Slideo: Slidable Bicycle Handle for AV Interaction

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This report introduces a new design concept to be used by cyclists interact with automated vehicles (AVs). The majority of existing literature focuses mainly on external human machine interfaces (eHMIs) positioned on AVs to tell cyclists and pedestrians what to do. The goal of this project was to allow cyclists to share their intentions with AVs. This project assumes that all AVs will communicate within a network to make the traffic flow as efficiently as possible, by planning their routes and speeds in such a way that will minimize the amount of times they have to slow down or stand still. This project proposes to allow cyclists to be a part of this network too, by using slidable handles to communicate their intention to turn. If AVs are aware that a cyclist is planning to make a turn, they can slow down to give this cyclist enough space to turn, ideally without having to come to a full stop. This can make cycling more enjoyable, comfortable and accessible.

This report describes a design sprint which originally introduced the idea, a questionnaire to compare multiple potential design concepts, the process of creating the final prototype and a user test to validate the haptic feedback using vibration motors. The results show that a design concept like is has enough potential to develop further.

1 INTRODUCTION

Cyclists have proven to be a challenge for Automated Vehicles (AVs). Of all the common types of road users, they are the most difficult to detect, due to their relatively small size, variation in appearance, and unpredictability [9]. This is a problem, because cyclists are a type of Vulnerable Road User (VRU), which is evident by the fact that more than 36% of traffic fatalities and 68% of severe injuries in the Netherlands are cyclists [23]. A solution proposed by Ford, Tome Software and Trek Bicycle together in 2017 is the use of bicycle-to-vehicle communications in the form of a device that any cyclist can attach to themselves or their bicycle [5]. In this way, the AVs around the cyclist would be wirelessly notified of cyclists nearby, allowing them to prevent collisions. This is not a proper solution, as VRUs should never be responsible for their detection in traffic; AVs should always be able to do this on their own [4]. However, there is an opportunity for bicycle-positioned technology to minimise the unpredictability of bicycles by communicating cyclists' intentions to the AVs around them. Not as a necessary means to offer safety, but instead to increase efficiency and comfort.

This type of communication would fit the vision of roadside vehicles and infrastructure nodes communicating with each other within a network based on vehicle-to-everything (V2X) communication [1, 6]. In addition to the AVs participating in such networks, humans should be able to participate in these networks as well, especially if cities are becoming more human-centred and promoting alternative travel methods to decrease the use of cars.

In a future where most vehicles are automated, creating a network of cooperative / communicative vehicles will be a great opportunity with many important advantages [1, 13, 24, 26]. The most important advantage of connected and automated vehicles (CAVs) operating in a network is the improvement of traffic safety, as connectivity allows for effective prevention of collisions and smoother driving [13, 26]. An additional advantage of CAV technology is its potential to deliver large environmental benefits, by planning more efficient routes for less stop-and-go driving, performing platooning for less aerodynamic drag, and making shared mobility and seamless integration with public transit real possibilities [24]. Some other potential benefits are a decrease in travel time and commuting becoming easier. Humans not having to perform the driving task can produce a reduction in stress and increased relaxation, resulting in an improved travel experience for

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passengers of AVs [7]. In summary, the literature agrees that a network of CAVs can have major advantages and is likely to become a reality in the future.

Existing research about the interaction between AVs and VRUs using an external human-machine interface (eHMI) focusses on the AV showing its intent to the VRU, or telling the VRU directly what to do [12, 15, 22, 25]. The topic of VRUs communicating their intent to AVs, like in Epke's [2019] research about pedestrians using hand gestures to communicate crossing intent, seems to be underexplored, especially when it comes to cyclists. This point is also made by Berge et al. [2022], who found that on-bike HMIs could be beneficial to improve the predictability and safety of cyclists, although the primary responsibility of safety should always lie with the AV.

1.1 Aim of this Project

A goal of this project is to take a different approach from the majority of the existing literature, taking the V2X communication for granted and trying to involve cyclists in this communication. The aim of this project is to design an interactive way for cyclists to communicate their intention to turn to the network of AVs around them, using the already existing network used by AVs to communicate with each other. The angle of approach will be that bicycle-to-vehicle communications should not become obligated to guarantee the safety for the VRU, but instead to make the cycling experience more comfortable and prioritise it over motorised traffic in an efficient way.

The chosen setting for the project is as follows: A cyclist commuting from point A to B in an area where they are familiar. They don't need navigation and prefer to reach the destination as quick as possible. Their reasons for choosing a bicycle over a car include being more sustainable, healthier, and faster and easier to park. They do not like having to stop and wait in traffic.

2 DESIGN PROCESS

2.1 Iteration 1: Design Sprint

To efficiently arrive at an innovative first iteration of the design, part of a Design Sprint was performed [10]. The methods performed were, in chronological order:

(1) "How Might We?" method
(2) Affinity mapping / clustering
(3) Importance - Difficulty matrix
(4) User mapping & Picking a target
(5) Defining design principles
(6) Boot-up note taking
(7) Crazy 8's
(8) Solution sketch

In order to quickly come up with potentially interesting ideas, the "How Might We" questions were rapidly formulated and written down on digital post-its, after which these could be sorted by similarity, resulting in the following categories of interest: Interaction, Traffic awareness, Manual vehicles, Network, Trust and safety, and Functionality. This can be seen in Figure 1. After plotting these categories on a (perceived) importance-difficulty matrix [16], it can be said that all categories except *Functionality* are relatively difficult to achieve, with *Trust and safety* and *Interaction* being strategically the most valuable ones.

User mapping was performed to identify the main target for the design sprint within the user flow, as shown in Figure 2. Here, the device to be designed is used to communicate the user's intention to turn. It can be divided into four phases: *travelling on a bicycle*, *using the device* when approaching a turn, *deciding whether to turn or wait* based on the device's feedback and their own

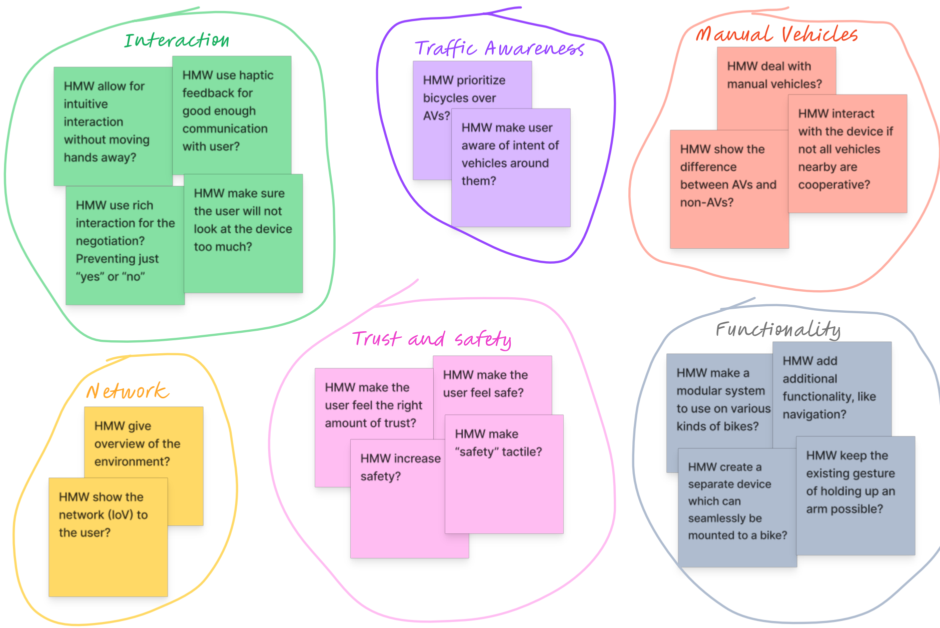


Fig. 1. "How Might We?" affinity clusters

monitoring of their surroundings, and finally *continuing their travel*. As shown in Figure 2, the steps within the decision phase of the user flow were identified to be the main target of the design sprint.

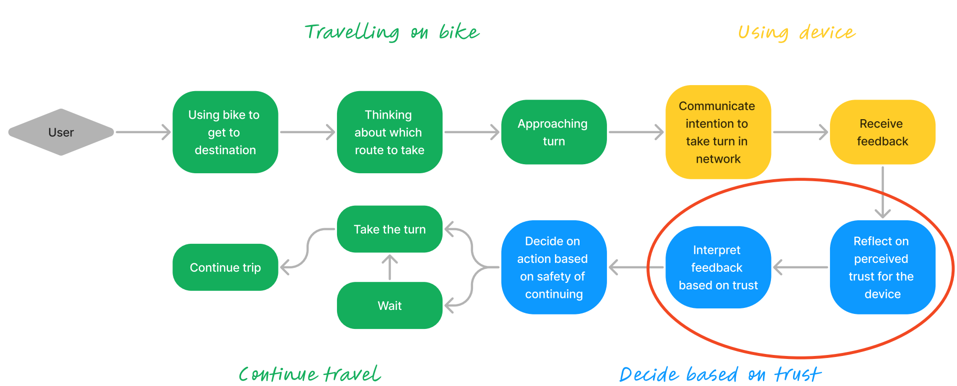


Fig. 2. User mapping and picking a target

In the final phase of the design sprint, a *Crazy 8's* method was performed to quickly sketch a variety of ideas based on the previous steps in the design sprint. As a final step, one of these ideas was chosen to create a more detailed solution sketch, which is shown in Figure 3. The proposed solution resulting from the design sprint is a smart handlebar with handles which can slide sideways. When sliding a handle, sensors in the handlebar register this, after which integrated communication technology will be used to wirelessly communicate this intent to AVs around the cyclist. Based on the communication with the network, the user will receive haptic feedback about when they can turn safely. Additionally, it can be communicated to other road users visually, for example, by activating a set of blinkers.

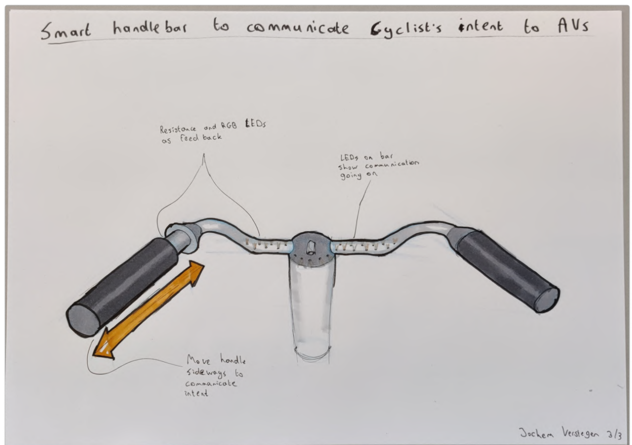


Fig. 3. Solution sketch showing slidable handles to communicate upcoming turn

2.2 Iteration 2: Questionnaire

An important factor in the first iteration is the rich and embodied interaction, where the interaction itself is explanatory of its meaning. In the design sprint, only one location for the interaction was really considered: The handlebar. While the hands are the most sensible body part to use in a design to indicate direction, as they are already used to do this, that does not mean other body parts should not be considered. Therefore, three additional concepts were compared to each other by means of an online questionnaire. Respondents were both asked to rate certain aspects of each concept individually, as well as to compare all four concepts to each other directly. The four concepts were to use the hands, feet, hips and knees to indicate direction, they were introduced by showing a sketch and explained with written text. The questionnaire and its results are explained in detail in Section 3.1.

Based on the results of the questionnaire, the hands are the preferred location for an interaction to indicate direction and were therefore considered in the next steps of this project.

2.3 Selecting Features

2.3.1 Commuting by Bicycle. The main desired features of the design can be based on the aim of this project as described in Section 1.1. The main target user is someone commuting from point A to B by bicycle, in an area where they are familiar. They do not need any navigation to get to their destination, because they are perfectly aware of which route they wish to take. To them, it matters most how quick and comfortably they can reach their destination. Therefore, they should not be forced to enter their destination before leaving, flexibility to just get on the bike and leave is important. In order to better understand this target user, a persona was made, which can be seen in Figure 4. Additionally, a value proposition canvas (VPC) is a useful tool to determine what the user cares about and how this design should offer value to them. The VPC for this persona is shown in Figure 5.

Fig. 4. Persona of a user who commutes by bicycle [2] (Image by Victoria Heath [2018])

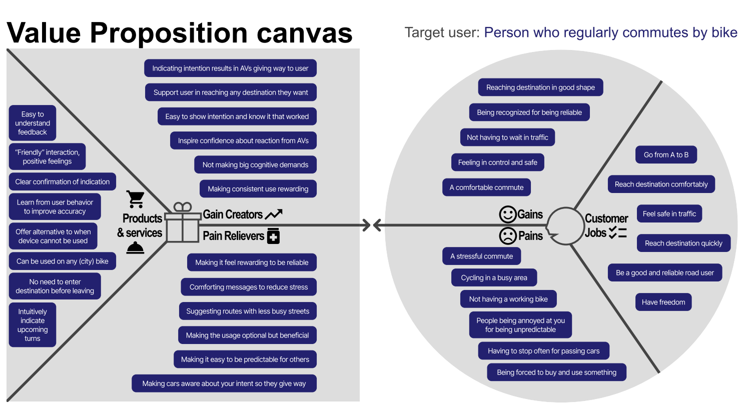


Fig. 5. Value Proposition Canvas for user segment commuting by bicycle

2.3.2 *Cycling for Leisure.* A second target user, but also a very relevant one, who matches the capabilities of a device with rich interaction and intuitive feedback, is someone cycling for leisure. They usually do not cycle from point A to B. They also don't always cycle somewhere familiar to them, it could also be on vacation or just some roads they don't usually visit. Also, they may want to follow some pre-made route they prepared before leaving, so for this target user, intuitive navigation capabilities would be a valuable addition. Note that one person can be part of multiple target groups, depending on their current actions. The persona and value proposition canvas for this second target user are shown in Figures 6 and 7 respectively.

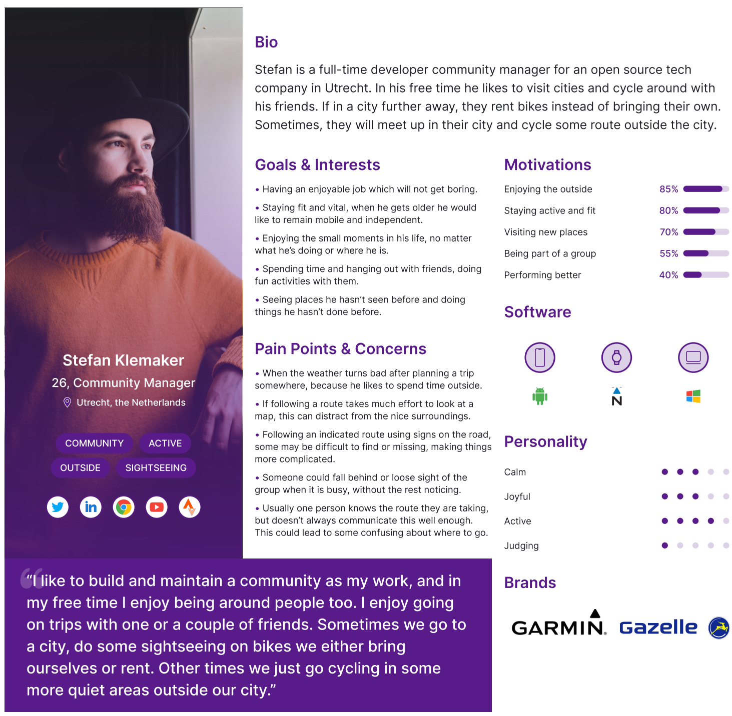


Fig. 6. Persona of a user who cycles as a form of leisure [2]

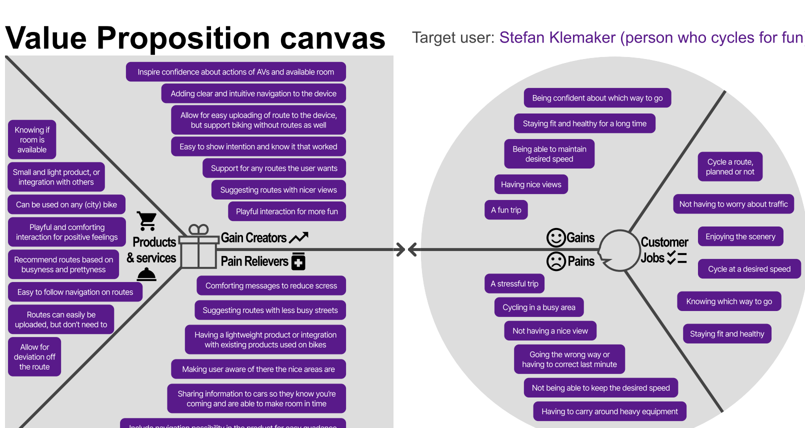


Fig. 7. Value Proposition Canvas for user segment cycling for leisure

2.3.3 Product Features. Based on these two target users and their respective value proposition canvases, it is possible to fill out a Business Model Canvas. This tool in Figure 8 can be helpful to determine which features the product needs to meet customer demands, as well as to discuss its feasibility from an entrepreneurial perspective.

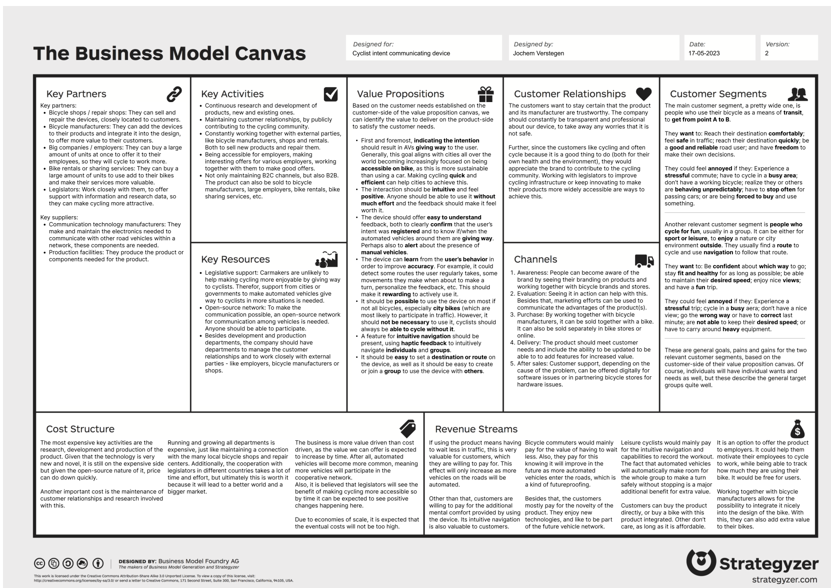


Fig. 8. Business Model Canvas

Based on the value proposition canvases and business model canvas, we can determine what kind of features are needed. Something both personas care about, is the capability to communicate their upcoming turns to traffic around them, so they will (often) receive room to take the turn safely without having to come to a full stop and wait. Emily mostly cares about this because it saves her time, while Stefan values this because it makes his cycling experience more enjoyable. Another valuable feature for both personas is the intuitive interaction with the device, not requiring any visual attention. This means they can keep their eyes on the road, contributing to their feeling of safety. For Stefan, this also means he gets to see and enjoy his surroundings more. The haptic feedback to let the users know an upcoming turn is registered and update them on their upcoming situation (whether nearby AVs will make room or if they still need to watch out for manual vehicles) is also useful for both, although they should always monitor their environments no matter what.

For commuting, Emily needs the device to be quick in use. She does not want to have to perform steps like turning it on, adding her destination, calibrating, etc. She just wants to get on her bicycle and go. Therefore, the device should work without the need for the user to perform any steps before leaving. It should support any kind of route the user wishes to take, without needing to know this route beforehand. Furthermore, ideally it should use power from the bike's battery if it is an e-bike, otherwise use power generated by a dynamo to run. Ideally, it will never have to be charged separately to the bike. Especially if not used on an e-bike, the power consumption needs to be low.

For leisure activities, Stefan can use some extra additional features from the device, which can be achieved using the same hardware already needed to achieve the basic functionality. The main feature being navigation capabilities, using the haptic feedback (vibrations) in the handles to indicate upcoming turns. Furthermore, it should be easy to add a route to the device for it to follow, as well as it should take little to no effort to connect multiple devices to one group, to allow for riding with a group of people where every participant can follow the navigation. This should prevent any confusion and last-minute turns, increasing confidence and comfort during the ride.

Based on these desired features, a list of hardware requirements can be made:

- Interactive sensing circuit (button/slider/etc)
- Vibration motor in each handle
- Communication technology to create groups and participate in network[1]
- GPS[1]
- Connectivity technology for operation with smartphone (adding routes/making groups/etc)[1]
- Mountable on existing handlebar OR complete handlebar with integrated technology
- *Optional: LEDs or simple display for additional information*

2.4 Iteration 2.5: Exploratory Prototype

Based on the questionnaire results, it was decided to keep focusing on using the hands to interact with the device. To determine what kind of interactive sensing circuit as described above to use, an exploratory prototype was made. In this prototype, three different interactions were made: The sliding handle, a lever for the fingers and a simple button for the thumb. These are highlighted in Figure 9.

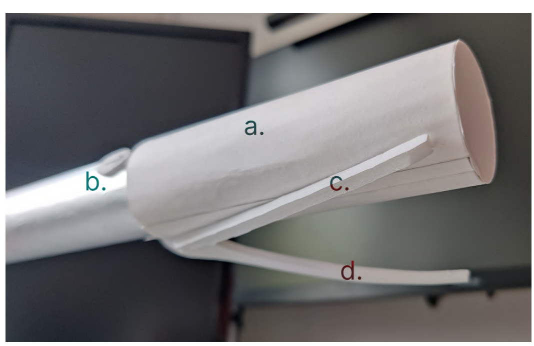


Fig. 9. Exploratory prototype to try out sliding the handle (a); a thumb button (b); and a lever to push with the fingers (c). A break handle (d) was also added to mimic the different ways one can hold the handle.

After handing the prototype to a few people to compare the different interactions, the lever for the fingers could be quickly eliminated. People have different sizes of hands and the fingers usually rest on the break handle, especially when approaching a turn. This leaves the sliding and button. Of these two, at first the button was preferred. This is likely because buttons are a common way to interact with digital systems and therefore easy to understand. People are familiar to them and generally, it is best to design familiar interfaces [19]. However, after talking about how there can be multiple buttons on a bike, for all kinds of systems (like switching gears, controlling an e-bike, etc), it could be argued that in a future scenario, it might be desirable to find an alternative for a button. Preferably an alternative which does not depend on any specific fingers, as all could be doing something different depending on the handlebar layout of the bike. Therefore, it was decided

[1]Would be in final product, not in prototype.

to continue with the sliding handle, although it should take less force than in this prototype, which was too firm.

2.5 Iteration 3: Final Prototype

To make a final prototype with a proper sliding function, it was decided to use 3D printing technology. The advantage of this is that it becomes possible to create two identical units with a mechanism which allows for sliding a certain distance and fit the default handlebar diameter (22.2mm) [20]. Furthermore, it is a modern prototyping technology worth exploring.

2.5.1 CAD Model. To start, a 3D computer aided design (CAD) model was created in SolidWorks, making sure everything has the right dimensions. The model consists of an inner and outer layer, which can slide over each other for 1 cm, while making sure it cannot be rotated or moved in any other way. Furthermore, enough room was cut out of the the inner layer to fit a coin-style DC vibration motor, while also leaving room to route the wires out of the handle. Additionally, there is room for a sensing circuit in the prototype to detect when the handle is slided out and rubber bands or some other spring system to move it back. All these features are visible in Figure 10.

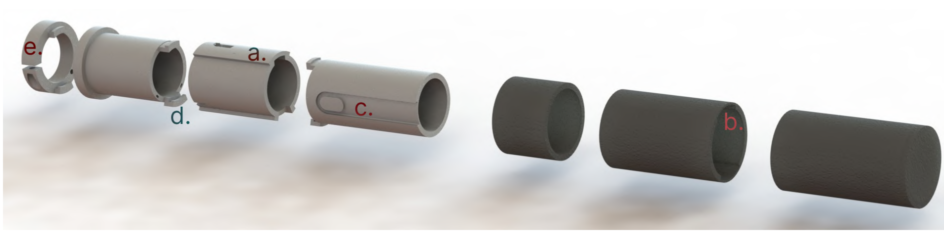


Fig. 10. Exploded view of 3D CAD model to be 3D printed. It consists of an inner and outer layer which can slide over each other. It features: (a) room for a coin-style DC vibration motor and its wires; (b) guide lips to prevent rotation; (c) room and hooks for a rubber band; (d) hooks for easy assembly without glue; and (e) a clamp with screw hole for mounting it to the handlebar (adapted from a CAD model by Johnson [2018]).

The 3D models are available in the public GitHub repository: https://github.com/JochemV01/Slideo

2.5.2 3D Print. Each part made in the CAD model shown in Figure 10 was printed twice, because there are two handles. In total, 14 parts were printed and needed to be assembled next. However, 3D printers print additional support material in order to be able to make any overhanging protrusions or cutouts. These support structures needed to be removed first, in order to make the printed parts fit each other, which is shown in Figure 11. Some surfaces were also filed down, to minimize the amount of friction during the sliding motion. The inner layer will be held together with the hooks ('d' in Figure 10), which should work properly when sliding the handle on a handlebar. The pieces of the outer layer will be held together using duct tape, which will also help keeping the inner layer in one piece.

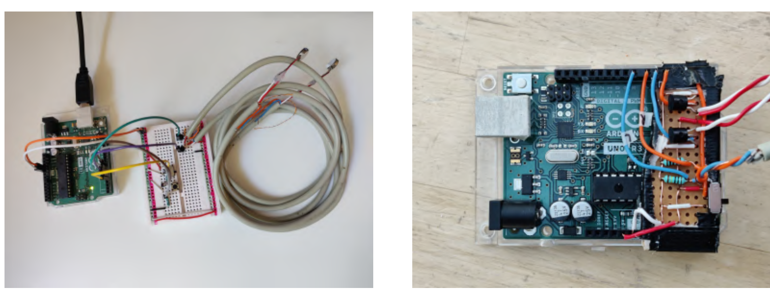
While originally it was planned to have room for a sensing circuit and rubber bands in the 3D print, due to the small sizes and relative inaccuracy of 3D printing, these plans were not possible. This means that the haptic feedback from the vibration motors needs to be triggered from an external button, and the handles will not move back automatically in this prototype.

2.5.3 Electronics. For the electronics, an input and output are needed. For the input, two buttons are used, one for either side. The output a DC vibration motor in each handle. An Arduino Uno Rev3 is used to program the vibration patterns, read the button states and drive the motors. In order to be able to read the button states reliably, two resistors are used to pull the relevant pins down to

(a) Removing support structures (b) Support structures removed (c) Handles mostly assembled

Fig. 11. The support structures need to be removed from the 3D printed parts.

ground by default, so they will only read `HIGH` when the button is pushed. Since the Arduino pins cannot output enough current for a vibration motor, they will be powered from the 5V pin instead, which can output more current. One transistor for each motor is then used to turn the motor on or off, and to control their speed by changing the voltage using PWM [21].



(a) Test setup of electronics (b) Final soldered setup of electronics

Fig. 12. The electronics of the prototype, with external button and vibration motors.

The Arduino code was kept organized by writing functions to control the DC vibration motor, these can be called in the main loop together with parameters for the direction, strength (between 0 and 100%) and duration of the vibration. One function written is for a single vibration of a certain duration, while another function results in a gradual increase or decrease in vibration power over the duration (e.g. going from 90% to 30% in 300 milliseconds). These two functions together can be used to program a large variety of different vibration patterns in a quick and easy manner.

This project was presented at Demoday, an event organized by the faculty of Industrial Design at Eindhoven University of Technology where all students can present their project to the public. For this day, the code was written to allow visitors to experience the haptic feedback at the stand. Since it already had to be activated using an external button, it could also be activated during the pitch to explain the vibration patterns to anyone interested. Additionally, a separate mode to showcase the navigation capabilities of the prototype was programmed, and can be activated using a physical switch on the microcontroller (visible in the bottom right of Figure 12b).

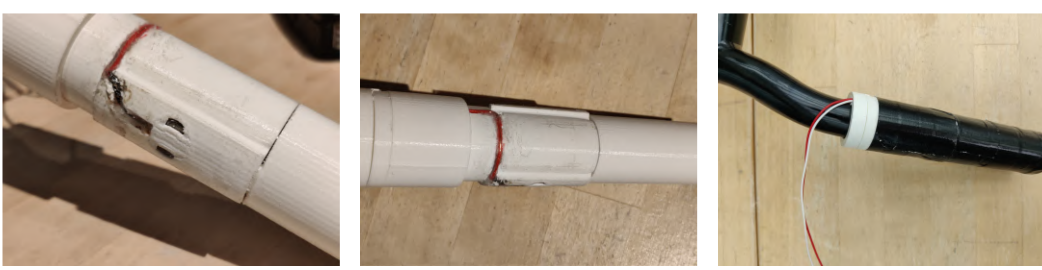
All code is available in the public GitHub repository, accessible via this link: https://github.com/JochemV01/Slideo

2.5.4 Assembly. After carefully removing any excess from the 3D printed parts they can be assembled relatively easily. As shown in Figure 13, the smallest outer ring must be placed on the inner part before assembling the inner part and sliding it onto the handlebar. After this, the other two outer parts can be slid in place, and held together using duct tape. Now, the outer layer as a whole can be moved sideways for one centimeter.

(a) Inner layer assembled (b) Two pieces of outer layer (c) Handle fully assembled

Fig. 13. The assembling process of the handle. The smallest outer piece can be put on its inner piece before assembling the inner part and sliding it onto the handlebar.

In the inner layer of the 3D print, there is a cutout for a coin-style DC vibration motor and the needed wires for it. With enough force, the motor can be pushed into this cutout from the inside. The wires can be routed through some channels and come out of the handle towards the middle of the handlebar. This is shown in Figure 14.



(a) Vibration motor inside handle (b) Wires routed through handle (c) Wires coming out of handle

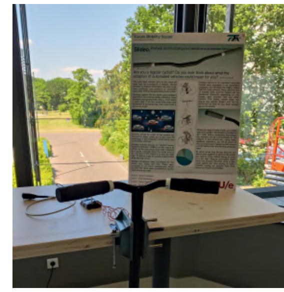
Fig. 14. The DC vibration motor is positioned inside the inner layer of the handle. Its wires can be routed out through their designated channels.

Since there were some issues with vibration motors either breaking down or their wires detaching, the actual vibration motors used are taped to the outside of the handles instead. First they are wrapped with a couple layers of black duct tape, afterwards with a layer of black nylon tape to create a neat and finished look and feel. For the demonstration (Figure 15), the handles are mounted to a handlebar of a children scooter, which is clamped to a table. Besides the prototype, there was a video playing and a poster to explain the concept.

2.5.5 Cycling Trial. Of course, bike handles are not meant to be used while standing still. Therefore, it is important to validate how they work while cycling. Therefore, the handles were placed on a bicycle while cycling around calm streets. Feedback during the Demoday already indicated that the handles might be too easy to slide out, which was also the first main finding of the trial. The handles could often be slid out unintentionally due to quick acceleration or bumps in the road. By

(a) A video was played on a laptop to explain the project

(b) The full stand with prototypes, poster and video



(c) The experienceable prototype was clamped to the table

Fig. 15. The stand for Demoday at which this project was presented for visitors.

(a) The handles on a bike

(b) At first, they were too smooth

(c) Tape increased the resistance

Fig. 16. During the trial, the force it takes to slide the handle was tweaked by adding some tape to the inside.

sticking a little piece of tape on the inside of the handle as shown in Figure 16c, the handle took more force to pull out, minimizing the times when they were slided out unintentionally quite well.

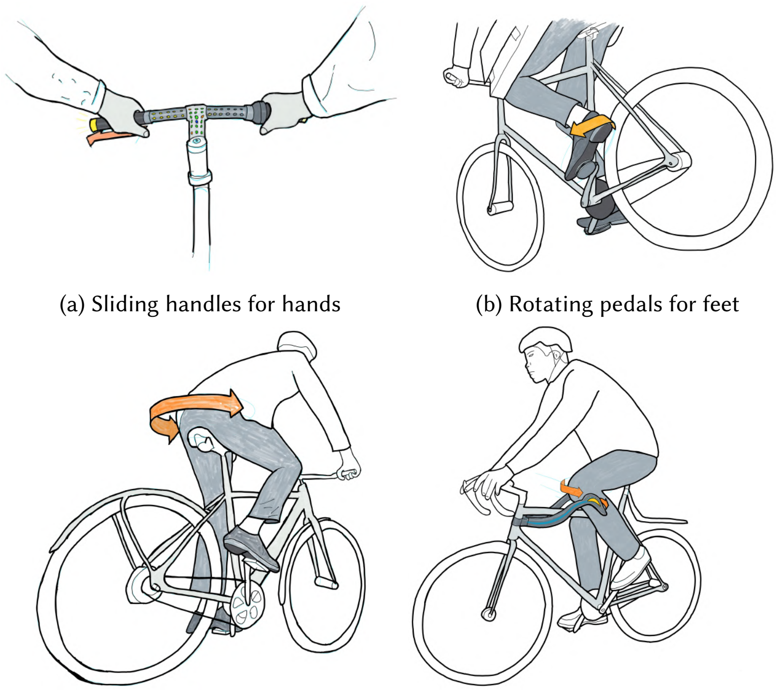
Another finding during the trial was that, in accordance with previous assumptions, the sideways sliding motion did not interfere with the steering motion. Steering did not cause a handle to be slided out, and sliding a handle did not make the bicycle start turning. This is not because of any corrections done with the other hand, it was perfectly possible to cycle with one hand while sliding the handle or making a turn.

3 USER INVOLVEMENT

Users were involved in multiple steps of the design process, this section will go over how they were involved and the results from the user involvement. Users were involved through an online questionnaire and a user test, both described in this section.

3.1 Online Questionnaire

To gain a better understanding about the kind of interactions users would be comfortable with, certain interactive concepts were developed and compared to each other by means of an online



(a) Sliding handles for hands

(b) Rotating pedals for feet

(c) Twisting seat for hips

(d) Knee rods for knees / legs

Fig. 17. The four design concepts compared in the questionnaire

questionnaire. Besides the slidable handles, sketches were made for three additional concepts, all using a different body part. The four different concepts can be seen in Figure 17 and were as follows:

- Hands: Handles which can be slided outwards slightly. Sliding the left handle to the left indicates a turn to the left (Figure 17a).
- Feet: Pedals which can rotate slightly. Rotating your left heel towards the left indicates a left turn (Figure 17b).
- Hips: Seat which can turn slightly. Twisting your hips to the left indicates a left turn (Figure 17c).
- Knees: Rods next to your knees which can be pushed with the knees. Pushing your left knee towards the left indicates a left turn (Figure 17d).

The questionnaire consists of two phases. In the first phase of the questionnaire, participants were asked to rate each design concept on five aspects on a scale of 1 to 5. A Likert scale was used where participants could indicate how much they agree or disagree with the statement. An advantage of using a Likert scale is that respondents can have various degrees of opinions, which can lead to higher quality insights than simple yes/no questions [18]. To allow for more qualitative insights, there were three optional open-ended questions for each concept, to ask what they liked about the concept, what they would improve, and any additional comments. The statements for each concept were as follows:

- I think *[concept]* will be very intuitive to use.
- I think *[concept]* will help me feel safer on my bicycle amongst automated vehicles.

- I would trust *[concept]* to properly register my intention and communicate it to the automated vehicles around me.
- I expect the feedback of *[concept]* to clearly tell me how the automated vehicles around me will react (and if I can safely cross the street).
- I would use *[concept]* to indicate my intentions while cycling.

In the second phase, six questions were asked to directly compare the four concepts. To answer each question, participants could select one or more of the four concepts as their answer. The questions were as follows:

- Which concept(s) would be the easiest to trigger / activate?
- Which concept(s) would be the most likely to "misfire"?
- Which concept(s) would allow for the best feedback about how the automated vehicles around you will react?
- Which concept(s) would make you feel the right amount of safety in traffic?
- Which concept(s) would you be most likely to use?
- Which concept(s) would you be least likely to use?

Furthermore, participants were asked about their cycling experience, the quality of their cycling infrastructure, their age, and how interested they are in technology. These demographics could influence someone's opinions about concepts like these, possibly leading to interesting results. The full questionnaire can be found in Appendix B.

3.1.1 Results. The questionnaire has been answered by 27 respondents.

Overall, the results in the first section were quite negative. Every statement about the individual concepts received "Fully disagree" as the most occurring answer, for almost every statement over 40% of answers was "Fully disagree". Even though the ordinal nature of a Likert scale means taking the mean of the responses is not always a suitable way to analyze the responses, it is still useful to quickly compare the different concepts to each other, as done in Table 1.

Question	Sliding handles	Rotating pedals	Twisting seat	Knee rods	*Average scores*
I think *[concept]* will be very intuitive to use.	2.07	**2.15**	1.78	2	*2*
I think *[concept]* will help me feel safer on my bicycle amongst automated vehicles.	**2.15**	**2.15**	1.59	1.96	*1.96*
I would trust *[concept]* to properly register my intention and communicate it to the automated vehicles around me.	2.15	1.96	2	**2.22**	*2.08*
I expect the feedback of *[concept]* to clearly tell me how the automated vehicles around me will react (and if I can safely cross the street).	**2.59**	2.11	2.15	2.48	*2.33*
I would use *[concept]* to indicate my intentions while cycling.	**2.33**	2.11	1.63	1.85	*1.98*
Average scores per concept	***2.26***	*2.1*	*1.83*	*2.1*	

Table 1. (N=27) Mean scores of statements (between 1 and 5) for every concept. The highest scores are bold.

The mean scores in Table 1 show that the sliding handles are considered to be the most promising concept. Due to the nature of most of these statements, it can be argued that the location of the handlebar has the most potential over the other locations (feet, hips, and knees). Regarding the hands, people mostly worry about the likelihood of accidental activation and lack of stability: *"I am afraid that the sliding can also happen when it is not needed, increasing the chances of a cyclist losing balance."* Another important remark in both the questionnaire and on the forum where the questionnaire was posted, was that none of these concepts should be required to guarantee safety while cycling: *"This problem (safety) should be solved by the driver or owner of the car, not by the cyclist."* However, the main intention of these concepts was not to guarantee safety, as this should indeed be done by the AVs, but to increase cycling comfort. This is a limitation of this survey, more about this in Section 4.

The results of the second phase, where participants were asked to directly compare the four concepts, agree with the results from the first phase. Full results are displayed in Table 2. In all six comparison questions, the respondents were among the most positive about the sliding handles, and most negative about the twisting seat. The only exception to this is that the respondents expect the knee rods to be less likely to misfire, and they are less against using the rotating pedals. Besides this, the respondents expect the sliding handles to be the easiest to use, allow for the best feedback, feel the safest, and are the most likely to be used.

Question	Sliding handles	Rotating pedals	Twisting seat	Knee rods
Which concept(s) would be the easiest to trigger / activate?	**37%**	31%	17%	14%
Which concept(s) would be the most likely to "misfire"?	19%	26%	39%	**17%**
Which concept(s) would allow for the best feedback about how the automated vehicles around you will react?	**47%**	14%	6%	33%
Which concept(s) would make you feel the right amount of safety in traffic?	**39%**	33%	12%	15%
Which concept(s) would you be most likely to use?	**43%**	33%	7%	17%
Which concept(s) would you be least likely to use?	21%	**16%**	33%	30%

Table 2. Results of comparison questions. The most positive answers are bold.

These results are not surprising and can be explained by the fact that the hands are used most frequently to interact with devices and other humans. Therefore, it makes sense that they feel like the most sensible option. One thing to note about these results, especially about the knee rods, is that not every respondent seemed to fully understand every concept. This might have affected the results slightly, although it is not expected to have any large consequences for these specific results.

An interesting finding when comparing the results of the first phase and comparing the scores with the ages of the respondents is that as the age increases, the general view becomes less positive. This can be seen in the graph in Figure 18. This shows that older people are more likely to be more negative about these concepts. One possible explanation for this trend could be that they did not grow up with technology the same way younger generations did, therefore, they might be less accepting of new technologies like the automation of vehicles. Another reason, also supported by multiple comments on the forum post, is that they may be more worried about their mobility while using some of these concepts. As someone on the forum mentioned: *"Do you think a grandma who can barely stay upright on her bike can use these concepts?"* to which someone responded: *"In that case, I highly doubt she should still be using a bike in the first place"*.

Fig. 18. Scatter plot comparing given scores to age

3.2 User Testing Vibration Patterns

During the public Demoday, the vibration patterns were set as follows:

(1) Two short vibrations at middle-strength to confirm that the handle is slid out.
(2) Constant weak vibration gradually getting stronger and weaker (in waves) to make the user aware of the communication going on.
(3) One short and one longer vibration at full strength to confirm that the AVs will make room to turn.

Some visitors offered feedback about the vibration patterns that they could feel during the demonstration. They were not sure what all of it means. After explaining it verbally, they understood and seemed fairly satisfied about the feedback. Others did not fully understand the middle part of the vibration. Therefore, a user test was performed to compare two versions of the haptic feedback: One with the communication waves in between, and one without. The user test took place as follows:

First, the design concept was explained to the participant. The network of AVs was explained, the goal of allowing cyclists to participate in this network was introduced, and the design concept was explained. The participants were shown a 2:30 minute video of the slidable handles being used on a bike while holding the prototype in their hands. The video is in first-person perspective and constantly shows the handlebar of the bicycle while cycling around. Before making a turn, the corresponding handle can be seen being slid out in the video to indicate the upcoming turn. At the same time, the same handle starts vibrating in their hand. The video stops after making 10 turns, after which the participant is asked to answer a few questions to rate their experience. Afterward, the video is repeated with a different vibration pattern, and the same questions are answered once more. Finally, there is a short semi-structured interview to ask about preferences.

The video and code used during this user test are available on the public GitHub repository: https://github.com/JochemV01/Slideo

The user-test setup can be seen in Figure 19. User tests were carried out in multiple locations. Every participant experienced the same two variations of the vibration patterns as described in Table 3. However, the order of which variation was tested first was randomized, so half of the participants experienced variant A first and the other half experienced variant B first. This was done

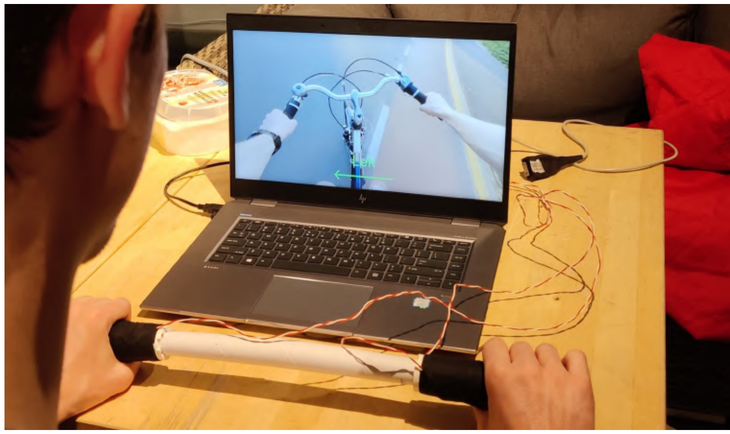


Fig. 19. User test setup, with video on laptop while holding prototype.

in order to account for the fact that the participants can get more used to the vibration patterns overtime, influencing their opinions. The video was made 2:30 minutes long, so the participants have enough time to get used to the vibration patterns without it taking too long and becoming boring resulting in distractions. To ensure that the participant always knows which direction they will turn next in the video, an arrow and text are displayed at all times in the bottom centre of the screen, which can also be seen in Figure 19.

Action	Variant A	Variant B
Sliding handle to indicate direction	3x 100ms short vibration at 70% strength, with gaps of 100ms in between.	3x 100ms short vibration at 70% strength, with gaps of 100ms in between.
Waiting while communicating with AVs	Gradually going up to 15% power and back to 5% in 700ms, repeating.	Nothing
Confirmation that gap will be formed to cross	200ms at 60% power, 100ms waiting, 500ms at 100% power.	200ms at 60% power, 100ms waiting, 500ms at 100% power.

Table 3. Both variations of vibration patterns tested during the user test.

The participants answered the following questions after trying each variation. All questions could be answered on a scale of 1 to 10:

(1) How effective were the vibration patterns in providing feedback?
(2) How well did the vibration patterns help you understand your environment?
(3) How comfortable did the vibration patterns feel?
(4) How easy to understand were the vibration patterns?
(5) How natural do the vibrations feel?
(6) Overall, how satisfied are you about this user feedback?

Additionally, the participants received an open question asking what they think the vibrations mean and if they think they need additional explanation in order to understand the vibration patterns properly.

3.2.1 Results. The user test was performed with 9 participants.

First of all, there seems to be no clear relation between the order or variations tried and which variation was preferred. Also, the understanding after watching the video a second time is not notably better than after watching it the first time, so the duration of the video seemed to be sufficient to understand the meaning of the vibrations. 6 out of 9 participants correctly understood the vibration patterns after watching the video for the first time; the participants who did not get the correct meaning after the first time also did not after the second time. Although only four participants correctly wrote down the meaning of the waves, the general haptic feedback was intuitive enough to be understood by the majority of the participants.

The opinions about which variation was preferred were mixed. The 4 participants who correctly understood the meaning of the waves preferred this variation (A in Table 3). The participants who did not write down the correct meaning of this vibration preferred the variation without it (B in Table 3). However, even after explaining the actual meaning of all the vibration patterns, all of the participants stayed in their opinion. When asked why, the participants who preferred variation B said that they did because it is simpler and more minimalist. There is less going on and less information that needs to be understood; it makes their experience more clear and to the point. The participants with a preference for variation A mentioned that they prefer to know what is going on. These communication waves tell them their intention is still being processed, allowing them to patiently wait until they receive a confirmation.

Based on the division within this user test and questions about which variation the users prefer, it can be stated that it is a matter of personal preference. While more work can be done to create the best vibration patterns for haptic feedback, in a final product it would make sense to allow users to personalise some aspects of it, like for instance being able to turn on or off the communication waves, or tweaking the intensity.

4 DISCUSSION

The original goal of this project was to attempt to look in a different direction from most of the existing literature about this subject. Therefore, this project can be considered a starting point for others to build further from. The hope is that this was achieved.

An obvious limitation for this project, is the fact that not much work being done in a similar direction as this project resulted in almost "going in blind". The difficulty of finding relevant literature resulted in this process taking more time than desired. The limited amount of information to go by also meant that various assumptions were made throughout the process, most notably that there will be a network of communication between AVs and that other types of vehicles can participate in this network too, even if these vehicles are driven by humans. Although existing literature does support this assumption, it is not yet confirmed. If this network were to never be created, a design concept as proposed in this report might not make any sense at all.

4.1 Limitations

One limitation has to do with the questionnaire. Perhaps due to the anonymity of it, it seemed some people thought it would be funny to make fun of the concepts instead of filling in the questionnaire seriously. With one respondent this was easy to detect, thanks to them mentioning that Kermit the frog should be placed on the bike and their age being over 110 years old, it is still very much possible that there are more subtle responses also not taking it seriously. Also, it seemed like not everyone understood the idea of the project and assumed that the concepts were meant to improve the cyclist's safety. It should have been communicated more clearly that this is not the case. AVs should be responsible for the safety of VRUs, but the concepts are an opportunity to make cycling more enjoyable and comfortable.

Participants of the user test might have understood the concept and the meaning of the vibration patterns better if at some point in the video they would be standing still to await a confirmation. In the video which was used, the cyclist did not come to a full stop and was able to take every turn without stopping or slowing down. This resulted in some confusion about the meaning of the final signal, some participants originally thought this confirmation was meant to tell them where to turn. Standing still in the video and starting to cycle again after the confirmation would have been more clear about its meaning.

Another limitation which might have slightly affected the outcome of the user test, is the fact that vibrations travelled through the frame to the other handle, sometimes making it difficult to differentiate which side was vibrating. Overall, one side was still stronger than the other, but in an ideal scenario the vibrations would stay on one side of the handlebar.

4.2 Future Works

The case of vibrations travelling through the handlebar to the other handle should be a focus point for a follow-up iteration. There are probably ways to minimize this, for example by the material on the inside of the handles to something more absorbing, or using a different type of vibration motor. The DC vibration motor used works by spinning a small weight around an axis, resulting in a vibration in all directions. A linear resonant actuator (LRA) is another type of vibration motor, where the weight only moves in one direction in a linear motion. These are more precise, and it's possible that this type of vibration is easier to contain on one side of the handlebar.

Next versions should also research the force it takes to slide the handle, as the prototype was found to work better with a little piece of tape to increase the resistance. This is a relevant step to take in order to minimize the amount of false positives, while making sure it does not become difficult to indicate a turn. It can also be explored whether a spring system to make the handle bounce back after sliding it out is desired or not, as it was observed during the Demoday that many people manually slided it back only after receiving the confirmation that they can take the turn. After finding a proper resistance combined with whether or not it is being pulled back, the prototype can be used to perform larger user tests on an actual bicycle while moving. It is also worth noting that a slidable handle like this will obviously not work with every kind of bicycle. For instance, racing bikes with drop handlebars are very different and would not work with a handle like this. Also, the classic Dutch "Omafiets" might not have an ideal handlebar for this design either, although that can only be said with certainty after trying it out, something that was not possible during this project.

4.3 Supplementary Material

The supplementary materials like the 3D model, Arduino code, video used for the user test and full results of the questionnaire and user test can be found on the public GitHub repository: https://github.com/JochemV01/Slideo.

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A LEGISLATION IN THE NETHERLANDS

Legislation around cycling differs for every country and is not always very clear. In the Netherlands, there are some rules in place to enhance safety on the road for cyclists. A straight-forward example is to always use a compulsory cycle track, if there is one. It is illegal to ignore this mandatory cycle path and use the road next to it. Furthermore, it is illegal to cycle on the sidewalk or without proper lighting. Additionally, cyclists should always indicate their direction when they are about to make a turn. The common way to do this is by holding the arm, but it is also allowed to use blinkers on a bicycle in the Netherlands [17].

B FULL QUESTIONNAIRE

Consent

Participation in this study is voluntary and can be ended at any time. No personal identifiable data (except age) will be collected, therefor your answers will be anonymous and cannot be traced back to you. This study is conducted by Jochem Verstegen, a bachelor student of Industrial Design at TU/e currently doing his final bachelor project. If you have any questions, you can always contact the researcher via j.r.p.verstegen@student.tue.nl. The questionnaire consists of multiple choice questions and a few optional open ended questions. Since it will not be about any sensitive subjects, there are no risks involved with participating in this study.

1. I acknowledge that I am sufficiently informed about the research project and have had the opportunity to ask questions. Furthermore, I acknowledge that I take part in this research project voluntarily and can end participation at any moment, without giving any reason. I consent to my answers being used for quotes in research publications and to the anonymous research data being made available for any future research.

❍ Yes, I consent and want to continue to the questionnaire.
❍ No, I do not consent and do not want to answer the questionnaire.

Introduction

Every major car company is working on developing automated vehicles (AVs). In the future, the use of these automated vehicles could lead to some major advantages, like increased road safety, faster travel times and less energy usage. To reach these advantages, it is very likely that the automated vehicles on the roads will form a network together to communicate all kinds of information like position, speed, route, road conditions, and more.

A current challenge with AVs is dealing with vulnerable road users like pedestrians or cyclists. Since these are human beings, it is difficult to predict their behaviour. A human could always make a sudden movement, like a turn, without indicating it in advance. Or, if a cyclist would indicate their turn by holding up their arm, it is possible for AVs to not properly recognize this for various potential reasons. Perhaps the cyclist does not hold up their arm long or high enough, or sunlight is causing glare in the AV's camera resulting in it missing out on the cyclist's indicated intention.

This problem could be solved by adding an interaction ability to the bicycle, either as a separate device or by embedding electronics into the bicycle. In this questionnaire, you will be shown 4 different design concepts that can be used to properly communicate your intention to make a turn to automated vehicles around you, without having to depend solely on their sensors or cameras. For each concept, you will be asked to answer a couple of questions, after which you can compare them to each other. It will take approximately 10 minutes. Please note that there are no correct answers, always choose the answer which is most fitting to you.

2. First of all: Do you have any thoughts about cycling with automated vehicles around you? *Feel free to share any thoughts, opinions, questions, concerns or ideas you may have.*

____

Cycling experience
The following questions are meant to understand your cycling experience, which could have an influence on your views about the topic of cycling amongst automated vehicles.

3. Which of the following statements applies to you?

❍ I cycle regularly, once a week or more.
❍ I cycle occasionally, approximately once or a couple times a month.
❍ I cycle rarely, only a couple times a year.
❍ I don't cycle anymore, but I used to cycle regularly or occasionally (once a month or more).
❍ I never cycled, or I only cycled rarely in the past but not any more.

4. How would you rate the cycling infrastructure at the location you currently live?

	0	1	2	3	4	5	6	7	8	9	10	
Awful	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Excellent

5. How would you describe the cycling infrastructure at the location you currently live? *Please choose the answer which matches closest with your opinion.*

❍ Very good, everything I need is safely accessible by bicycle.
❍ Pretty good, most places are accessible by bicycle and it is safe enough.
❍ Mediocre, I can reach places by bicycle but it is not always safe or comfortable.
❍ Pretty bad, I mainly use roads meant for cars and it does not feel very safe.
❍ Terrible, there is no infrastructure for bicycles at all and riding a bicycle is dangerous.

6. Did you use a bicycle when you were growing up?
For example biking to primary school or for fun at young age.

❍ Yes, at the same location as where I live now.
❍ Yes, but at a different location as where I live now.
❍ No, I started riding a bicycle at an older age.

7. How would you rate the cycling infrastructure at the location you grew up?

	0	1	2	3	4	5	6	7	8	9	10	
Awful	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	Excellent

8. How would you describe the cycling infrastructure at the location you grew up? *Please choose the answer which matches closest with your opinion.*

❍ Very good, everything I needed was safely accessible by bicycle.
❍ Pretty good, most places were accessible by bicycle and it was safe enough.
❍ Mediocre, I could reach places by bicycle but it was not always safe or comfortable.

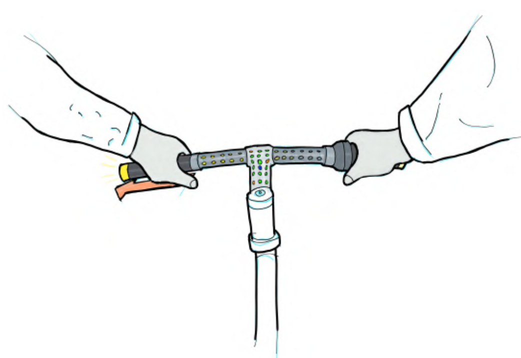
❍ Pretty bad, I mainly used roads meant for cars and it did not feel very safe.
❍ Terrible, there was no infrastructure for bicycles at all and riding a bicycle was dangerous.

Concept 1/4: Sliding handles (hands)

Now you will be given a short explanation of the four design concepts along with a sketch, and asked to answer a few questions about each concept. Please note that all the motions that would be required to use the concept do not interfere with someone's cycling ability.

The first design concept is about using hands to indicate the intended upcoming turn. As the cyclist, you can still keep both your hands on the handlebar. Both handles can slide sideways a small amount, towards the direction you will turn. So, as can be seen in the picture, if you want to go left you slide the left handle towards the left.

It is possible to add blinkers to the handle as well, to show you that your turning intention has been registered. Additionally, LEDs can be added into the handlebar frame, for example to show whether the automated vehicles nearby are aware of your intention and giving you room to complete the turn. Furthermore, it is a possibility to give you feedback in the form of sounds or vibrations in the handles.



Please indicate how much you agree with the following statements:

1 = *Fully disagree*
2 = *Disagree*
3 = *Neither agree nor disagree (neutral)*
4 = *Agree*
5 = *Fully agree*

9. I think the sliding handles will be very intuitive to use.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

10. I think the sliding handles will help me feel safer on my bicycle amongst automated vehicles.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

11. I would trust the sliding handles to properly register my intention and communicate it to the automated vehicles around me.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

12. I expect the feedback of the sliding handles to clearly tell me how the automated vehicles around me will react (and if I can safely cross the street).

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

13. I would use the sliding handles to indicate my intentions while cycling.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

14. What do you like about the sliding handles?

____

15. How would you improve the sliding handles?

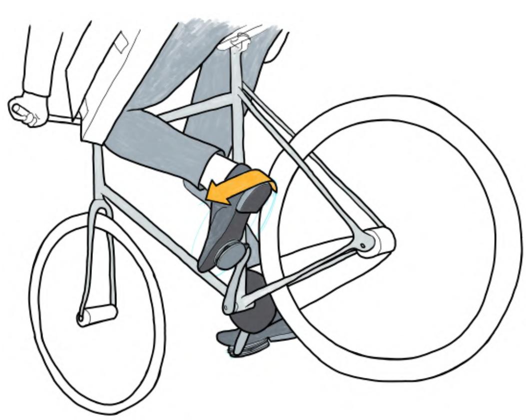
____

16. Is there anything more you would like to say about the sliding handles?
Share anything you like, for instance types of feedback you can think of or criticism about this idea.

____

Concept 2/4: Rotating pedals (feet / heels)
The second design concept is about using feet to indicate the intended upcoming turn. As the cyclist, you can still keep both your hands on the handlebar. Both pedals can rotate a slight amount, allowing you to push your heel towards the direction you will turn. So, as can be seen in the picture, if you want to go left you push your left heel towards the left, causing the pedal to rotate together with your foot.

It is possible to use this concept together with a kind of feedback positioned elsewhere on the bike, like LEDs in the handlebar, vibrations or sounds. Additionally, it can be used to activate a set of blinkers somewhere on the bike as well.



Please indicate how much you agree with the following statements:

1 = *Fully disagree*
2 = *Disagree*
3 = *Neither agree nor disagree (neutral)*
4 = *Agree*
5 = *Fully agree*

17. I think the rotating pedals will be very intuitive to use.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

18. I think the rotating pedals will help me feel safer on my bicycle amongst automated vehicles.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

19. I would trust the rotating pedals to properly register my intention and communicate it to the automated vehicles around me.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

20. I expect the feedback of the rotating pedals to clearly tell me how the automated vehicles around me will react (and if I can safely cross the street).

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

21. I would use the rotating pedals to indicate my intentions while cycling.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

22. What do you like about the rotating pedals?

____

23. How would you improve the rotating pedals?

____

24. Is there anything more you would like to say about the rotating pedals?
Share anything you like, for instance types of feedback you can think of or criticism about this idea.

____

Concept 3/4: Twisting seat (hips)

The third design concept is about using hips to indicate the intended upcoming turn. As the cyclist, you can still keep both your hands on the handlebar. The seat can twist a slight amount, allowing you to turn your hips towards the direction you will turn. So, if you want to go left you turn your hips towards the left, causing the seat to twist together with your upper body.

It is possible to use this concept to activate a set of blinkers at the back of the seat. Additionally, it can be used together with a kind of feedback positioned elsewhere on the bike, like LEDs in the handlebar, vibrations or sounds. It is also possible to make the seat vibrate as a kind of feedback, for instance to tell you that your turning intention has been registered.

Please indicate how much you agree with the following statements:

1 = *Fully disagree*
2 = *Disagree*
3 = *Neither agree nor disagree (neutral)*
4 = *Agree*
5 = *Fully agree*

25. I think the twisting seat will be very intuitive to use.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

26. I think the twisting seat will help me feel safer on my bicycle amongst automated vehicles.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

27. I would trust the twisting seat to properly register my intention and communicate it to the automated vehicles around me.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

28. I expect the feedback of the twisting seat to clearly tell me how the automated vehicles around me will react (and if I can safely cross the street).

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

29. I would use the twisting seat to indicate my intentions while cycling.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

30. What do you like about the twisting seat?

____

31. How would you improve the twisting seat?

____

32. Is there anything more you would like to say about the twisting seat?
Share anything you like, for instance types of feedback you can think of or criticism about this idea.

____

Concept 4/4: Knee rods (knees)
The fourth and final design concept is about using knees to indicate the intended upcoming turn. As the cyclist, you can still keep both your hands on the handlebar. There are rods positioned next to your knees which can be pushed sideways a slight amount, allowing you to push your knee towards the direction you will turn. So, as can be seen in the picture, if you want to go left you push your left knee towards the left, pushing the rod towards the left.

Blinkers can be implemented into the design. Additionally, the concept can be used together with a kind of feedback positioned on the rods themselves or elsewhere on the bike, like LEDs, vibrations or sounds. Furthermore, this design could be made as a stand-alone device, which can be mounted to and used with any bike.

Please indicate how much you agree with the following statements:

1 = *Fully disagree*
2 = *Disagree*
3 = *Neither agree nor disagree (neutral)*
4 = *Agree*
5 = *Fully agree*

33. I think the knee rods will be very intuitive to use.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

34. I think the knee rods will help me feel safer on my bicycle amongst automated vehicles.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

35. I would trust the knee rods to properly register my intention and communicate it to the automated vehicles around me.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

36. I expect the feedback of the knee rods to clearly tell me how the automated vehicles around me will react (and if I can safely cross the street).

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

37. I would use the knee rods to indicate my intentions while cycling.

	1	2	3	4	5	
Fully disagree	❍	❍	❍	❍	❍	Fully agree

38. What do you like about the knee rods?

____

39. How would you improve the knee rods?

____

40. Is there anything more you would like to say about the knee rods?
Share anything you like, for instance types of feedback you can think of or criticism about this idea.

____

Comparing
In this section, you will be asked a few questions, for which you can choose one or more of the concepts.

41. Which concept(s) would be the easiest to trigger / activate?
So which do you think will take the least effort to use?

- ❏ The sliding handles
- ❏ The rotating pedals
- ❏ The twisting seat
- ❏ The knee rods

42. Which concept(s) would be the most likely to "misfire"?
So which do you think will trigger accidentally, when it should not?

- ❏ The sliding handles
- ❏ The rotating pedals
- ❏ The twisting seat
- ❏ The knee rods

43. Which concept(s) would allow for the best feedback about how the automated vehicles around you will react?
So which do you think will keep you aware about what the automated vehicles around you will do?

- ❑ The sliding handles
- ❑ The rotating pedals
- ❑ The twisting seat
- ❑ The knee rods

44. Which concept(s) would make you feel the right amount of safety in traffic?
Not too much, not too little.

- ❑ The sliding handles
- ❑ The rotating pedals
- ❑ The twisting seat
- ❑ The knee rods

45. Which concept(s) would you be most likely to use?
So which do you think you will probably use?

- ❑ The sliding handles
- ❑ The rotating pedals
- ❑ The twisting seat
- ❑ The knee rods

46. Which concept(s) would you be least likely to use?
So which do you think you will certainly not use?

- ❑ The sliding handles
- ❑ The rotating pedals
- ❑ The twisting seat
- ❑ The knee rods

Final questions
Almost done! I'd like to know some general things about you, because these things can influence your thoughts and opinions about the topic in general and the concepts.

47. What is your age?

____

48. For which reason(s) do you use your bicycle most often?
If there are multiple equally frequent reasons, please select both.

- ❑ Traveling to work / school
- ❑ Recreational
- ❑ As a sport
- ❑ Other: __________________________

49. Which statement regarding technology applies to you most?
Please select the one which most accurately describes your situation.

- ❍ I am not interested in technology and don't know how to use most of it.
- ❍ I don't mind using technological products when I need to.

❍ I think technology is useful and I regularly use it.
❍ I like using technological products and enjoy trying out new ones.

50. Do you have any thoughts about cycling with automated vehicles around you, while using a concept like these to communicate your intentions?
Feel free to share any thoughts, opinions, questions, concerns or ideas you may have.
____