responsiveness, safety, and usability requires combining technical knowledge, creative problem-solving, and real-world testing. I hope to contribute to ongoing discussions about the future of automotive control systems by gathering user feedback and analysing how drivers adapt to a touchscreen steering system.

Beyond the technical aspects, I see this project as a stepping stone toward a career in automotive technology or UX design. The skills I develop here - prototyping, usability testing, and analysing human interaction with digital controls - are highly applicable to modern innovations, intelligent vehicle systems, and emerging technologies like autonomous driving interfaces.

Requirements

In this section, I will delve into the requirements for the user interface that I will be developing.I will discuss what the functions of the project need to be and why each section of the interface is necessary.

Functional Requirements

Below is a list of all functional requirements required for the interface to provide an adequate user experience

- Users should be able to interact with the interface in real-time, with no significant input delays
- Interface should interact with a driving simulator in real time
- Users will be able to control the speed of a vehicle
- There should be a steering control section that has reasonable tracking of the car's steering
- Braking and emergency braking must be easy and quick to access
- There must be a form of visual feedback to the user to confirm inputs

Non Functional Requirements

The non-functional requirements also exist to provide an adequate user experience.

- The layout should be simple and intuitive to use with limited instruction

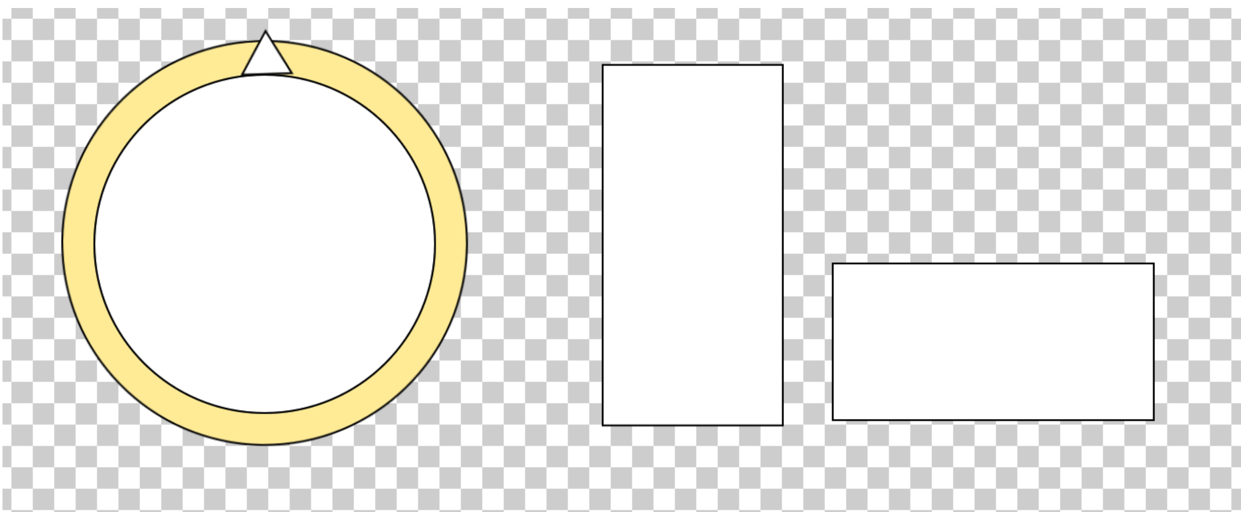
- There should not be more than the necessary amount of features to avoid visual clutter and for speed of making choices (hick's law)
- The interface should be adaptable to future improvements

Design

The design of the interface intends to be intuitive and efficient. Providing as little clutter as possible. There will be a few low-fidelity prototypes that I went through, each with different features that were abandoned for one reason or another.

Initial Idea

Following is an initial idea as a sketch on a transparent background.

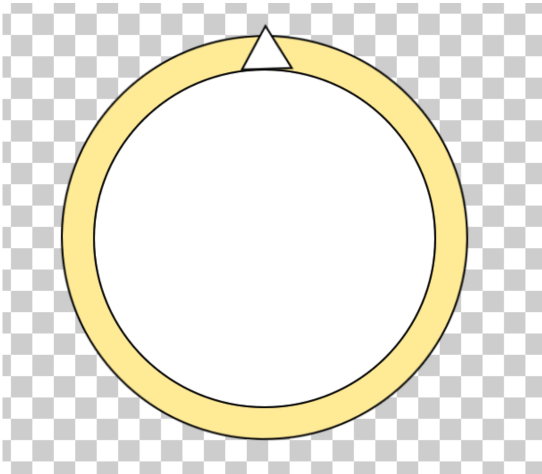


Low fidelity sketch of the prototype

The design aims to be very simple, and invoke the designs of current interiors of vehicles, with a steering wheel, pedal, and brake all very similar to current apparatus.

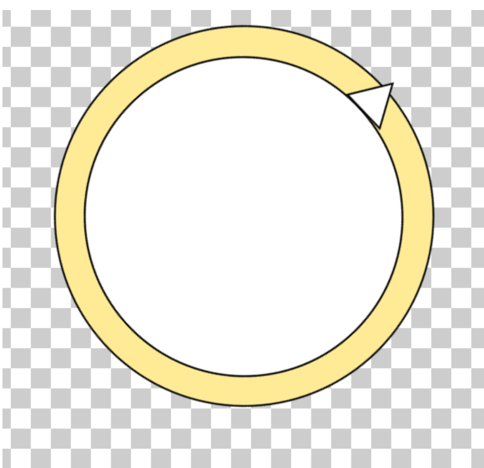
Steering wheel

After reading a study on the design principles behind steering wheels (Meschtscherjakov, A., 2017. The steering wheel: A design space exploration) - I decided to carry over a lot of the same principles to assist in intuition and familiarity within the design. The paper discussed that it is crucial for road safety to know the orientation of the steering wheel at any given point. This helps with the driver finding their bearings. To remedy this the final design for the steering wheel will have an indication of the top of the wheel, either via an asymmetrical design from top to bottom or a pointer at the top as illustrated above.



Centred steering wheel

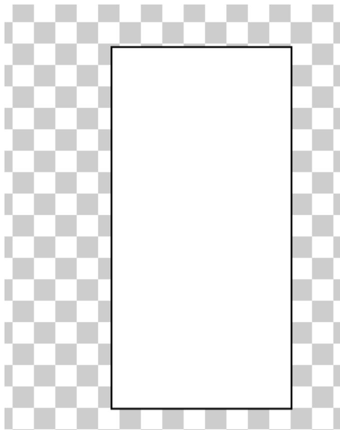
The indicator for this prototype is the triangle at the top, this will always point to the upwards direction of the steering wheel at rest and will rotate along with the steering wheel in order to show the direction that the wheel is pointing, for example, if the driver were to turn right (by about 45 degrees) the steering wheel would look more like this.



Turned steering wheel

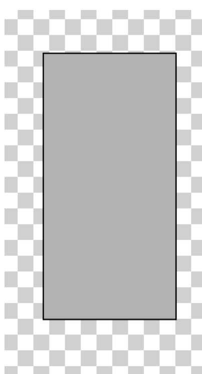
Pedals

Following my research (Bhonge, A., Gunai, P. and Joshi, K., 2016.) I decided to keep the core design philosophy of the gas pedal. This pedal is generally a more extended and thinner pedal than the brake pedal (which shall be discussed later). Having a unique design is essential as the gas pedal needs to be easily identifiable to lend itself to the user experience and intuitive design I am going for.



Gas pedal (stationary)

When in use I intend to give visual feedback to the user so that they are aware that the pedal is in use, this is similar to how a person will feel the gas pedal going forward in a real car - in this case the feedback will be visual as opposed to physical. There are a lot of potential ideas, however I have chosen to go with a subtle colour change to indicate the usage of the pedal.



Gas pedal (in use)

The brake pedal will be very similar in all aspects to the gas pedal, however it will be rotated horizontally. This is so it's easy to distinguish between them both.

Unlike real cars, I decided to put the brake pedal on the right side instead of the left, as I decided it will be harder to reach the middle of the screen in emergency situations where the brake pedal is needed, and it needed it to be the most accessible point of the interface.

Final Design

The final design was intended to not be highly colourful to prevent distraction and cognitive load. So it uses a lot of grey colours that are easily distinguishable to provide a simple interface that won’t overwhelm a driver.

Similarities to initial prototypes

The initial prototypes have the same layout as this final design, all including a steering wheel, brake pedal, and gas pedal in the same shape and positions. The changes come in the details of the control features themselves, such as the gas pedal having horizontal lines and a different colour scheme to the brake pedal - which has vertical lines. It was essential that the gas and brake pedals were easily distinguishable. The steering wheel has been changed to not have a triangle pointing upwards but a design on it that allows the user to very easily tell which way is upwards, as the design will start on the right and if it does not remain on the right the user will know that the steering wheel has moved.

Implementation

The implementation of the user interface primarily focuses on a driver interacting with a driving simulator using the touchscreen interface in order for feedback and thoughts on the simulator to be collected. User experience and ease of use are most important in the implementation. The implementation should follow the following key concepts of usability in HCI:

- Learnability: How easy is it for users to start using the system?
- Efficiency: How quickly users can perform tasks?
- Memorability: Can users easily remember how to use it after a break?
- Errors: How many mistakes do users make, and how severe are they?
- Satisfaction: Is the experience enjoyable?

The touchscreen interface developed in this project explicitly aligns with Nielsen's usability heuristics, particularly focusing on visibility of system status, consistency and standards, error prevention, and recognition. Visual feedback, such as the steering wheel indicator and pedal activation color changes, directly addresses the heuristic of visibility by ensuring drivers receive immediate confirmation of their inputs. By maintaining familiar design conventions—such as positioning and shape similarities with traditional steering wheels and pedals—the prototype adheres to consistency, enhancing learnability and intuitive interaction.

Error prevention is achieved through thoughtful placement of the brake pedal for rapid access during emergencies, minimising user mistakes and response delays. Furthermore, the simplistic layout reduces cognitive load, allowing drivers to operate the system efficiently without extensive memorisation or training. These heuristics directly improve the interface's usability, reliability, and overall acceptance among potential users.

Development Overview

This section outlines the implementation and evaluation process for the custom touchscreen-based driving interface integrated with the CARLA driving simulator. The system was developed in Python so that modularity, OOP, and rapid prototyping would be emphasised.

System Design and Tool Selection

The first step was selecting a suitable driving simulator to conduct user testing in a realistic and controllable environment. CARLA was chosen for its open-source nature, high-quality visuals (via Unreal Engine), and robust Python API. These features allowed seamless integration with a custom Python-based UI and enabled direct control of in-simulation vehicles.

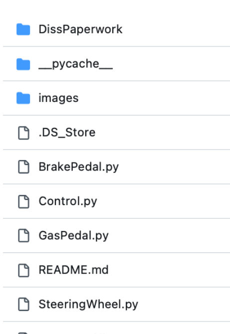
For the user interface, Python with Pygame was selected. This choice was made due to:

- Fast iteration and development cycles
- Simple graphics and event handling
- Wide community support and documentation

While Python may have speed limitations, these are negligible in early-stage UI prototyping. Pygame was sufficient to handle inputs, rendering, and interactivity with negligible latency.

Version control was managed through GitHub, and Visual Studio Code served as the primary IDE throughout development.

Here is the file structure of the project (this code is all without the interfacing with the Carla simulator):



Interface Implementation and Modularity

The user interface was built with modularity and readability in mind. The code was organised into clearly defined modules:

- prototypeUI.py – The main entry point and event loop
- controls.py – Contains classes for steering, brake, and acceleration
- base_control.py – Abstract class from which all controls inherit

This structure allows components to be independently updated or tested without affecting the core loop logic. Each control uses resolution-independent positioning, expressed as relative fractions of the screen dimensions. This ensures the interface remains functional across different screen sizes and aspect ratios. I found this to be a key feature that was needed, as it allows for future adoption of the software into different hardware and allows easy resizing on the go.

Object-Oriented Design

Each interactive element (steering wheel, pedals) is implemented as a class. This follows key OOP principles:

- Encapsulation: Control-specific logic (e.g., rotate, return_to_center) is self-contained
- Inheritance: A base Control class is used to reduce redundancy and improve maintainability
- Polymorphism: Allows unified treatment of controls in the main event loop

The steering wheel class required particular attention, with custom rotation calculations and smoothing logic to prevent jumpiness. A return_to_center() method simulates spring-back behavior, improving realism.

Integration with CARLA Simulator

Once the UI was developed and tested in isolation, the next phase involved integrating it with the CARLA simulator to support real-time vehicle control.

CARLA version 0.10.0 was selected for its compatibility with Python 3.12 and Windows 10, ensuring a stable development environment. CARLA operates using a client-server architecture—the simulator runs as a server, and control scripts act as clients by connecting through CARLA's Python API.

Connecting to the server is straightforward, involving the Carla Client class. After establishing the connection, the world is accessed, and a custom environment is set up. The prototype uses a generic vehicle model, focusing on interface interaction rather than driving physics or vehicle-specific dynamics.

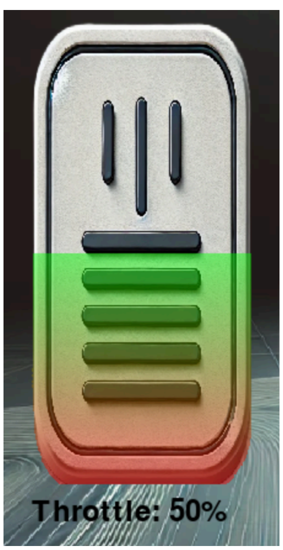
Once integrated, all throttle, brake, and steering values generated by the UI were mapped to CARLA's control commands (Carla.VehicleControl) and transmitted in real-time. This allowed users to control a virtual vehicle directly using the touchscreen interface.

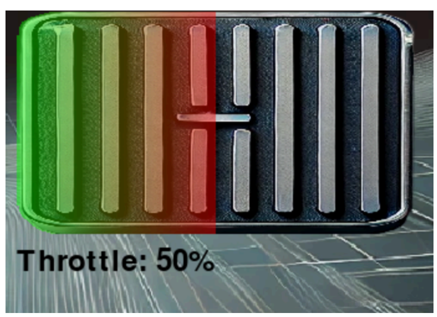
Limitations during implementation:

One of the main challenges encountered during development was replicating pressure-sensitive controls (e.g., throttle modulation) on a touchscreen, which typically lacks analog input. Traditional driving relies heavily on varying pressure on pedals, something not natively supported by basic touch inputs.

To mitigate this, a visual system was designed where the touch position on the pedal interface corresponds to the control output. For the accelerator, a higher tap on the pedal results in lower throttle, while a lower tap yields higher throttle. Tapping further left reduces the braking force for the brake, while tapping further right increases it.

This mapping was made intuitive through gradient visuals and live throttle/brake percentage displays, providing users with real-time feedback. The design was informed by user-centered principles, ensuring learnability and feedback without requiring external training.





Evaluation and Testing

To validate the effectiveness and usability of the prototype, several forms of testing were conducted:

Unit Testing

Individual control components were tested independently to ensure correct behaviour:

- Steering wheel rotation bounds and reset behaviour
- Throttle/brake percentage calculation from touch position
- Rendering and updating of visual elements

This testing ensured that logic bugs (such as incorrect angle snapping or value calculation) were resolved early in development.

Integration Testing

Once the UI and CARLA components were connected, integration tests were used to ensure:

- Commands were accurately sent and received in real-time
- Vehicle movement reflected UI input without delay
- There were no crashes or synchronisation issues between modules

During testing, CARLA’s log outputs and performance monitors were used to confirm that input latency was consistently low and control updates were being processed as expected.

Limitations and Future Improvements

The prototype is functional and demonstrates a feasible touchscreen-based vehicle control interface, but several limitations were identified:

- Lack of Haptic Feedback: The prototype is currently entirely visual, which can increase cognitive load and make it harder for a user to focus on driving. A potential haptic or vibration-based feedback system could greatly improve this aspect.
- Single Touch Input: The current system does not support multi-touch gestures, which limits simultaneous control (e.g., steering and braking). Adding multi-touch support would be crucial for more realistic control. Multi-touch is not natively supported by PyGame, and other libraries, such as Kivy, could have been used to implement this. This is a slight oversight; however, as proof of concept, this is still appropriate.
- Edge Case Behaviour: Some edge cases, such as quick taps near control boundaries or dragging outside the interface, caused inconsistent output. Better bounds checking and input filtering could mitigate these.

Despite these limitations, the system fulfills its intended role: to demonstrate a conceptual shift from mechanical to digital control in vehicles, and to act as a platform for further experimentation and feedback.

User Testing

The user testing phase aims to evaluate the functionality, usability, and user acceptance of the custom touchscreen-based vehicle control interface. This phase is essential in determining how intuitive and effective the system is under simulated driving conditions and will help identify any shortcomings in design or control fidelity.

Participants will engage in a controlled simulation session lasting approximately 10–15 minutes, during which they will interact with the touchscreen interface developed for the project. Feedback will be collected through pre- and post-test surveys (administered via Qualtrics) and short semi-structured interviews.

Participant Grouping

Participants were selected based on driving experience and categorised into two distinct groups. Group A—Drivers: These individuals drive regularly and are familiar with traditional vehicle controls (steering wheel and pedals). This group is expected to provide insights based on real-world driving experience and highlight the contrast between physical and touchscreen interfaces. Group B – Non-Drivers / Infrequent Drivers: Participants who do not have a driver's license or do not drive regularly. Their feedback will focus more on intuitiveness and learnability without being anchored to conventional control expectations.

This division reflects the methodology used in prior human factors research, particularly the work of Large, D.R., Banks, V., Burnett, G. and Margaritis, N. (2017), where separating participants by driving experience yielded diverse and valuable insights. Similar variability is anticipated in this study, especially concerning users' trust in touchscreen systems and adaptability during critical driving tasks.

Testing Protocol

1. Pre-Test Survey

Before the simulation, participants will complete a short Qualtrics survey designed to capture:

- General attitude towards driving
- Familiarity with digital/touchscreen controls
- Initial perceptions of touchscreen steering interfaces
- Any preconceptions about system safety or usability

This data will establish a baseline for comparison with post-test feedback and help contextualise each user's experience.

2. Introduction and Familiarisation

Participants will be introduced to:

- The touchscreen interface layout (steering wheel, brake, accelerator)
- The virtual driving environment within the CARLA simulator
- The objective of each simulation phase

They will be given a brief period (1–2 minutes) to explore the controls without constraints, allowing for initial adaptation and minimising learning bias during testing.

After completing all phases, participants will complete a post-test survey in which they will:

- Rate each phase from 0–5 based on ease of control and confidence
- Reflect on the overall usability of the interface
- Comment on perceived safety, realism, and learnability
- Suggest improvements or report any points of confusion

Following the survey, a brief semi-structured interview will be conducted to capture more nuanced feedback that may not emerge from structured questions. This will also allow clarification on specific issues encountered during testing

User Testing Script

The interactive session is structured into six driving phases designed to test specific control abilities. The goal is to observe whether the user can perform key driving tasks safely and confidently using only the touchscreen interface.

Simulation Phases

Each phase focuses on a core driving skill:

- Phase 1: Accelerating to the speed limit

- Objective: Observe throttle control precision and responsiveness.
- Phase 2: Adjusting to a new speed limit while in motion
- Objective: Test the user's ability to adapt acceleration and braking under pressure.
- Phase 3: Performing an emergency stop
- Objective: Evaluate the reaction time, braking responsiveness, and control under stress.
- Phase 4: Executing a left turn
- Objective: Assess fine control of the steering wheel and lane discipline.
- Phase 5: Executing a right turn
- Objective: Mirror Phase 4, but from a different angle and timing perspective.

- Phase 6: Performing a lane change on a motorway
- Objective: Combine acceleration, steering, and timing under simulated high-speed conditions.

Results will be recorded in a structured format for each phase. A successful attempt is marked as a “pass,” while instances involving a crash, near-miss, or loss of control are noted as a “fail.” Combined with performance metrics, these binary outcomes allow for qualitative and quantitative analysis.

Performance Metrics

In addition to subjective feedback, several objective performance metrics will be recorded during the simulation to quantify user input behaviour and control quality:

Braking Speed: Measures how quickly the user comes to a stop

Turning Harshness: A note on how harsh the user turns around corners

Speed accuracy: Compares the user’s speed to the intended speed in that section

Attention level: Note on any distraction or confusion during the simulation

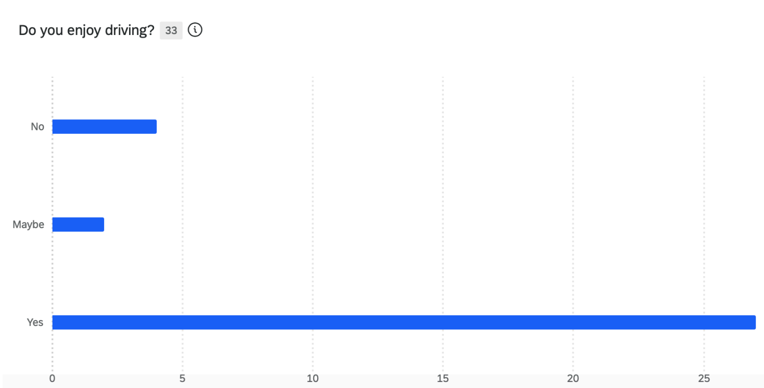
Error Inputs: Any unintentional input during the simulation

These data points will support the evaluation of the interface's functional reliability and control granularity.

User feedback collection

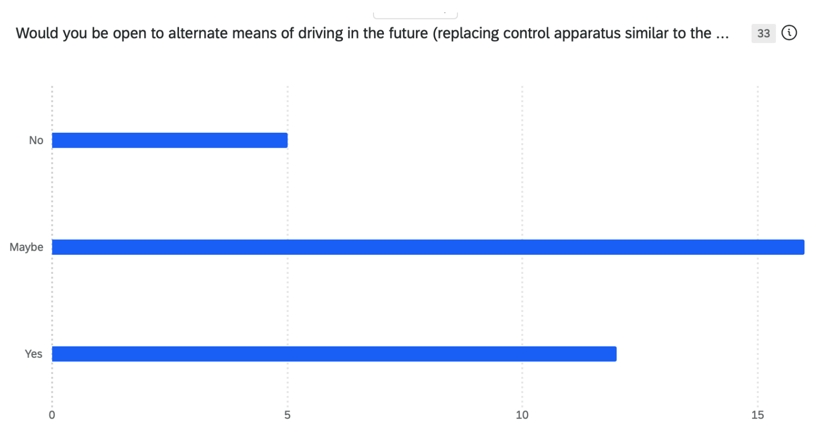
Pre-Survey Results: Analysis and Interpretation

General Attitudes Toward Driving



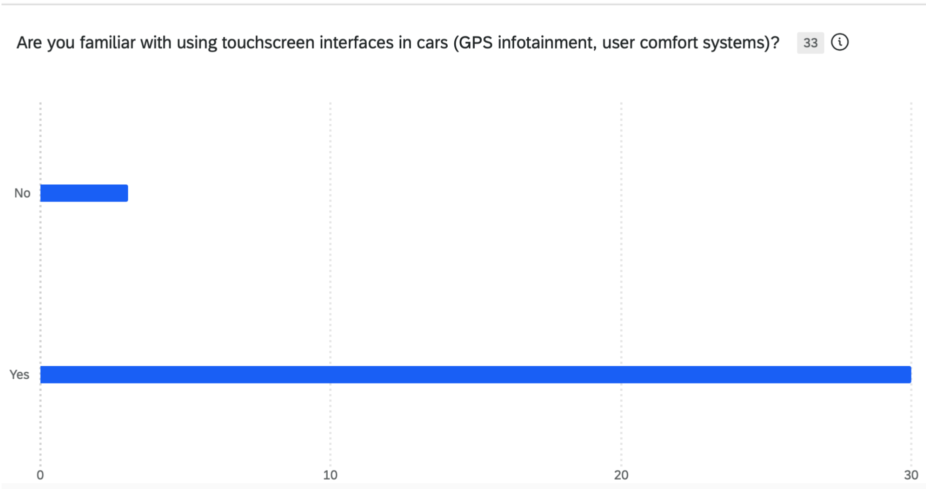
The initial survey responses indicated that most participants enjoyed the driving experience. This aligns with the assumption that driving is a practical activity and an enjoyable and engaging experience for many users. The emotional connection people have with driving is a key factor when introducing the touchscreen interface to them. Since most participants expressed positive sentiments toward driving, it highlights that any change to the core driving experience, such as the control interface, must retain or enhance this enjoyment to gain widespread acceptance.

Despite the use of traditional driving apparatus being deeply ingrained in driving culture, participants were relatively open to the idea of alternative driving interfaces. Notably, the most common response to the question about future driving controls was "maybe", suggesting a conditional openness. This indicates a willingness to explore innovation, provided it is implemented thoughtfully and with user confidence in mind.



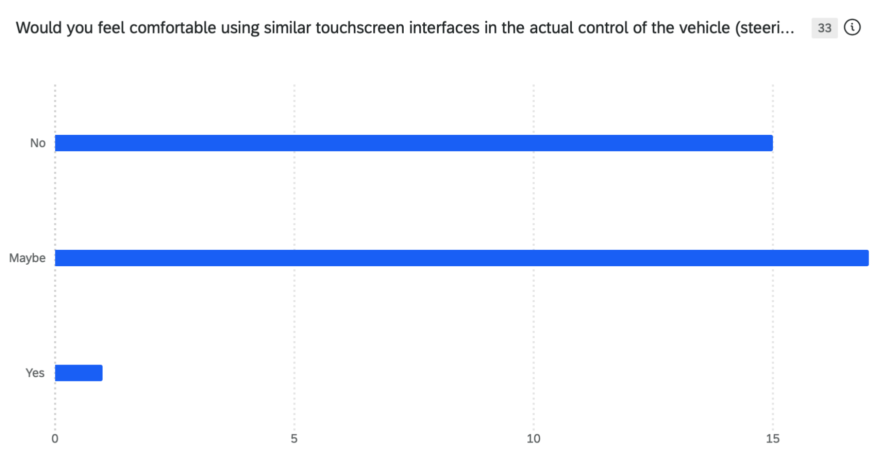
The most popular result being ‘maybe’ shows that people could be open to it if implemented correctly, however people will be unsure until it would be properly implemented and safe. Users being open to a new interface does show that if they find the one designed intuitive and easy to use they would very likely want it further implemented.

This result is significant because it shows that the use of a new driving interface isn’t inherently flawed—instead, it depends heavily on execution. If a new system (such as the proposed touchscreen interface) can be shown to be safe, reliable, and intuitive, users appear willing to transition. This reinforces the importance of usability testing and human-centered design principles in developing new vehicle control systems.



Most users indicated they are already familiar with vehicle touchscreen interfaces, such as infotainment systems and climate control. This is a promising insight, demonstrating that vehicle touch-based interactions are not entirely new to users. As such, introducing a touchscreen-based steering interface would not involve teaching an entirely new interaction model—it would be an evolution of existing habits.

This existing familiarity can act as a foundation for smoother adoption, particularly if the touchscreen interface is designed to align with users' mental models and expectations formed from current in-car systems. This was an important aspect of the interface’s design and implementation.



Despite their familiarity with touchscreens, many participants expressed concerns about using such interfaces for vehicle control, especially for critical operations such as steering. The main concern was safety. Users expressed anxiety over touchscreens' reliability, responsiveness, and potential for failure during operation. The following user responses illustrate these concerns clearly:

- "I would feel worried that the technology would go wrong and fail, causing an accident."
- "I would drive this, but I would need to see it in action & be confident in its safety first. It's just because it's currently the unknown…"
- "I would be nervous initially as such a different experience and touchscreen is not always quick or reliable."

These comments show that people consistently worry about their trust in technology, and it must be earned, particularly in high-risk applications like vehicle control. Users are not necessarily against innovation, but must be assured of the technology's reliability through demonstrations, testing, and safety validation.

The pre-survey results provide a valuable baseline for understanding users' initial thoughts on the interface. While resistance to change exists, it is not absolute. Users are more hesitant than opposed, indicating a real opportunity to shift perceptions if the system is designed and introduced with care, transparency, and a focus on safety.

The prototype used for the simulation has considered all these worries, and it has been especially designed to ensure ease of control and simplicity.

Simulation test

I invited users to the simulation test, linked to the computer running Carla was a touchscreen laptop running the python script connected to the Carla server. They were told to familiarise themselves with the simulator and were asked their thoughts about it soon afterwards. Some of the responses included:

"It works well, I do feel like I can control the car safely and even though it took a bit of getting used to I'm comfortable with it now."

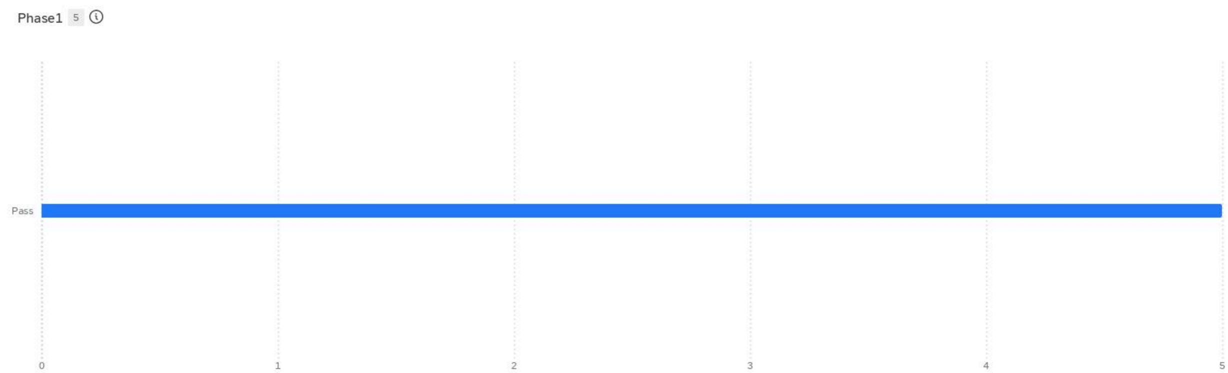
"I like that its all very simplistic, I feel like theres enough information to what I need to but not an overload"

Overall the users seemed to enjoy the simulation at first, backed up by data in the questionnaire in a later section.

Phase 1: Accelerating to the speed limit

This phase was shown to prove the feasibility of the acceleration and the fine control needed to reach an appropriate speed. It is also a key feature in daily driving where you are constantly starting from rest and reaching the speed limit. A pass in this phase is defined by the criteria of

“Can accelerate to the limit shwn in a smooth way, not exceeding the limit by more than 15%”. This is a realistic depiction of accelerating to the limit as sometimes a user will overaccelarate but slow down again to reach the limit.

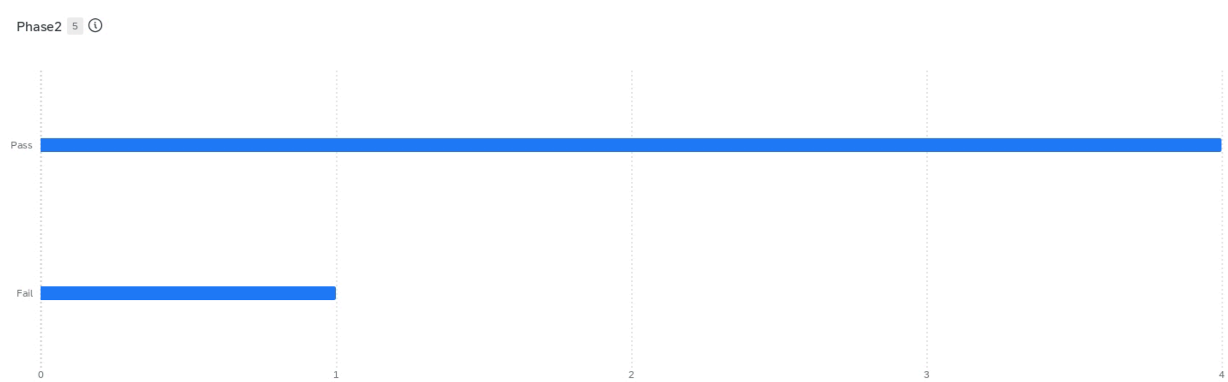


Of the 5 drivers, all of them passed this. There was no major note taken in their acceleration.

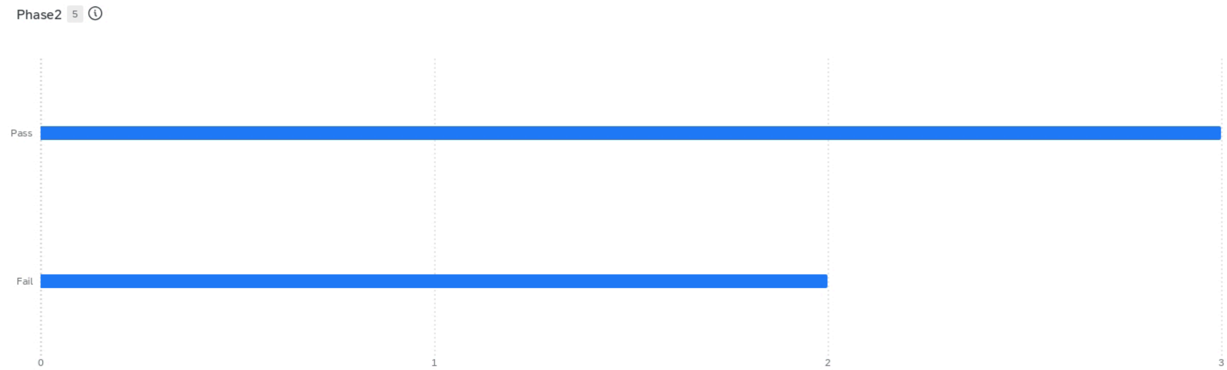
The 5 non-drivers also passed this, with identical success.

Phase 2: Changing speed limit

In daily driving a user will sometimes accelerate from one speed limit to another when changing zones or areas. This tests similar control of the vehicle as phase 1 and affirms that the user can convincingly accelerate the vehicle. A pass in this phase is defined as “The user can accelerate from one speed limit to another within 10 seconds not exceeding the limit by more than 15% in either part of the road”.



The 5 drivers had a majority pass rate, however one of the drivers overaccelarated from 30mph, to 48mph instead of 40. This indicates that the driver had some trouble getting fine control of their speed in the simulation.



The 5 non drivers similarly did pass on majority, however, there were 2 drivers who did not pass. One non-driver made the same error as the driver in the previous point, overaccelarating by 40%, showing much less speed control and reaching 56mph. However, another non-driver was more hesitant and didn't reach even 35mph within 10 seconds, showing a lack of confidence with the touch screen control.

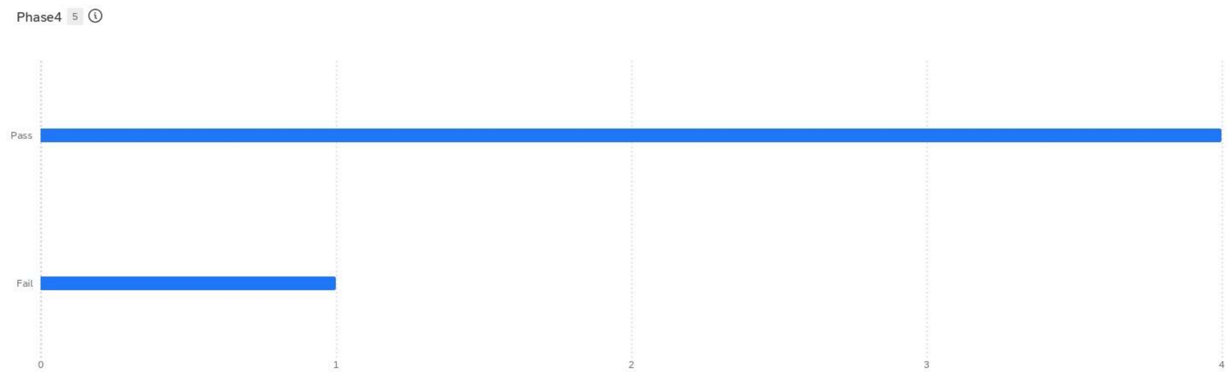
Phase 3: Performing an emergency stop

This manouvere is assessed in the UK driving exam, administrated by the DVLA. It is a key skill to be able to stop the car as quickly as possible in an emergency. An emergency stop will pass if "the user can bring the car to a stop as quickly as possible as soon as they hear the stop command, they must be using more than 80% of the car's braking potential, and not leave their lane, causing an accident". The user was not made aware of the success criteria.

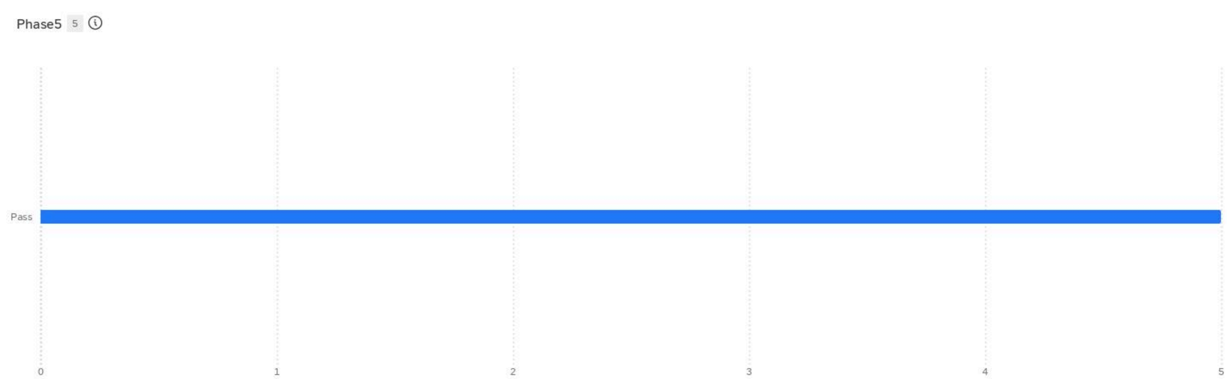
Both the drivers and non-drivers had identical results in this scenario. 2 of each failed the manoeuvre. There was one scenario that the user failed on, which was that they didn't hit the brakes in time. There was a small amount of hesitation in the user before they hit the brakes, meaning they did not meet the success criteria for phase 3. No users crashed or lost control of the vehicle.

Phase 4 and Phase 5: Executing a left turn and a right turn

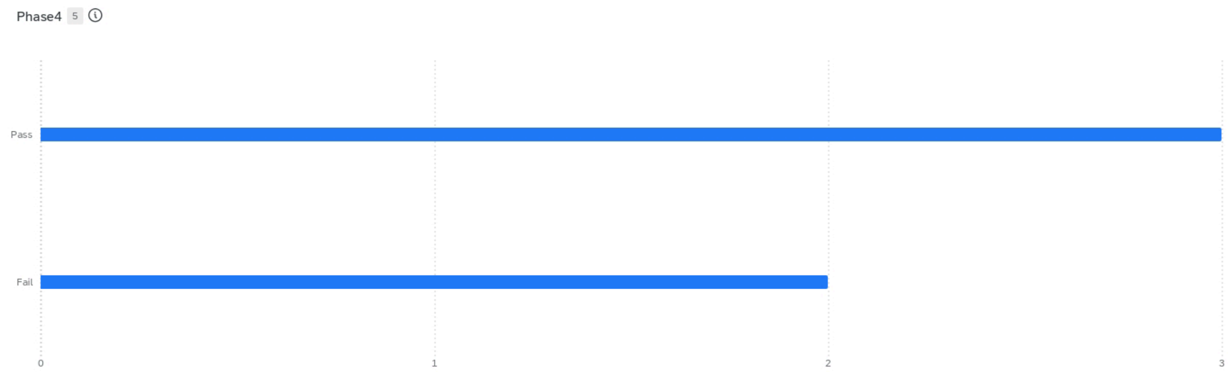
This is a key skill in driving; executing a turn is needed in order to be able to manoeuvre any road effectively. They will pass these phases if they meet the following criteria: “User will be able to turn onto the road on either left or right side without veering into another vehicle’s lane at an appropriate speed and straightening up after the turn has been made”.



The drivers in phase 4 were overall able to turn left, however one driver mistimed the vehicle turning and veered onto the pavement, suggesting less control in the steering than typical vehicles.



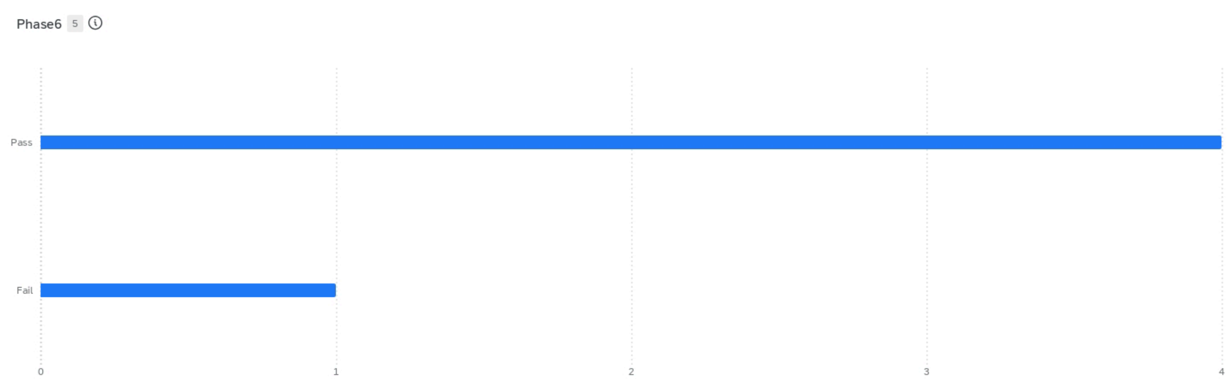
The drivers in phase 5 all turned right without fail. This was because they had more practice turning after phase 4, resulting in a greater success rate.



Non-Drivers in both phases 4 and 5 had similar good performance on the turn; howeve, they were less used to turning the steering system, and often missed the fine movements in the steering application. This resulted in only 3 of the 5 non-drivers passing these phases.

Phase 6: Performing a lane change on the motorway

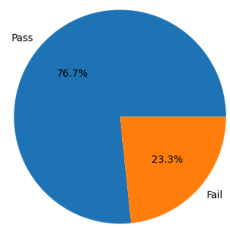
The final phase is a key skill in driving, and a user can not be deemed safe if they are unable to change lanes. Success criteria for this phase is as follows: “A user will succeed if they can change from one lane to another, within 10 seconds, maintaining speed and positioning in the middle of the lane”



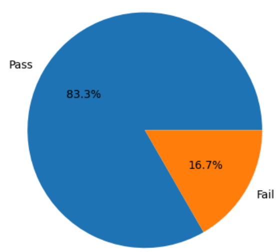
Phase 6 was overall a positive phase for the drivers; four out of five users were able to change lanes, matching the success criteria successfully. One user overshot the steering and ended up in an extra lane over, resulting in them failing this phase.

The results for the non-drivers in phase 6 were identical; however, the failure from the non-driver in phase six was due to being too hesitant and not changing lanes within the given time, and riding between the lanes for too long.

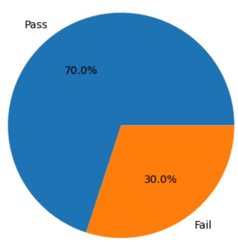
Overall results:



Overall, between both drivers and non-drivers, there was a total of a 76.7% pass rate for the phases. This suggests that overall, the prototype is safe 76.7% of the time. 76.7% is an extremely good metric for safety for an early prototype of the touchscreen interface.



This figure shows the success rate for the drivers, which is even higher than the overall success rate. This suggests that drivers who are more aware of their skills and are able to use regular steering and driving apparatus will perform better than non-drivers. This could also suggest that the success rate could reach even higher if people practiced with the touchscreen interface more.



Even though they have very limited previous driving experience, the non-drivers were passing the phases 70% of the time, which suggests that the interface is intuitive enough that you can pass these safety exercises at a high success rate with minimal knowledge of driving and controlling a vehicle. Once again with more practice and familiarity, it is entirely possible that this success rate could climb even higher.

Performance Metrics:

Critical Evalutation

Success:

There is a lot that went well in this project. The implementation wasn't too complex and allowed for quick development time meaning plenty of UI features could be implemented, such as the gradient on the pedals. The UI itself is also very sleek and well built, making it simplistic and intuitive. The implementation with Carla was also very seamless, it translated well taking very simple metrics and transforming them into controls, for example the angle of the steering wheel mapping from -1 to 1 very easily, or the throttle mapping from 0-1 very easily.

The user testing was also a resounding success, the users were able to easily use the prototype on the touchscreen laptop and most of the phases were passed. The driving on the simulator was very fun and it became quite interesting to see how the different users would use the environment during the time they were getting used to it.

What didn't work well:

The interface does miss out some functionality, such as gear controls even in automatics and other metrics, however as this was a bare bones proof of concept prototype it is fine that there is some missing functionality.

User testing also tells a different story. While in concept this is a fine test, there a lot of aspects that the simulator won't be able to simulate as it is only on a screen. Users in the pre survey brought up: "You need feedback from the vehicle, driving is a tactile experience". This is a valid point that I was not able to simulate in the user testing simulation.

What was surprising:

The integration with Carla was extremely simple, meaning an expansive code base wasn't needed. I expected Carla to have a very complex set of controls that would need a lot of functions and interactions, however it was very easy to map my interface directly and send those messages to the Carla server.

The high rate of success was also very surprising. Every single user passed more than half of the phases. As the interface was new to all people I expected there to be more problems with control, especially as it wasn't fine tuned and was a very early prototype.

What should be changed:

For any future implementations, pygame running on a separate device will not be adequate. The interface will require a system built for more real time application. If it were to be applied to real life vehicles, it is likely a specialised touchscreen with embedded software would be the best way to achieve the touchscreen interface, allowing for more forms of feedback such as haptic control as discussed before, but also speedy processing in the embedded software.

Other things would need to be considered too, such as error mitigation. This was largely skipped over in the prototype for convenience however more software checks would need to be carried out on inputs to ensure that they are intentional. Things that come to mind are a maximum rate of jerk (the change in acceleration over time), or maximum rate for turning the steering wheel. These features would be hard to implement and fine tune however as there may be times in emergency where a user will want to make very quick movements, and these need to be considered.

Ethical Considerations

Future Work and Applications

Conclusion

References

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Many references made to Human-Computer Interaction Dmitrijs Dmintrenko, 2024 University of Sussex

Carla driving simulator - carla.org

Sentdex created a video series on self-driving cars in Carla in 2019, this video helped significantly with the setup of the API on my device

The prototype uses designs for the steering wheel and pedals that were initially designed by user adamk19 on reddit, this user posted them on the site as potential game assets and stated they were free to use

Appendix