HANDLE - High tech communication solutions for safer bicycles

Public report

Project within Electronics, software and communication
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Content

1. Summary

This project is about the development and testing of a smart handlebar for bicycles. The handlebar can warn a bicyclist of oncoming traffic and/or obstacles using vibrations, blinking lights or using a display mounted to the handlebar. The functionality of the handlebar has been tested in a virtual reality bicycle simulator. 24 participants experienced 3 different scenarios with and without the smart handlebar and their movements within the virtual reality was recorded. They were also asked to fill in a questionnaire regarding the functionality of the smart handlebar.

The results from the development of testing of the handlebar show that the idea of a smart handlebar with vibration warnings is feasible and the experiment show some good results. However, more research is needed before the handlebar could be integrated into a real bicycle, specifically focused on how such a product could be integrated into the production of a comprehensive smart bicycle with many different functions.

2. Sammanfattning på svenska

Målet med detta projekt var att utveckla och utvärdera funktionaliteten av ett smartcykelstyre som kan kommunicera med en cyklist. Cykelstyret som har utvecklats i projektet kan varna en cyklist för ankommande fordon och/eller hinder med hjälp av vibrationer i styret, blinkade ljus-varningar samt via en skärm monterad på styret. Målet med designen är att i första hand varna cyklisten med information på skärmen och blickande ljus och sedan varna cyklisten med vibrationer om det behövs. Funktionaliteten av cykelstyret har testats i en ”virtual reality” cykelsimulator där 24 deltagare har fått testa 3 olika scenarier med och utan det smarta cykelstyret. Resultatet av experimentet är baserat på hur deltagarna cyklade med och utan styret i simulatorn i kombination med deras svar ifrån ett frågeformulär.

Resultatet ifrån simulatorn visar att deltagarna i experimentet cyklade mer försiktigt med det smarta cykelstyret vilket indikerar att informationen ifrån cykelstyret var användbart för deltagarna. Svaren ifrån frågeformuläret tyder också på att dem flesta deltagarna tyckte cykelstyret verkade positivt och användbart. Dock tydde svaren också på ett antal saker som kunde förbättras. Sammanfattat så är resultatet positivt och det verkar som om det utvecklade cykelstyret kan vara användbart för cyklister. Det behövs dock mer utveckling fokuserat både på själva designen och på hur ett smart cykelstyre kan integreras i en smartcykel i praktiken.

3. Background

The European Vision Zero white paper [1] on Transport targets a goal of close-to-zero road fatalities by 2050 following the Swedish Vision Zero concept. Recent statistics indicate a trend of reduced road accidents[2], those statistics show a reduction of road fatalities on motorized traffic (-29%), a different trend emerges for cyclists with a reported substantial increase of bicyclists involved in fatal accidents (6%). In addition, accident reduction for motorized vehicles is mainly due to the increasing transport automation and the introduction of Advanced Driving Assistance Systems (ADAS), functionalities that are not yet available for cyclists. In the Swedish context, where the exposure is very high since the use of the bicycle is continuously promoted, this problem is central when traffic safety is under investigation.

Cyclists are often already more than twice as vulnerable as other road users, even in the current well defined mobility ecosystem. This is mainly because due to the lack of technologies supporting cycling safety, due to the fact that cyclists do not have access to the ADAS-type systems that protect car drivers. However, there is theoretically nothing that stops similar systems for being developed and used to aid bicyclists

4. Purpose, research questions and method

The HANDLE concept is built on the notion that there are scientific research and technological gaps between motorized vehicles and bicycles (or micro-mobility in general) that make non-automotive personalised transport less safe than automotive transportation. These gaps are exacerbated by the trend in society to embrace new sustainable modes of transport, giving rise to an emerging social problem that is changing the perspective of traffic safety management. In this context, it is also worthwhile mentioning that while research is ongoing worldwide in the area of Connected and Automated Vehicles (CAVs), very few of these works concern their interaction with non-automotive traffic. A particular challenge is the lack of verbal and nonverbal communication between a driverless vehicle and a bicyclist generating a lack of ability to predict the behaviour of the users that are interacting in the same physical space.

Within this project, the aim is to create a prototype which can be tested in a simulation environment[3]. Modelling and simulation rely on a virtual environment with virtual agents to generate knowledge about an ADAS's behaviour without the need for a physical

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[1] EC EU Road Safety Policy Framework 2021-2030 - Next steps towards "Vision Zero". Commission Staff Working Document. Brussels, 19.6.2019 SWD (2019) 283 final. https://ec.europa.eu/transport/sites/transport/files/legislation/swd20190283-roadsafety-vision-zero.pdf

[2] Organisation for Economic Co-operation and Development, et al. (2020). Road safety annual report 2020: 65p. https://www.itf-oecd.org/sites/default/files/docs/irtad-road-safety-annual-report-2020_0.pdf

[3] Thorn, E., Kimmel, S., and Chaka, M. (2018, September). A framework for automated driving system

vehicle and actual testing in the real world. Hazard analysis and risk assessment will be also performed in the simulated environment[4]. The simulation-based approach provides an automatic and systematic method to assess the complex interaction of the system under analysis with other vehicle functions in possibly complex operational situations.

5. Objective

This project has two main objectives:

(1) Studying how HMI solutions can be developed for bicycles with a specific focus on how the handlebar can be used to seamlessly communicate with a bicyclist leading to the creation of a smart handlebar physical prototype.

(2) Show the potential benefits of the handlebar using a cost-effective approach based on virtual reality (VR) simulations. This includes testing the physical prototype in a VR environment in which the functionality of the smart handlebar is tested.

6. Results and deliverables

The main aims of the project have been achieved as planned. A smart handlebar for bicycles has been developed and tested in a VR environment. The following sections provides some more information about the development of the handlebar, the VR simulation, and the experiment testing the handlebar.

6.1 HMI design and Smart handlebar prototype

HMI design : The HMI (Human-Machine Interaction) design were built based on the multi modal interface systems approach as it could enhance recognition, understanding, faster and intuitive reactions from users[5]. The HMI consists of a set of three interfaces (Fig.1) such as motor (vibration cue), display unit (visual stimuli) and LED bar (visual stimuli) providing multimodal cues. In total, three scenarios were considered for evaluating the effectiveness of the proposed HMI designs solutions.

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testable cases and scenarios (Report No. DOT HS 812 623). Washington, DC: National Highway Traffic Safety Administration.

[4] Jacopo Sini, Massimo Violante, A simulation-based methodology for aiding advanced driver assistance systems hazard analysis and risk assessment, Microelectronics Reliability, Volume 109, 2020, 113661, ISSN 0026-2714.

[5] Manawadu, Udara & Kamezaki, Mitsuhiro & Ishikawa, Masaaki & Kawano, Takahiro & Sugano, Shigeki. (2017). A Multimodal Human-Machine Interface Enabling Situation-Adaptive Control Inputs for Highly Automated Vehicles. 10.1109/IVS.2017.7995875.

Scenario 1: vehicle overtaking a bicyclist from left side: HMI warns by providing an vibration cue on the left side of the handle bar (conveying the direction of the car) in combination with LED bar lit up with red color in synchronization with icons on the display unit, conveying that the overtaking car is in close proximity with bicycle and possibility of potential collision.

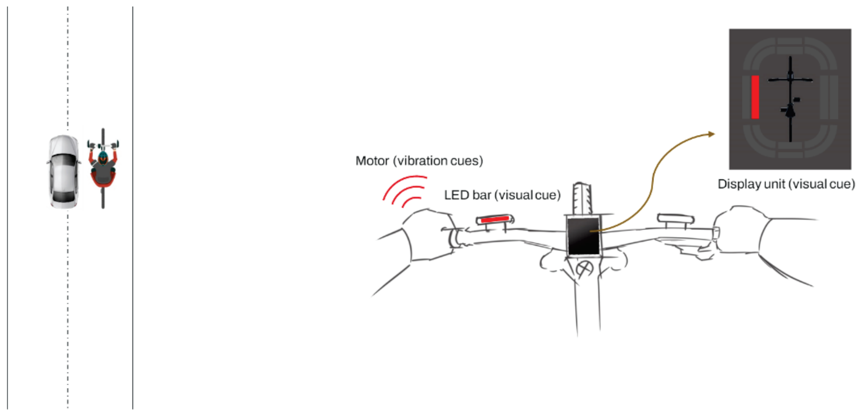

Figure 1 HMI design for scenario 1

Scenario 2: pothole on bicyclists' path - HMI warns the bicyclist by providing a vibration cue on both left and right side of the handlebar, in combination with LED bar lit up in amber color including an icon conveying the distance to the pothole. An escalation HMI design is also proposed when the distance to pothole is minimum, in which three vibration cues are delivered in combination with LED bar lighting up in pulsating red color and icon displaying the distance to pothole.

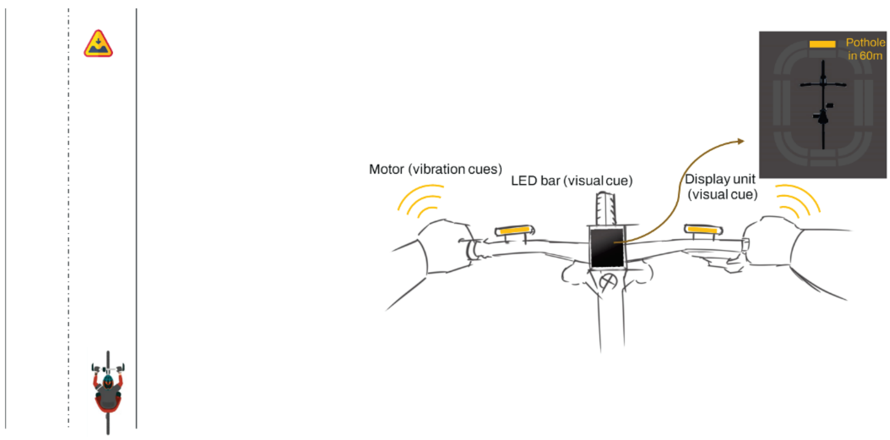

Figure 2 HMI design for scenario 2

Scenario 3: vehicle performing a right turn - HMI warns by providing a vibration cue on the left side of the handlebar (conveying the direction of the car taking the turn) in combination with LED bar lit up with red color in synchronization with icons on the display unit, conveying that the overtaking car is in close proximity with bicycle and possibility of potential collision.

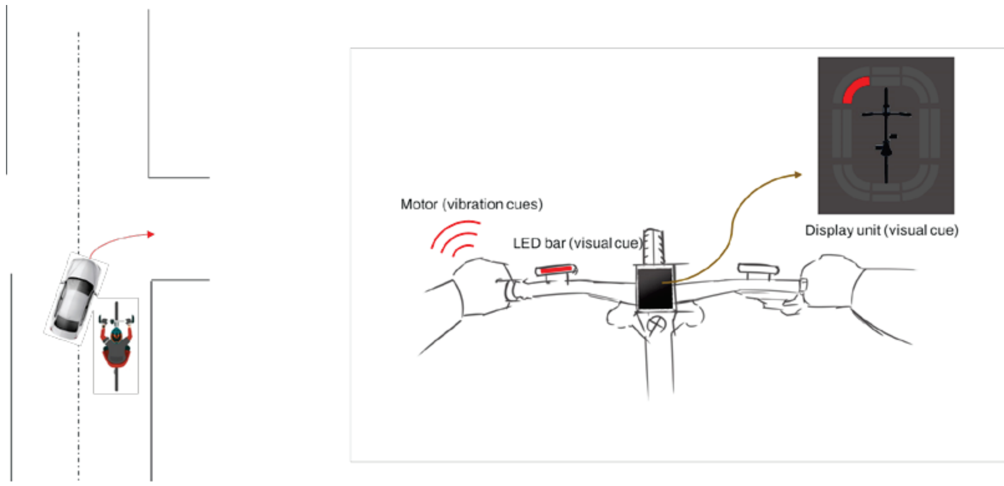

Figure 3 HMI design for scenario 3

Handlebar prototype: The smart handlebar prototype was built by integrating HMI interfaces (as motor, display unit and LED bar) on an existing handlebar design (Bontrager Crivitz, L 31.8mm, 690mm). A12V DC motor (see appendix 1 for specification) with eccentric rotating mass is used for generating the vibration cues.

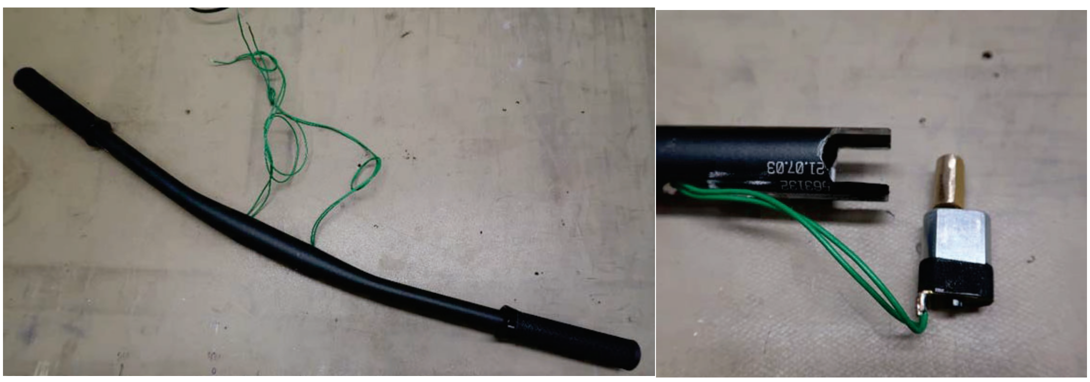

Figure 4 Handlebar integrated with motor on the grip region to produce vibration

The vibration intensity for the HMI designs were chosen based on the insights gathered by conducting on road tests with real bike (see Fig. 5) biking at speed range between 10-15 kph on different road surface (gravel, cobble and paving stone).

Figure 5 Measuring the vibration while biking on different road surfaces

Accelerometers (PCB 356A16 triaxis accelerometer) were mounted on the handlebar (Fig.6) to measures the vibration signals generated while riding on different road surfaces

Figure 6 Accelerometer positioned on the handlebar during measurment

The results from on-road tests showcased no major difference in vibration intensity generated from different road surfaces. However, it was found that the HMI design with vibration frequency above 100Hz would be better perceived by the bicyclists.

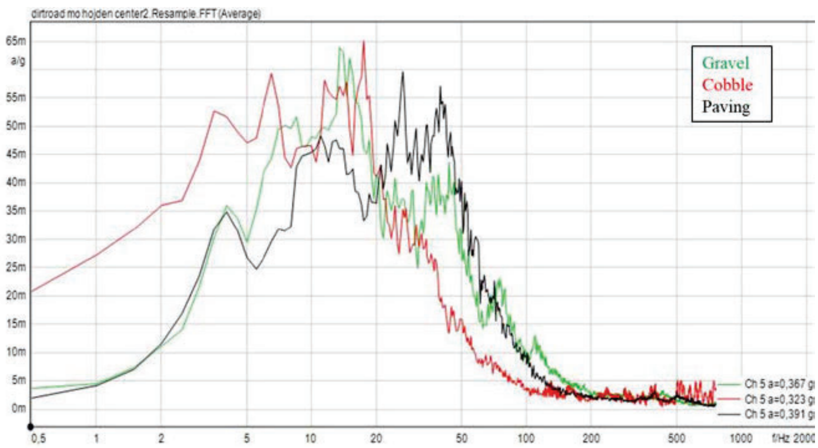

Figure 7 Vibration levels generated while biking on different road surfaces

So based on the findings from on-road tests and recommendations in the literature[6], the vibration frequency of 120Hz was chosen for the HMI design used in the study. In total four different vibration patterns were developed with altering variables such as pulse duration, inter-pulse interval and number of pulses to suit all three scenarios. The defined vibration patterns were implemented in the handlebar and further integrated in the bike simulator. Few tests were carried out to better understand the perception of the vibration cues while biking with handlebar (with HMI design) in a simulated environment. It was observed that the vibration frequency of 120Hz used in the HMI for the handlebar to warn the bicyclist was perceived of higher intensity while biking in the bike simulator compared to on-road. Therefore, the vibration frequency was further reduced to 90 Hz to suit to biking in a simulation environment, however the other parameters (pulse duration, inter-pulse interval, number of pulses) remained unchanged. The final vibration patterns integrated in the handlebar are showcased in Table 1.

Table 1 Vibration patterns tested for all scenarios

Scenarios	**Vibration frequency**	**Pulse duration**	**Inter –pulse interval**	**Number of pulses**	**Activation region on the handlebar**
Vehicle overtaking (close to bicyclist)	90 Hz	200	200	3	Left
Pothole on bicyclists’ path	90 Hz	100	100	1	Both left and right
Pothole on bicyclists’ path (minimum distance)	90 Hz	200	200	3	Both left and right
Vehicle turning right (close to bicyclist)	90 Hz	200	200	3	Left

As the proposed HMI designs includes LED bar and the display unit, those were realized in the virtual environment as shown in figure 8. Amber colour illumination was used to alert, and red were used to warn the bicyclists about potential danger.

[6] Elke-Henriette Erdei, Jochen Steinmann, Carmen Hagemeister,Which signal modalities do cyclists prefer based on experiences in road traffic?,Traffic Injury Prevention,Volume 22, Issue 8, 2021,Pages 640-645,ISSN 1538-9588,https://doi.org/10.1080/15389588.2021.1985113.

Figure 8. The handlebar in the virtual environment showing the yellow alert (left) and red warning (right).

6.2 The bicycle simulator

The bicycle simulator is developed using a virtual reality head mounted display (HMD) using commercially available hardware (HTC VIVE pro-2[7] and one VIVE Tracker[8]) and software in the Unity[9] framework. The bicycle simulator consists of a bicycle trainer (wahoo kickr snap[10]) which allows the user to pedal and a steering plate (Sterzo smart[11]) which allows the user to swerve within the simulation. The image below shows what the simulator looks like in practise.

Figure 9. The bicycle simulator

[7] https://www.vive.com/us/product/vive-pro2/overview/
[8] https://www.vive.com/us/accessory/tracker3/
[9] https://unity.com/
[10] https://eu.wahoofitness.com/devices/indoor-cycling/bike-trainers/kickr-snap-buy
[11] https://www.elite-it.com/en/products/home-trainers/ecosystem-accessories/sterzo-smart

The software was developed in Unity and consists of three main parts, more information about the bicycle simulator development can be found in the thesis by Norén (2022):

1. Code interpreting the movement of the bicycle including pedalling, swerving, and braking. This code is opensource and can be downloaded here: https://github.com/Whampaz/LU-VR-Bicycle-2022

2. A virtual environment based on the road "*Bondevägen*" in Lund[12]. The environment consists of a circa 500 meter stretch of road in an industrial area of Lund. The location was chosen since it does have bicycle interacting with both cars and trucks without any bicycle infrastructure. The virtual environment was manually constructed, and the figure below shows what the area looks like in the simulation.

Figure 10. A part of the virtual environment

3. Realistic traffic in the simulation is generated by first filming the location using drones and then tracking the movement of road users at physical location. These tracks were then imported into the simulation making it possible to replay their movements. The drone video have been analysed using the T-Analyst software[13] which makes it possible to manually track road users in the video and to translate these movements into their position on the road (Figure 3).

[12] https://goo.gl/maps/ZhsRLPUxtJ4BuTsu6
[13] https://bitbucket.org/TrafficAndRoads/tanalyst/downloads/

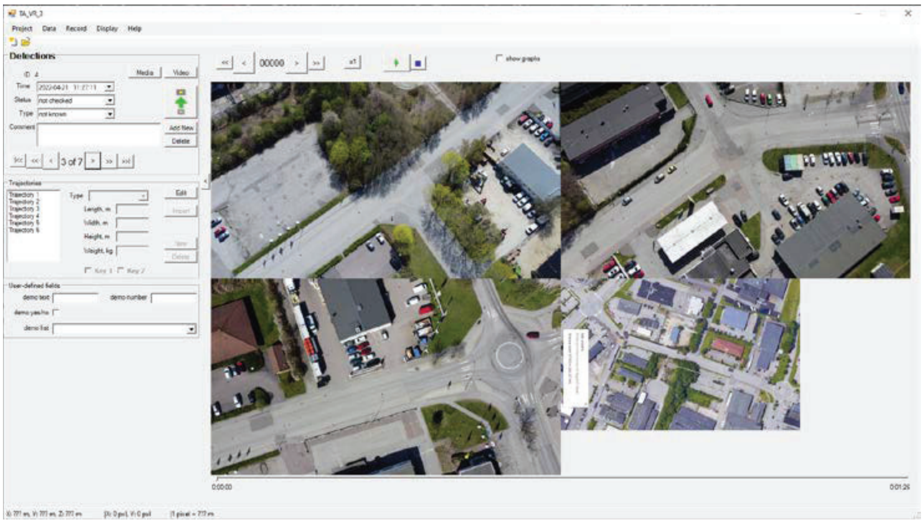

Figure 11. The T-Analyst software with the drone videos loaded

6. 3 Testing the handlebar

An experiment has been conducted to test the potential benefits of the handlebar. The experimented consisted of three distinct scenarios and a tutorial in which the participants got used to biking in the simulated environment:

1. The participants were asked to bike along the street and were then passed by a car traveling straight ahead.

2. The participants were asked to bike along the street while a truck passed them and turned right in front of them.

3. As the participants biked along the street they are warned of an oncoming pothole, when they get closer a stronger warning including vibration is played.

All participants experienced all three scenarios with and without the HMI being activated (the screen and the vibration), however half of participants first experienced the HMI being active and half the scenarios with the HMI inactive. This design was chosen since quantitative results from the experiment were based solely on the first round of scenarios. Each participant filled in a questionnaire regarding the efficacy of the HMI after the experiment using the subjective perceptions of the usability of a system (SUS) score[14].

[14] Grade rankings of SUS scores from "Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale," by A. Bangor, P.T. Kortum, and J.T. Miller, 2009, Journal of Usability Studies, 4(3), 114-123.

The experiment involved a total of 24 participants including 16 men and 8 women with an average age of 28.

The quantitative results include an analysis of the participants speed, pedalling, braking, and steering as the other road user approached and whenever a warning was played. The figure below shows how many participants that were actively pedalling as the yellow and red warning were played, the results show that both the yellow and red warning made the participants in the simulation stop pedalling to a larger extent compared to without any HMI. A similar result but was seen regarding speed changes and to a lesser degree when it comes to braking. No noteworthy changes in steering behaviour were observed.

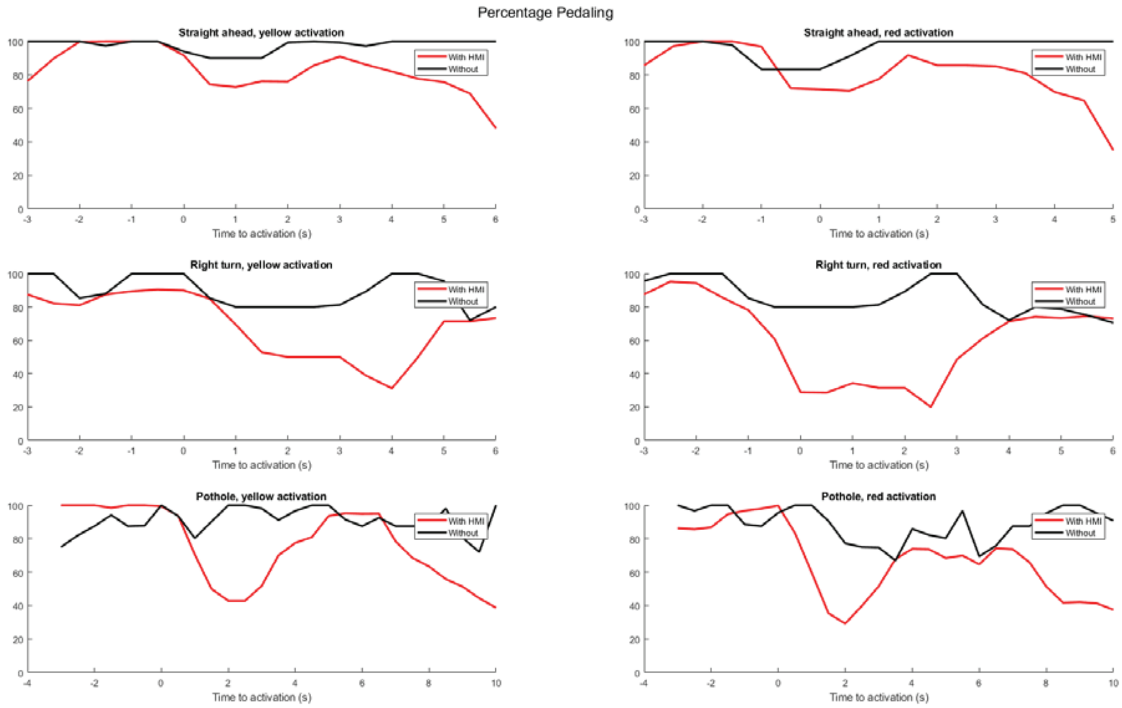

Figure 12. The percentage of participants braking before and after the yellow/red warning

Based on the questionnaire responses, a SUS score of 78.4 was calculated. This indicates a good[15] perception of the HMI solution with some potential for improvement. The user experience questionnaire response highlighted participants' experience in using the HMI solution (see Fig.13) For, the item " *the assistance system is understandable*" nearly 45% of participants chose " strongly agree" and for the item " *the assistance system is useful*" nearly 80 % (30% chose *strongly agree*, 15% *chose agree*, 35% chose *somewhat agree*) of participant agreed to this statement. Similarly for the item " *the assistance system*

[15] Grade rankings of SUS scores from "Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale," by A. Bangor, P.T. Kortum, and J.T. Miller, 2009, Journal of Usability Studies, 4(3), 114-123.

increases traffic safety" nearly 70 % (30% chose *strongly agree*, 15% *chose agree*, 35% chose *somewhat agree*) of participant agreed to this statement. Additionally, for the item focusing on vibration intensity " *The haptic vibration stimuli on the handlebar are optimal*" nearly 75 % (20% chose *strongly agree*, 15% *chose agree*, 40% chose *somewhat agree*) of participant agreed to this statement.

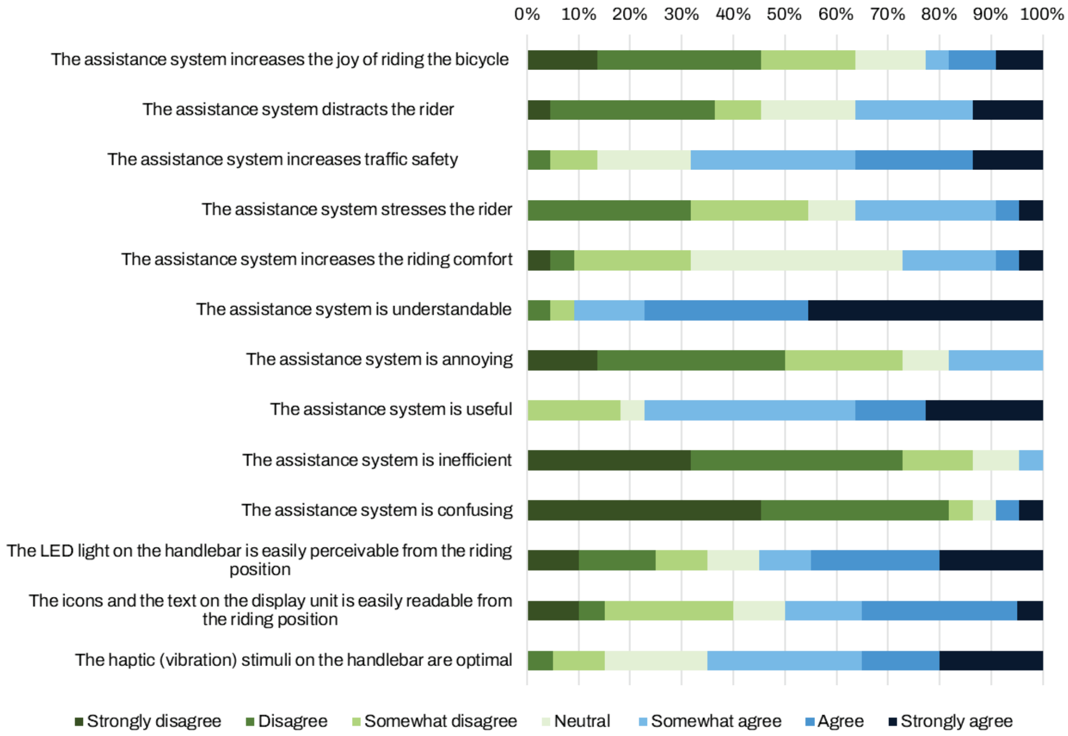

Figure 13 User experience questionnaire responses

Additional comments were received from few participants on the proposed HMI design solutions, see table 2.

Table 2 Comments received from few users regarding the proposed HMI design

The haptic stimuli were perhaps too strong, could panic some riders. In traffic safety, the main concern with close passes is to reduce drivers doing them rather than being alerted to them	*I think vibration should be lower, they stress the most.*
very good but might make feel safer than they actually are. For example, more people riding with headphone etc	*Mostly distracting especially pothole scenarios as instructions are unclear*
The display is too low, so i had to turn my head down, lost orientation and started to wiggle	

7. Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	The prototype handlebar will tell us about how feasible ADAS for bicyclists could be in the future. Using virtual reality to test the prototype provides more knowledge about the effectiveness and simplicity/difficulty of testing in a VR environment.
Be passed on to other advanced technological development projects		
Be passed on to product development projects		
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions		

7.2 Publications

- Norén, H., *Developing a Virtual Reality Bicycle Simulator in Unity for Traffic Safety Research Integration*, 2022, Bachelor's Thesis in Game Development, Malmö University (*not yet published as of 2022-06-27*)

- Opensource code for the movement within the bicycle simulator: https://github.com/Whampaz/LU-VR-Bicycle-2022

8. Conclusions and future research

The results from the development of testing of the handlebar show that the idea of a smart handlebar with vibration warnings is feasible and the experiment show some good results. However, more research is needed before the handlebar could be integrated into a real bicycle, specifically focused on how such a product could be integrated into the production of a comprehensive smart bicycle with many different functions.

The development of a VR bicycle simulator using commercially available hardware and software showed that it is relatively simple to create a functioning bicycle simulator which can be used to test early technology concepts. Integrating the prototype was simple and the entire process was relatively efficient. One noteworthy consideration is that the virtual environment allows for a purely virtual design of a technology which is both good in the sense that it doesn’t require a physical prototype to also include design aspects, but it is also bad in the sense that it is unclear how realistic the design of the porotype is in VR and to what extent it can be trusted. Using a large screen (a so-called cave) instead of VR would allow for a physical prototype to include the design of the prototype which could be a better simulation set-up if the physical design of the prototype is of the utmost importance.

9. Participating parties and contact persons

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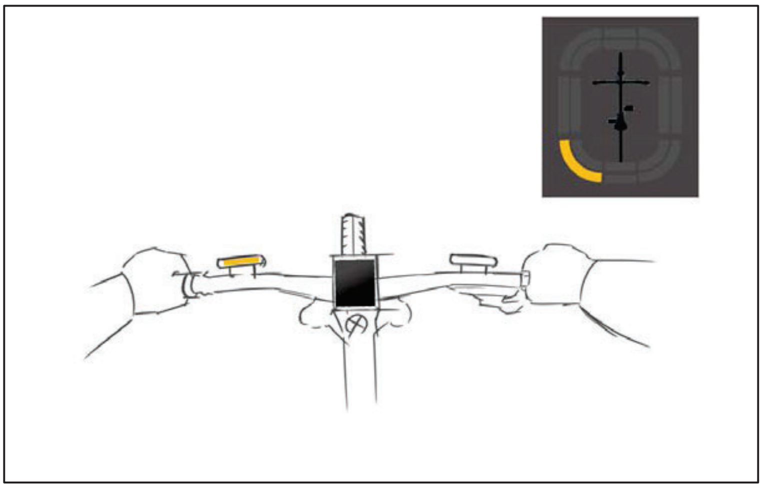
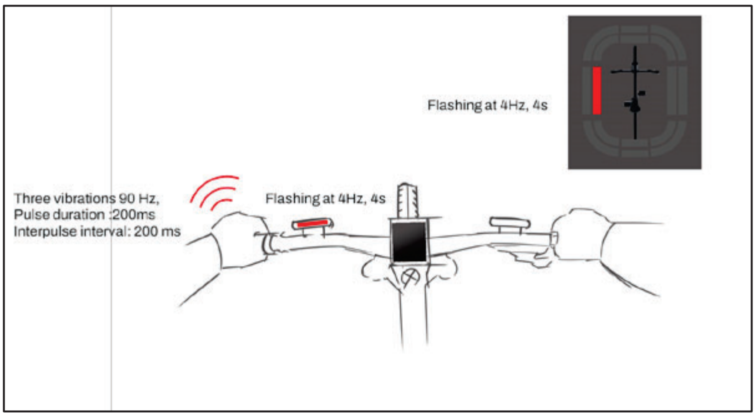
10.Appenix

10.1 Questionnaires

Assistance system for bicyclists





The assistance system consists of multimodal interfaces: LED bar on the handlebar, display unit and haptic actuators (vibration) on the handlebar. Fill in the below questionnaires based on your experience in using the assistance systems.

Usability of the assistance system

Participant ID…………

Please tick your response in the below table

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system is unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very Cumbersome (complicated) to use	1	2	3	4	5
9. I felt very confident using the System	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

	Strongly disagree						Strongly agree
	1	2	3	4	5	6	7
1. The assistance system increases the joy of riding the bicycle	☐	☐	☐	☐	☐	☐	☐
2. The assistance system distracts the rider	☐	☐	☐	☐	☐	☐	☐
3. The assistance system increases traffic safety	☐	☐	☐	☐	☐	☐	☐
4. The assistance system stresses the rider	☐	☐	☐	☐	☐	☐	☐
5. The assistance system increases the riding comfort	☐	☐	☐	☐	☐	☐	☐
6. The assistance system is understandable	☐	☐	☐	☐	☐	☐	☐
7. The assistance system is annoying	☐	☐	☐	☐	☐	☐	☐

8. The assistance system is useful

1	2	3	4	5	6	7

9. The assistance system is inefficient

1	2	3	4	5	6	7

10. The assistance system is confusing

1	2	3	4	5	6	7

11. The LED light on the handlebar is easily perceivable from the riding position

1	2	3	4	5	6	7

12. The icons and the text on the display unit is easily readable from the riding position

1	2	3	4	5	6	7

13. The haptic (vibration) stimuli on the handlebar are optimal

1	2	3	4	5	6	7

Any other comments or feedback regarding the assistance systems……………………………………………………………………………………
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10.1 Motor specification

Model	Volts (V)	*Diameter (mm)*	*Length (mm)*	*Weight (g)*	*Speed (rpm)*
517EB	20	20.2	25.2	48	------