Automation transparency: Designing an external HMI for autonomous passenger ferries in urban waterways

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ABSTRACT

Automation transparency – the visibility of responsibilities, capabilities, goals, activities, and effects of autonomous systems – is not only important for the operator, but also relevant for other humans in the system's environment. This pictorial investigates current trends in the development of External Human-Machine Interfaces (eHMIs) and highlights the most important factors for designing eHMIs. Further, it explores automation transparency for a self-driving passenger ferry for urban waterborne transport and how it can communicate messages about the system's perceptions, current state and future intention to nearby ships and bystanders through an eHMI. As a result of a user-centred design process, we propose a unique eHMI design making an urban autonomous passenger ferry capable of expressing its state and intention to nearby ships and humans via displays, light, and moving panels. The results of this paper can inform designers of the importance of automation transparency for autonomous waterborne transport systems.

Authors' Keywords

Autonomous vessels; automation transparency; maritime communication; external human machine interface.

CSS Concepts

• Human-centered computing~Human computer interaction (HCI)

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GRAPHICAL ABSTRACT

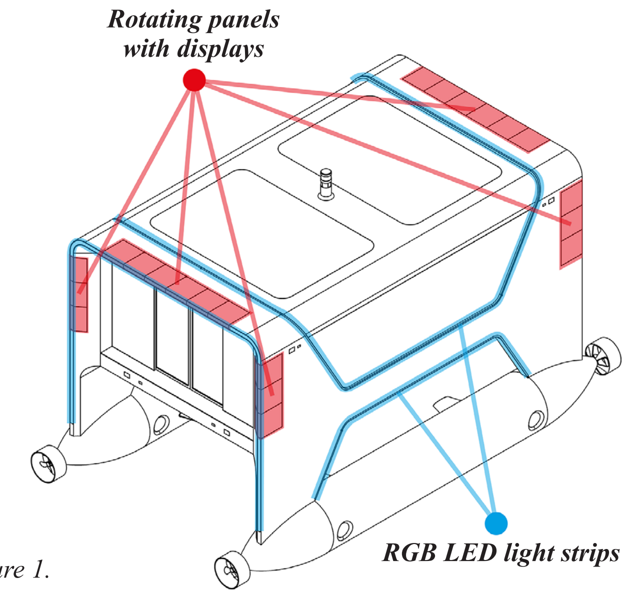


Figure 1.

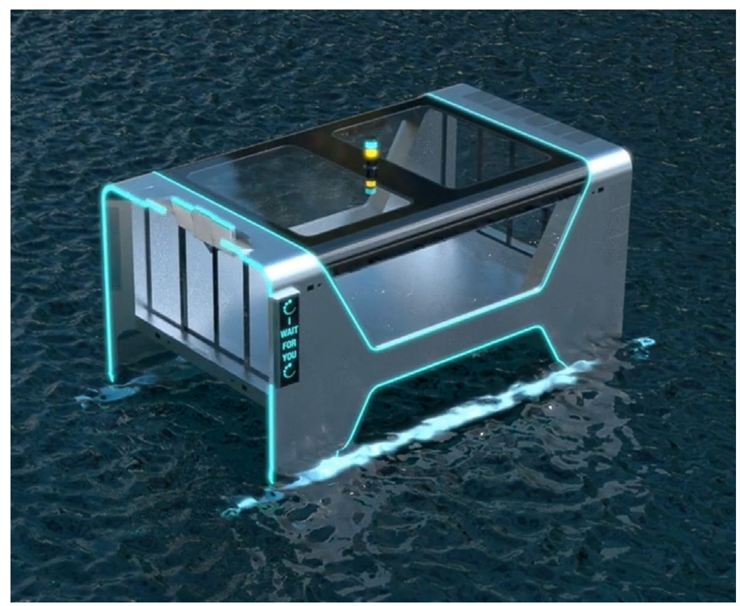


Figure 2.

INTRODUCTION

With recent advances in technology, urban autonomous passenger ferries (UAP) are becoming a new infrastructure tool in the toolbox of urban planners and will offer citizens a cost-efficient, environmentally friendly and safe mobility across rivers, canals and harbour basins [23]. In cities around the world, UAPs are currently being researched and developed to improve urban mobility and move traffic from congested roads over to less utilised waterways. However, the urban waterways have mixed traffic ranging from large ships with professional seafarers with extensive training and strong safety culture, to smaller boats and kayaks with little understanding of maritime rules and regulations. To make UAPs a reality, researchers and developers are therefore working on improved autonomy sensors and smarter autonomous systems to handle the complexity of urban waterways, as well as remote control centres (ROC) where human operators can monitor the UAP's status and intention and intervene if necessary. There are also ongoing efforts in making the autonomy transparent for the passengers onboard through information screens and automated speech messages [18].

One overlooked research challenge is the communication between the UAP and actors in the environment it operates in. Today, human-operated ships use a range of communication methods to display their status and future intentions to nearby ships to avoid deadlocks, dangerous situations, and collisions. With methods and tools such as waving and shouting, distinct course changes and navigation lights, radio and Automatic Identification Systems (AIS), they ensure safe navigation and resilient operation. However, autonomous ships are currently only able to understand and express a few of these communication methods [1], and are therefore like a silent pantomime, only able to display their status and actions through course changes and use of navigation lights. This makes them more or less unable to communicate efficiently with other ships, in particular leisure boats, kayaks, and other smaller ships, which rarely have electronic communication equipment onboard.

We hypothesise that an urban autonomous passenger ferry (or any autonomous ship) needs to be capable of interacting with nearby ships and vessels by clearly displaying what it is currently thinking, what its future intention is, and that it is aware of its surroundings. The aim of this paper is to propose an external human machine-interface (eHMI) for a UAP that can communicate its current status, perception, future intention, and advice to the navigators onboard nearby ships, boats, and kayaks, as well as bystanders onboard these ships or on shore. We start by showing the case of urban autonomous waterborne mobility. Then, we define eHMI and show examples of how eHMIs are used by car manufacturers on autonomous vehicles. Further, we present the concept UAP *Zwipp*, and how we designed an eHMI for it. We then go into detail on how we used the eHMI to communicate 13 distinct messages of the ferry. Lastly, we present the evaluation of the eHMI.

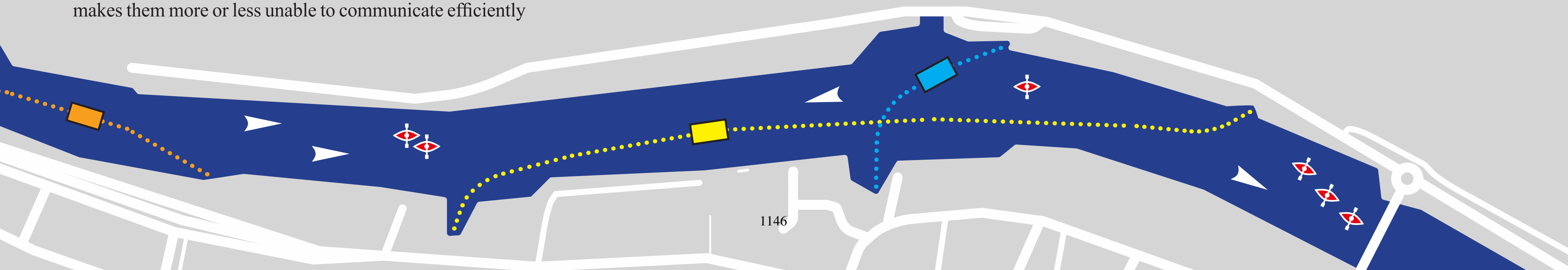
URBAN AUTONOMOUS WATERBORNE MOBILITY

Humanity's first civilizations were created around rivers [16]. Today, around 40% of all people live in coastal areas [20], and the possibilities of urban waterways have been rediscovered across the world [2]. Many cities now see the potential for moving traffic from congested roads and bridges to almost empty waterways with autonomous passenger ferries [23]. The ferries can remove the need for expensive and inflexible tunnels and bridges, and offer a car-free alternative that can work as a supplement to trains, buses, bikes, and other urban mobility options [25].

Urban autonomous passenger ferries and their area of operation

Urban autonomous passenger ferries (UAPs) are designed to be self-driving; they can operate without a human captain onboard. However, this does not mean that they necessarily operate without a crew; some ferries are designed to have a safety host onboard to handle passengers and as an extra safety measure. Other UAPs can be remotely monitored by operators located in a Remote Operation Centre (ROC) where they can take over control if needed. The ferries are equipped with a range of advanced sensors – such as LIDAR, radar, cameras, infrared cameras and ultrasonic distance sensors – to detect other boats, objects and land [4]. They also have high connectivity to the ROC, as well as powerful computers running advanced autonomy systems that allow them to safely and efficiently navigate between their destinations in complex urban waterways. Since the ferries often have an electric driveline, they offer a convenient, silent and environmentally friendly alternative to traditional modes of transportation, and are increasingly being used to solve mobility challenges in cities around the world.

One of the specific use cases for UAPs are river, canal or harbour basin crossings. Their flexibility makes them a feasible alternative to permanent constructions such as bridges and underwater tunnels, which have a high cost, high environmental footprint, take up much space, and can not be relocated when built. Further, UAPs can create new shortcuts, connect new parts of the city, and move traffic from congested roads to underutilised waterways.



Stakeholders of urban autonomous passenger ferries

The stakeholders of autonomous ships are more than its operator and passengers. Veitch and Alsos [28] identified 5 groups of stakeholders of autonomous ships that need to know how the ship is performing; developers, primary users, secondary users, organisations, and regulatory bodies. In this article, the primary and secondary users are in focus. Primary users are the ferry's operator, crew, and passengers. Secondary users are ships, sailboats, leisure boats, fishing boats, ferries, cruise ships, kayaks, and all other marine traffic in proximity to the autonomous ship. All these stakeholders need information concerning the state and intention of the autonomous ship to be able to safely navigate in its vicinity. Even bystanders, such as waiting passengers, are secondary users who need to relate to the ship, for example when to board it. It is important to note that most of these boats and vessels fall under the category of non-SOLAS (The International Convention for the Safety of Life at Sea). Such vessels carry minimal equipment on board capable of maritime communication [1]. Therefore, secondary users can only experience the system by observing its behaviour or by getting a direct response from the system's operator [11].

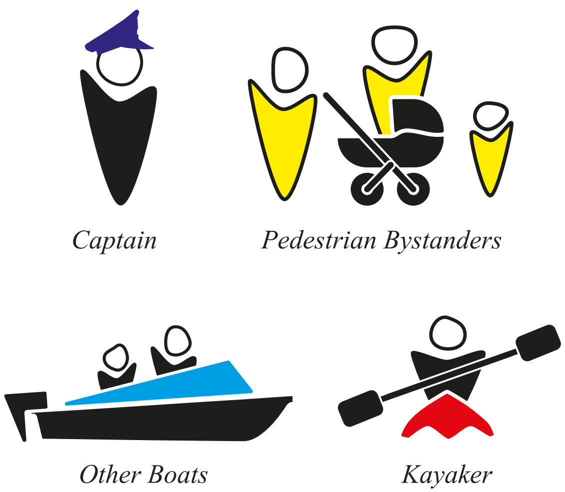


Figure 3. Stakeholders of urban autonomous passenger ferries.

Maritime regulations and solutions

Maritime regulations include the Convention on the International Regulations for Preventing Collision at Sea (COLREG). This is a set of rules that apply to all vessels on water, regardless of size, and they need to be followed to ensure safety at sea. In short, COLREGs regulate who should yield for whom, how lights, shapes and signals should be used, how course changes should be done, and much more. Often, skilled seafarers perform distinct course or speed changes – or in some cases adjust their course slightly to show or hide their side lanterns to other ships – to communicate their state and intention to nearby ships. To be on the safe side, they often use Very High Frequency (VHF) radio to communicate their intention and to resolve misunderstandings to ensure a smooth traffic flow and to avoid dangerous situations.

The challenge with UAPs is that they often operate in areas with non-SOLAS vessels, such as leisure crafts, small sailboats, and kayaks, that are not familiar with the "rules of the sea" [19]. These users lack the knowledge and the nautical experience necessary to adhere to the COLREGs. Additionally, if the person in charge of the boat tries to communicate with the UAP through eye contact, waving hands or shouting, they will soon find out there is no human operating the ferry. This begs the question of which actions need to be taken to safely resolve the crossing predicament.

On the other hand, if a skilled seafarer encounters the UAP and is aware and knowledgeable of COLREGs to address a crossing situation, they might be unsure if the autonomous vessel is COLREG compliant. How might one know if the autonomous vessel will act as a human seafarer would? This calls for ways for the UAP to communicate its state and intention to nearby ships.

COLREGS RULE 15

When two power-driven vessels are crossing so as to involve risk of collision, the vessel which has the other on her own starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel.

Maritime communication

In the maritime domain, there are a number of ways for vessels to communicate. Alsos et al. [1] presented and analysed different methods of maritime communication. This study showed that non-SOLAS vessels (such as leisure crafts, boats and kayaks) and autonomous ships have a limited ability to communicate with each other. Non-SOLAS vessels often do not have the proper equipment for electronic communication (such as radio communication, AIS, VDES) nor proper navigation lights. Autonomous ships, on the other hand, cannot handle analogue means of communication, such as waving, shouting, day shapes, flag signals, search lights, and fog horns. Further, autonomous ships are currently not able to communicate on the radio, but are dependent on a human operator to do that for them. Therefore, the only certain way autonomous ships and smaller boats and kayaks can communicate is through distinct course and speed changes. Consequently, there is a need for an additional way of making the state and intention of autonomous ships transparent to their surroundings – their automation needs to be transparent.

AUTOMATION TRANSPARENCY AND EXPLAINABLE AI

The autonomy sensors and the autonomous system with its algorithms are essential for safe and resilient operation of UAPs. One of the challenges with these systems is that they are inherently complex. This complexity makes their inner workings and decisions partly inaccessible and opaque for the remote operators of the systems, not to mention the onboard safety hosts, crew, passengers and nearby ships [10,28]. To make it easy for the remote operator (or onboard safety host) to know when the UAP's sensors and system fail – for example by sensing false tracks or taking hazardous decisions – the autonomy system needs to provide a clear and transparent explanation of their decision-making processes and outcomes. This is often referred to as Explainable AI (XAI), or in the context of autonomous ships and robotics, Automation Transparency [1]. The ultimate goal of XAI and automation transparency is to increase the trust and accountability of AI and autonomous systems, in particular safety critical systems such as operating an UAP full of passengers in a complex urban environment.

EXTERNAL HUMAN MACHINE INTERFACE (EHMI)

External Human Machine Interface (eHMI) is a term coined by the automotive industry [29]. It is defined as an interface mounted on or protruding from a vehicle's exterior that can communicate with other vehicles or vulnerable road users (VRUs), such as pedestrians or cyclists. Examples of highly standardised eHMI implementations (also required by law) include indicators and brake lights [3]. For autonomous vehicles (AV) many car manufacturers are currently researching and experimenting with external interfaces to communicate the AV's status, behaviour and intention to other vehicles and VRUs to avoid misunderstandings, prevent dangerous situations, and to increase the VRUs' trust towards the AVs [3]. Examples of eHMIs are shown on page 5.

Likewise, ships have legal requirements for navigation lights, day signals or flags to show nearby traffic their status and intention. Examples include side lanterns to show their sailing direction during night sailing, day signals to show that they are fishing, or flags to show that there are divers in the water. For restricted urban waterways, these signals are not enough. Eye contact, waving and shouts are important signals used to maintain traffic flow and prevent dangerous situations. Unfortunately, UAP cannot interpret these signals. Therefore, there is a need for additional eHMIs.

There are several similarities between urban roads and urban waterways: Both (1) are complex environments, (2) have users with highly varying expertise and safety culture, (3) have vulnerable users, and (4) have users who react on the explicit signals (such as brake lights or honks) or silent signals (such as eye-contact or speed reductions) that other road users send out. However, there are also some dissimilarities; for urban waterways, speeds are lower, the traffic density is lower, and distances between users are longer. Despite these differences, the similarities argue for eHMIs also for urban autonomous passenger ferries that operate in urban waterways. For autonomous ships, there are currently very few examples of eHMIs, with one exception [19] (see Figure 10.). Consequently, we take inspiration from the automotive industry when look for candidate eHMIs for UAPs.

eHMI communication categories

What should be communicated through an eHMI for a UAP? Looking towards the car industry, Schieben et al. [20] presents 4 distinct eHMI communication categories for AVs. These categories include communicating the AV's (1) **status**, i.e. how the vehicle is currently operated; autonomously, manually, or remotely controlled, (2) **perception**, i.e. showing bystanders that the vehicle is aware in its immediate surroundings, (3) **intent**, i.e. showing what it is going to do, for example stopping for a pedestrian, and (4) **advice**, i.e. an instruction to other participants of traffic on how they need to act.

In a research study by Faas et al. [9], combinations of these concepts were evaluated. Using an on-road real-world crossing scenario and a modified car with an added light-based eHMI, the study measured participants' perceived cognitive trust, affective trust, perceived safety, user experience, perceived intelligence, and transparency. The evaluated eHMIs included (1) Status, (2) Status + Perception, (3) Status + Intent, or (4) Status + Perception + Intent. The results showed that all of these options had a positive impact on the user's overall experience, and the presence of any eHMI had an impact on the perceived safety and trust towards the Self-Driving Vehicle (SDV). However, this research also demonstrated that including perception in the eHMI design does not generate any value in the interaction. Not only had pedestrians seen the act of showing perception as an obvious capability of an AV, but including it had a negative effect which caused distraction and slowed down the traffic flow.

Approach to communication

The communication between the AV and the secondary user can either be allocentric or egocentric [5]. The allocentric approach, from the vehicle's Point of View (POV), implies that the ferry instructs other traffic participants on which actions to take. For example, the eHMI could display text messages such as *Please move, go ahead, stop, or wait*. However, if an autonomous vessel meets more than one secondary user, it cannot instruct all of them simultaneously; one message intended for all secondary users could cause confusion, uncertainty, and accidents. Possibly, the eHMI design needs to be scalable in a way that AVs can give separate messages to several secondary users. Moreover, recent research states that autonomous vehicles should not give explicit instructions to others [13]. In case of a casualty the instruction can be viewed as an explicit order the vehicle has given to the secondary user, putting in question who is liable.

On the other hand, an egocentric approach, from the vehicle's POV, has been agreed upon as more coherent [24]. This perspective creates an identity for the AV. To illustrate, the ferry would communicate its own intentions: *I am stopping, I am waiting for you to pass first, I will be going first*. In this setting, conditions remain the same for all secondary users, assuming the AI takes all of the surroundings into account. As a whole, secondary users should make decisions on their own, while the autonomous ferry should only ever display its own intent. As previously stated, whatever the AV chooses to display, users will try to confirm their assumption through the vehicle's movement and behaviour.

Modes of communication through eHMIs

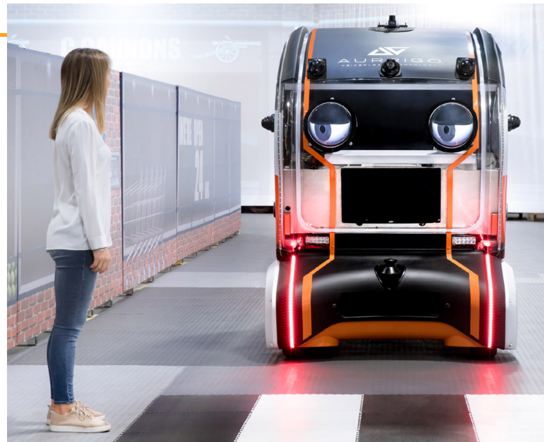
Text, symbols and lights in eHMIs can display information that could help users discern what the status and intent of the AV is [5]. Text is unambiguous and easily interpretable. However, children, visually impaired, illiterates, or people who do not know the language, will have challenges interpreting the eHMI. One way to reduce these challenges is to display symbols on the eHMI. Symbols can exceed the language barrier and be effective across cultures. In addition, symbols are accurate and legible from a distance but require learning. Finally, lights and light animation patterns can be used to convey a message. Their application can be made fairly simple, but result in an abstract way of communication. Dey et al [7] points out how users prefer uniform patterns (flash, pulse) as opposed to sweeping ones when it comes to road-going AVs.

Regardless of what the eHMI displays, the behaviour of the vessel needs to reflect its intentions. A paper by Dey et al [7] points out that users always try to confirm the alleged information coming through a communication channel with the actual movement of the vehicle. For example, if a UAP displays the text *I will stop* the ferry must slow down to a stop, thus validate the displayed intention of the system. Research also suggests that an AV should act passively, without aggression in its behaviour and movements [7]. Even if it contradicts maritime regulations, it should not try to exert control over the situation; instead, it should act in an adaptive manner and try to stay compliant [7,1].

The colour of the eHMI lights used to communicate is important as well. It is imperative that the light colour used for the scenario of UAPs does not interfere with any other colours that already have a meaning for users. Green, red and yellow lights are already used on the roads in traffic lights or to direct traffic, and their meaning should not change when moving onto waterways. Most research agrees that cyan blue / turquoise is the colour that should be used when displaying that a vehicle is indeed an autonomous one [5, 7, 27, 32]. Based on the above, we hypothesise that messages displayed using eHMIs should be easy to learn, clear, unambiguous, standardised, and avoid uncertain outcomes.

Examples of eHMI's

Figure 4.



Jaguar Land Rover autonomous concept utilising eyes to create contact with the pedestrian. Lights below the eyes turn green or red depending if the vehicle is moving or stopping. Anthropomorphism, the attribution of human characteristics or behaviour to an object, can be used as a technique on AV's, as pedestrians often try to establish eye contact with the driver. It makes the interaction feel more human, creating a better relationship between subjects [12].

Figure 5.

Nissan IDS concept using cyan-coloured text written behind the windshield applying both an egocentric and allocentric approach in one phrase [17].

Figure 6.

Volvo 360c concept uses a light strip to communicate its perception to secondary users. It also utilises directional sound to signal and grab pedestrians' attention, when needed [31].

Figure 7.

Mercedes-Benz F015 Concept uses projections to instruct a pedestrian, like STOP text in place where the person should stop. It can also display zebra crossing and other icons that can help in the interaction [14].

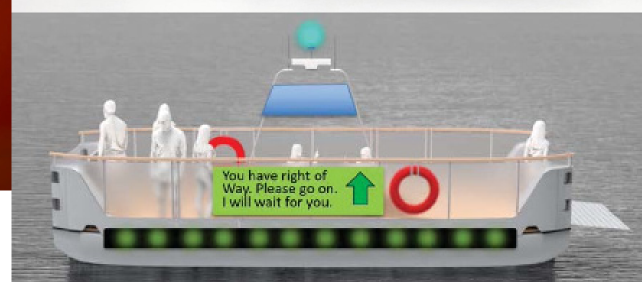
Figure 8.

Mercedes-Benz AVTR Concept vehicle has 33 scales mounted on the roofline. Named Bionic Flaps, these elements move to show the direction the vehicle is turning in. Additionally, when the vehicle is accelerating or slowing down the flaps pivot, while also being illuminated by a blue or red coloured light [15].

Figure 9.

Volkswagen's concept using screens to display symbols in an attempt to communicate with pedestrians. It also has a 360 degree light strip around the body of the vehicle for signalling through animated light concepts [30].

Figure 10.



A concept designed by Porathe [19] for a UAP. It uses a screen to display text and a symbol. A light strip is placed below the display, while the masthead shines a turquoise light signal, indicating the ferry is operated autonomously.

THE URBAN AUTONOMOUS PASSENGER FERRY ZWIPP

In 2022, as a part of the project Scalable Autonomy for Urban Passenger Ferries (SCAPE), a concept UAP for urban mobility was designed by a team of three graduate industrial design students and their academic supervisors from the Norwegian University of Science and Technology (NTNU). The project was done in close collaboration with the NTNU spin-off Zeabuz, a company specialising in autonomous technology to revitalise urban waterways. The ferry's design was built on the knowledge and experiences from previous UAP projects, the milliAmpere 1 and 2 [4], which were two of the world's earliest prototype UAPs demonstrated. The purpose was not to design a ferry for production, but to challenge current ferry designs and be an inspiration for current and future ferries built by the company. The concept ferry, named ZWIPP, considered the entire ferry design including hull, superstructure, interior, passenger flow, and passenger information, as well as how the ferry communicated with the environment through an eHMI [6] . It is outside the scope of this paper to describe all the details of the design process and the result. However, for this pictorial we present the final design of the ferry and describe in detail the design of the eHMI. The vessel is 12 metres long, intended for 12 passengers and is based on the *small waterplane area twin hull* (SWATH). It is made out of aluminium and during operation it gives the appearance of floating above the water. Sensors are integrated into the hull and are almost invisible to the surroundings. Besides being designed with 2 planes of symmetry, it is bidirectional.

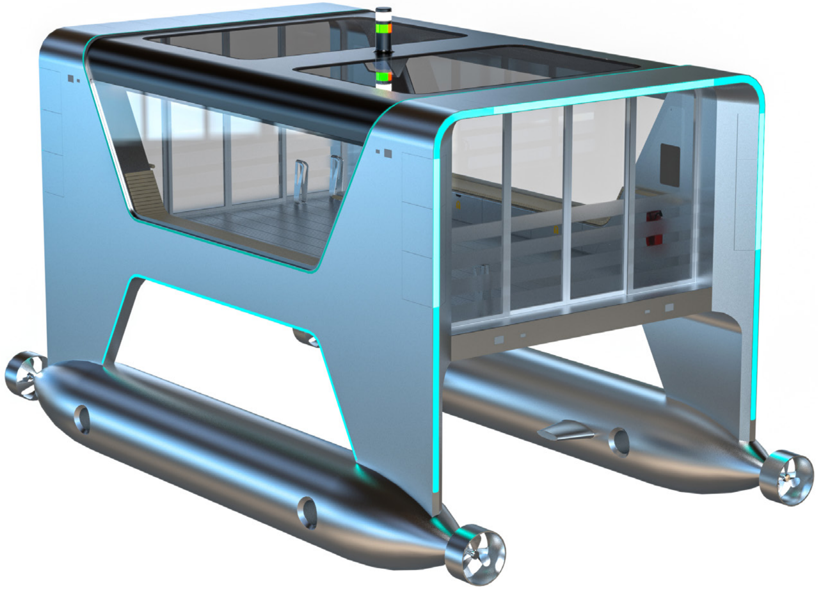


Figure 11.

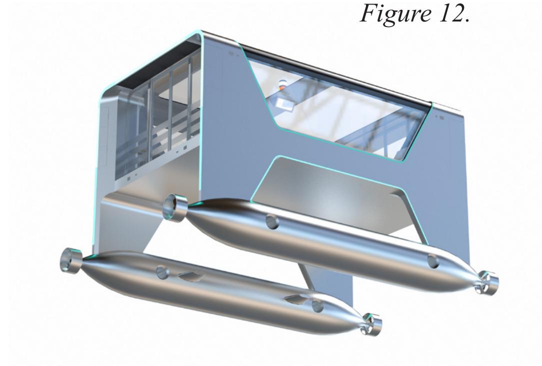


Figure 12.

Figure 13.

Figure 14.

FERRY'S EHMI DESIGN

In parallel with the design of the ZWIPP ferry, we developed the following design brief:

Design an external human-machine user interface that can communicate to nearby ships, boats and kayaks what the autonomous ferry is doing and planning to do.

Additionally, based on the design brief, the following research question was developed.

How can an eHMI for a UAP be designed to communicate XAI to primary and secondary users?

Inspired by the car industry, as well as how seafarers read the status and intention out of the movements of approaching ships, we had the idea of combining physical moving parts on the exterior of the vessel with displays and lights. Only relying on a display for the eHMI inhabits the compromises of a display, such as glare, resolution or shape. By including the physical dimension, mimicking a movement of stopping or accelerating, we hypothesised that the eHMI could intensify the message, resulting in more trust, better user responses and an overall increase in safety. However, establishing a non-verbal method equally or more effectively than text seemed very hard. As this project was part of a bigger task of creating a completely new autonomous ferry concept, the eHMI needed to be tailor made to the shape and design in the envisioned ZWIPP concept.

Communication Cases

Assessing the case of an UAP operating in urban waterways, we identified 13 unique messages that could be displayed through the eHMI to nearby boats (e.g. autonomous mode or distress). The messages were developed through an ideation process and on previous conceptual work on the milliAmpere2 ferry [22]. The messages are presented in Table 1 and categorised according to Schieben et al. [21] (status, perception, intent, and advice).

N	Case	Status	Perception	Intent	Advice
1	The ferry is in autonomous mode.	●			
2	The ferry is in manual mode.	●			
3	The ferry is docking.	●		●	
4	The ferry is in distress mode.	●			
5	The ferry is attracting attention to itself.	●			
6	The ferry is performing a turn.			●	
7	ww			●	
8	The ferry is slowing down.			●	
9	The ferry is performing an emergency stop.			●	
10	The ferry is showing its direction of movement.			●	
11	The ferry perceives a secondary user.		●		
12	The ferry goes first, while the secondary user has to wait.		●	●	●
13	The secondary user goes first, while the ferry waits for them to pass.		●	●	●

Table 1.

Design of the eHMI concepts

In the iterative design process of creating an eHMI that could communicate the 13 messages presented above, a number of preliminary concepts were designed. During the user-centered design process, users were actively involved by being invited to see, discuss, and sketch design solutions, allowing for their input and feedback to be incorporated into the design [6]. The ferry and the concepts were first developed through hand-drawn sketches, then modeled in the CAD program Fusion 360, and at last rendered and animated in an open environment in KeyShot. This demonstrated how the messages could be communicated to actors in the environment. This eHMI design focuses on visual opportunities for communication. Auditory modalities, such as alarms, signal sounds, horns etc. were are not considered in this study, although they offer another channel for interaction.

The optimal position for the eHMI was also considered. Since the ferry's design resembles a cuboid, placing an eHMI on the sides of the superstructure could have resulted in secondary users not seeing the message, if not perpendicular to the surface. Thus, corners were decided as the position of the eHMI. The final concepts delivered the messages through (1) screens to display words and symbols, (2) moving panels of the ferry's superstructure, and (3) light signals along the superstructure. The iterative design process resulted in 12 animations, which were then used for testing.

All of them can be seen in action here (**Miro**):
https://miro.com/app/board/uXjVOwQQ3Ew=/

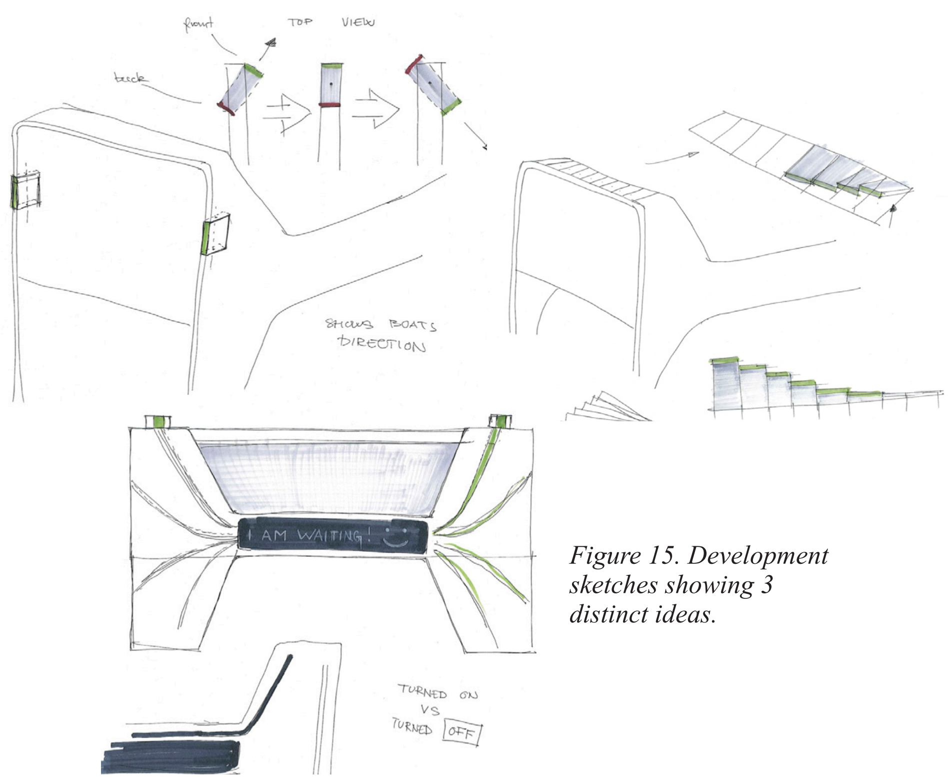


Figure 15. Development sketches showing 3 distinct ideas.

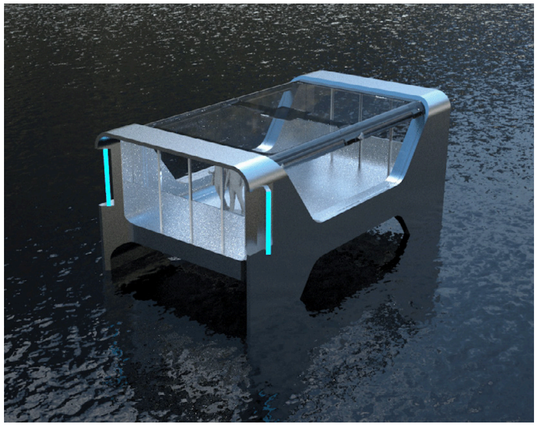


Figure 16. Idea of using parts of the superstructure to point in the direction the ferry is moving in.

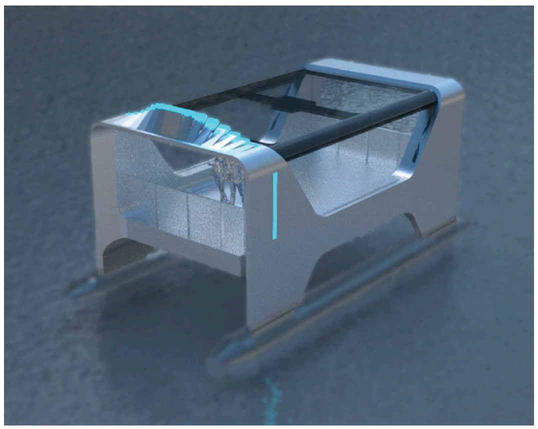


Figure 17. Idea of communicating perception by moving a dynamic set of elements.

Figure 18. Communicating intent by displaying text on a side mounted screen.

Evaluating eHMI concepts

To evaluate the eHMI designs we developed two web-based forms and recruited participants to perform an online survey. Participants used for the survey were students, and their detailed demographic information was not collected due to General Data Protection Regulation (GDPR). However, participants were asked if they have (1) a design education background, or (2) any type of visual disability, such as color blindness, low vision, etc. The participants were asked to take the point of view of a kayaker. In the first evaluation, 20 participants were presented with 10 3D animations from the kayak's POV displaying eHMI solutions, one at a time, together with 3 candidate statements describing what the boat was signalling. The used animations were 1, 3-7, 9-12, from the Miro Board. Their task was to rate their agreement to the statements on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). 3 participants reported a visual disability (astigmatism, partial sight, low vision). A 5 point Likert scale was used as it has previously been used in research regarding automation transparency [7]. In addition, there was also a blank field for a short answer text, where the participant could express what they thought the signal meant if they found none of the provided statements fitting.

In the second test 25 new participants were given a statement (e.g. "the boat is signalling that it is speeding up") and then presented with 3 different animations. The second survey used animations 1-12 from the Miro Board. For each animation, participants rated on a 5-point Likert scale (as above) to what extent the statement could be understood from the presented animation.

The evaluation was done this way for three reasons. First, to place the user, or in this case, the kayaker, in the position of the designer, allowing them to choose a design best fitting for a particular eHMI message. Second, we wanted to find out if there was a consensus among the participants on which design best fits the statement. Lastly, we wanted to confirm or deny the results from the first test, to see if participant chosen statements from the animation also get chosen as the animation from the statement.

The most important results of the two user evaluations were that signals which do not use the textual channel were open to unlimited interpretation. For users, the moving parts of the superstructure trying to convey a message resulted in having an arbitrary meaning. Some users responses included: "I would stop as I do not understand it"; "The boat is dancing"; "I am not sure about the meaning". Due to the vastness of material regarding the evaluation, full results can be found in Claes et al. [6].

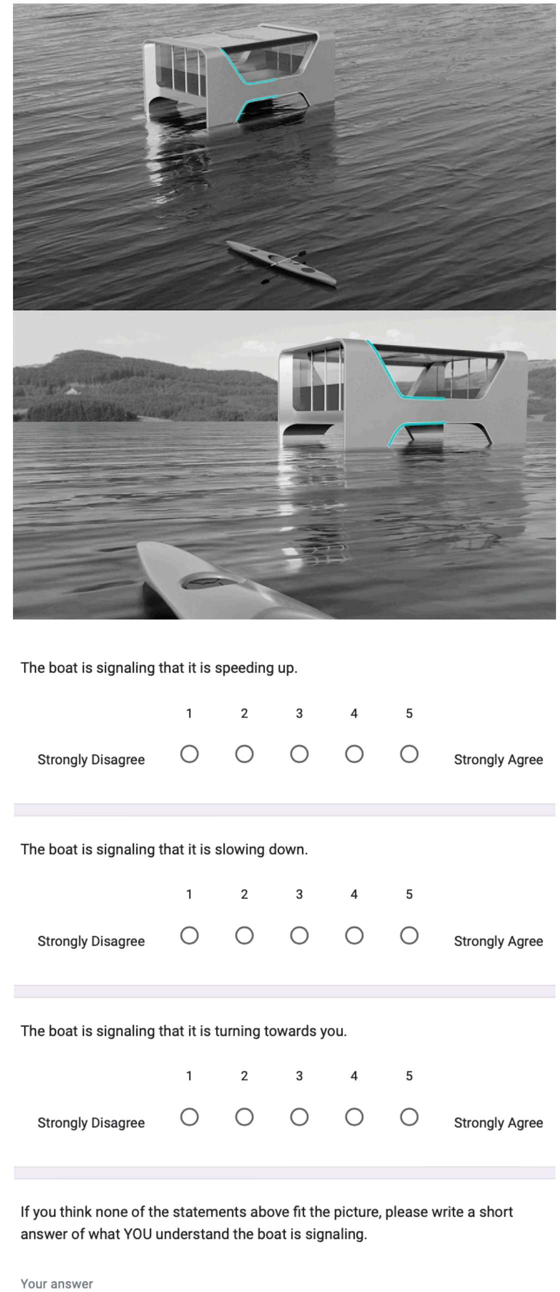


Figure 19. Example screenshot from one of the animations and questions used in the test with users. In the GIF version of the question, the turquoise light pulses on and off.

On the other hand, when displaying pure text on a screen the participants reached complete consensus on what the meaning of the message was.

It is important to note that this test has a number of drawbacks which makes the results from these surveys vague. Offering closed questions limited the interpretation of offered answers and animations. The collected answers to the survey indicated that designs which do not use text for conveying information have essentially no consensus on what they mean, and each user creates a meaning for themselves. This inspired the final design of the eHMI for a UAP to include unambiguous forms of communication such as text, while supplementing less critical cases with other modes, such as light and movement.

Final eHMI design

Based on the evaluations we iterated on the eHMI design and ended up with a solution with a combination of (1) screens to display words and symbols in the front and on the corners, (2) moving panel on the ferry's superstructure, and (3) light signals along the superstructure. Iterative changes were made based on user feedback from the evaluations, as well as our own observations and design goals. This design was chosen as it provides much flexibility, not only for establishing an eHMI, but also for future development of the eHMI. The main goal for combining movement, lights and screens into one eHMI was to provide redundancy during signalling. Although advantageous, this should be used carefully as it can easily result in cognitive overload, thus reducing the effectiveness of communication between the ferry and the secondary user. A way of doing that, for example, would be to use one part of the eHMI to display status, another one for perception and the third one for intent (light, movement, text-on-screen).

The design is symmetrical on both sides of the boat and it consists of 24 adjustable panels capable of rotating depending on the given situation. The top of the eHMI is a set of 6 panels that can be individually rotated, resembling a piano. When not in use the panels sit flush with the rest of the body's shape and are only activated when it is needed. To make this possible, the top of each panel is made out of aluminium. The front portion of the panel houses a light strip that can display any colour in the RGB spectrum. The bottom of the panels houses a screen that is hidden from plain sight when not in use. When needed, individual panels can be rotated any number of degrees, either to display a movement or to expose the screen and display text or symbols to nearby traffic. This shape-changing eHMI has been designed as movement based interfaces have been shown to be more to be more understandable and intuitive than conventional approaches [8].

The 3 panels placed on each corner follow a similar formula. They have the shape of a prism to match the contours of the boat's design. Two of the three panel surfaces match the rest of the exterior, while the third surface, hidden when not in use, is a screen that can be exposed by rotating the prisms around. These prism-shaped panels also serve another purpose, which is to point in the direction of the boat's trajectory, showing users in the environment the direction where it is heading. Additionally, light strips are integrated and follow the contour of the ferry's design, highlighting its dimensions. They wrap around the complete superstructure creating a continuous piece of illumination.

This eHMI design is a result of understanding the needs for what must be displayed and when, while still flexible enough to be discreetly hidden from plain sight and integrated into the simplicity of the vessel's design. Its flexibility allows the eHMI to have a variety of ways of displaying a message, increasing the chance that the secondary users will understand the message. This flexibility also enables certain communication conditions to be exclusive to one part of the eHMI, making it possible to display multiple meanings at the same time. For example, this can be used to simultaneously show the boat is changing the direction it is moving in, as well as displaying that it has noticed a secondary user. In case multiple secondary users are interacting with the ferry in different positions around it, each corner can communicate with that user independently. The eHMI is still flexible enough to be discreetly hidden from plain sight when not in use, and integrated into the vessel's design. Off-loading the ferry's non-critical intent to more ambiguous parts of the eHMI (like lights and movement) was the way to ensure unequivocally perceived parts of the interface were available for crucial situations.

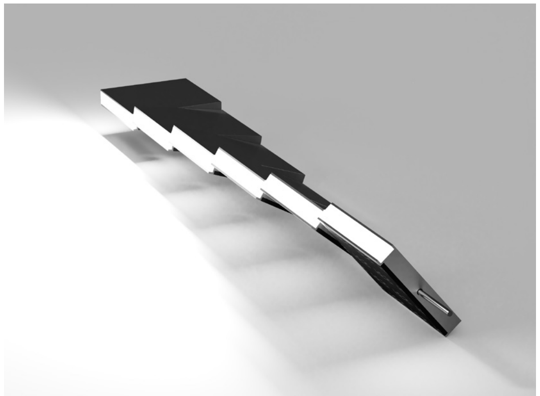


Figure 20.

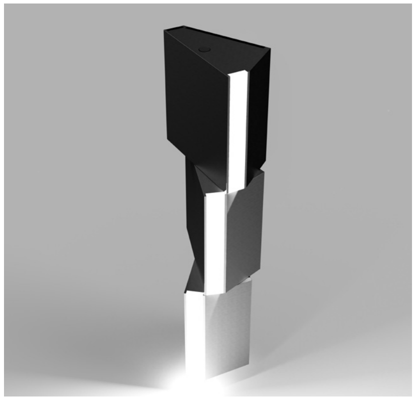
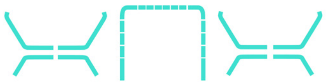


Figure 21.

Panels on top and sides of the ferry. The top of the ferry has 6 panels, while the corners have 3. Each one can individually rotate to expose a screen. The front of the panel houses an RGB LED light strip.

EHMI STATES

The design space of this eHMI is large, but considering previously outlined communication messages, the following list of solutions was designed. Animation of the implementation can be seen in a short video on the provided link (**Youtube**): https://youtu.be/Mqcevf4T5YQ
We highly advise the reader to watch the film as graphics in the text are merely a static representation and do not tell the whole story.



1 The ferry is in autonomous mode.
All lights glow turquoise.

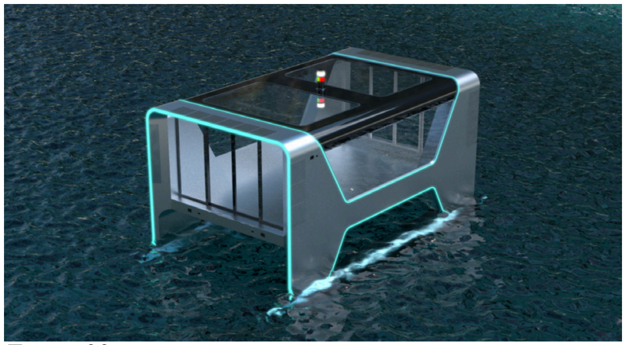
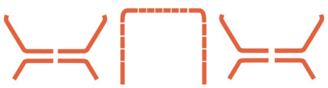


Figure 22.



2 The ferry is in manual mode.
All lights glow orange. Orange is a complimentary colour to turquoise in the RYB colour model.

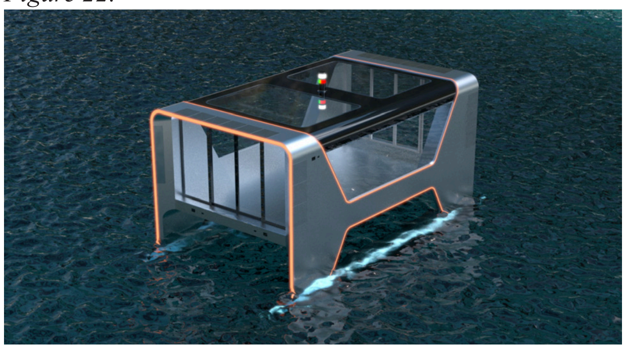
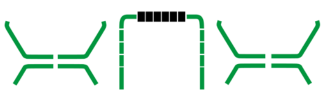


Figure 23.



3 The ferry is docking.
All lights pulse turquoise. The top panels move in a sequence starting from the inside out. When the docking procedure is complete all lights turn green and the word DOCKED appears on the top display.

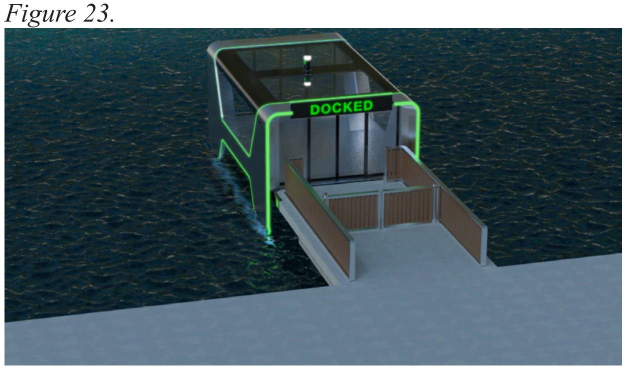


Figure 24.

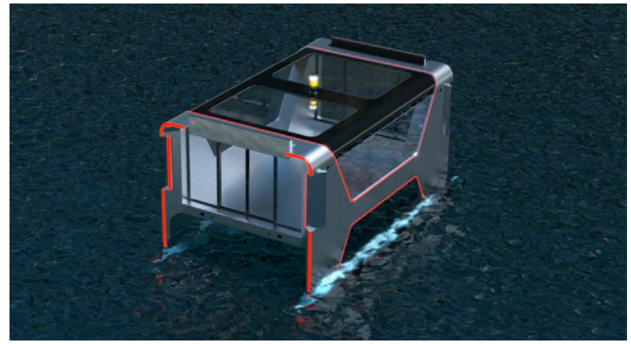
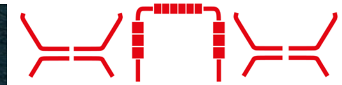


Figure 25.



4 The ferry is in distress mode.
All lights pulse red, the side panels move left to right while the top panels move up and down.

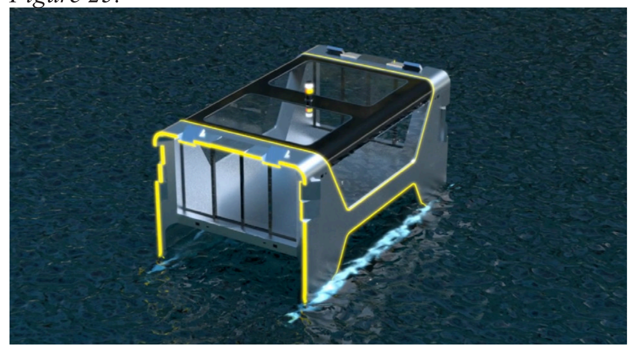


Figure 26.

5 The ferry is attracting attention to itself.
All lights pulse yellow, the top panels and the side panels create one complete sequence which starts from the middle going out.

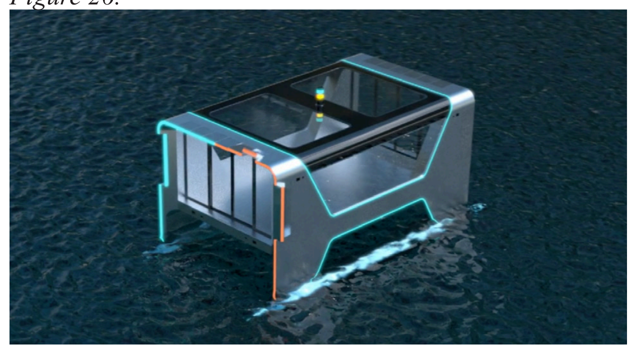
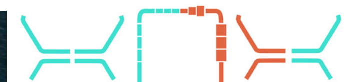


Figure 27.



6 The ferry is performing a turn.
The front 3 panels point in the direction of movement and the turn while blinking orange, very similarly to a car. One half of the top panels also blink orange while moving from inside out.

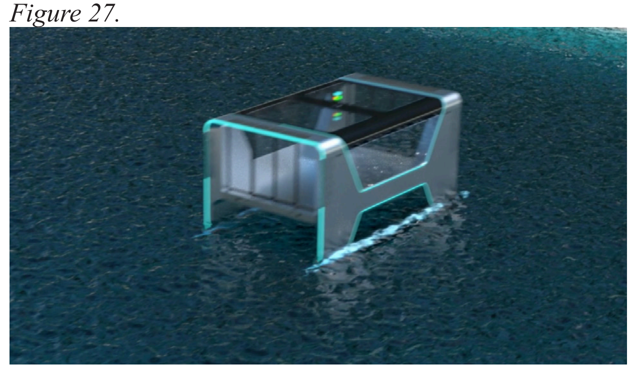
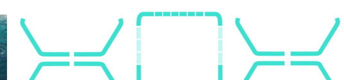


Figure 28.



7 The ferry is speeding up.
The panel parts of the front lights pulse while the ferry is accelerating.

8 The ferry is slowing down.
The bottom parts of the side lights pulse.

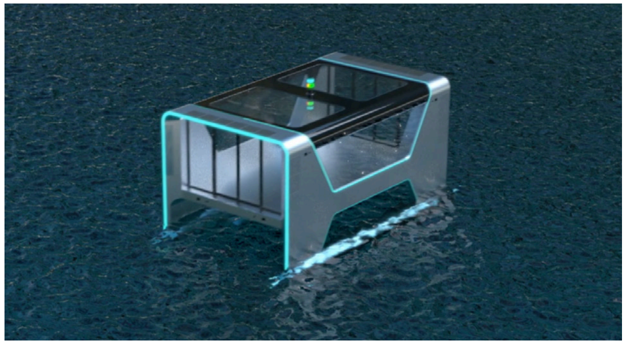
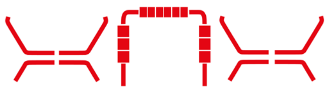


Figure 29.



9 The ferry is performing an emergency stop.
The side and top panels point inward, simultaneously. This idea is meant to remind people of aeroplane flaps during braking. The lights flash red.

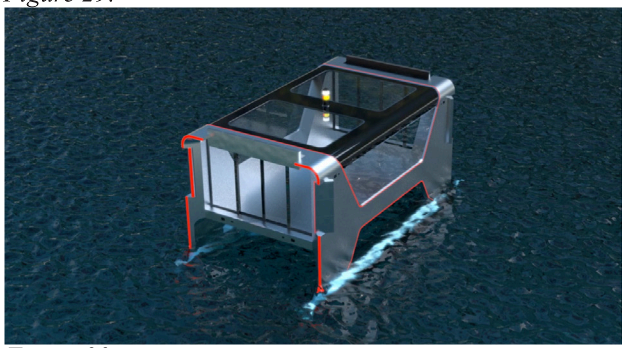
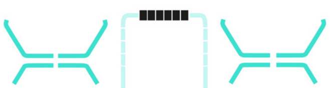


Figure 30.



10A The ferry percieves a secondary user.
When the user is in front of the ferry, the top panels rotate to expose a screen and display a message: I SEE YOU, following up with a smiley face. The whole front of the vessel pulses turquoise.

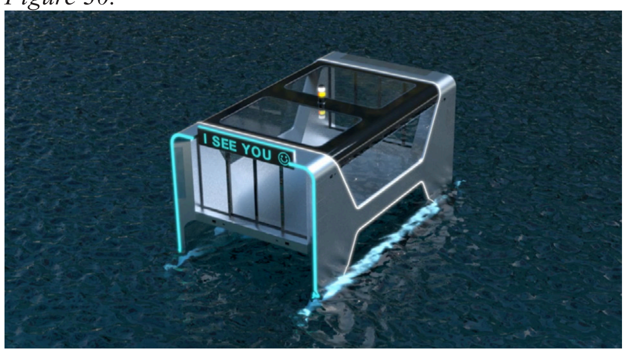
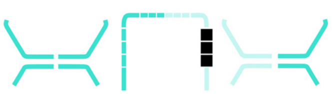


Figure 31.



10B The ferry percieves a secondary user.
When the user is on the side of the ferry, the closest panels turn to a screen and display a message: I SEE YOU, following up with a smiley face. The quarter closest to the user pulses turquoise.

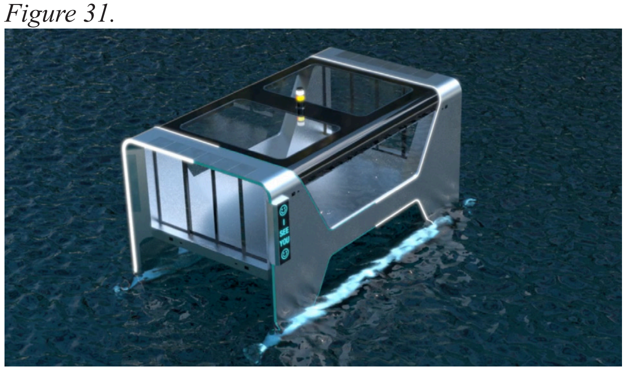


Figure 32.

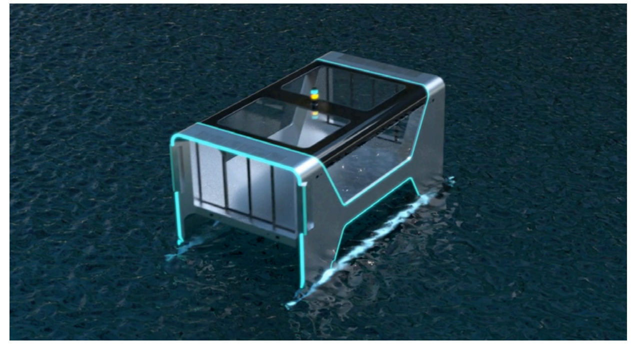
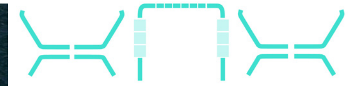


Figure 33.



11 The ferry is showing its direction of movement
The side panels point in the direction the ferry is going in. Those panels also glow turquoise.

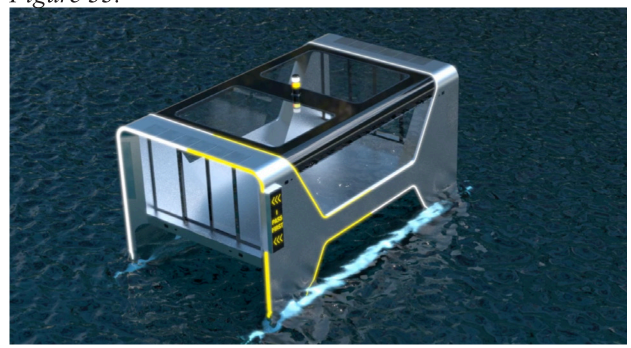
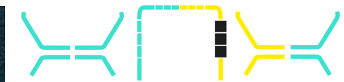


Figure 34.



12 The ferry goes first, while the secondary user has to wait.
The quarter of the ferry starts pulsing yellow. The panels closest to the user, rotate to a screen displaying a message I CROSS FIRST. A symbol, in the shape of a pointed arrow is also included, showing the direction the boat will be moving in.

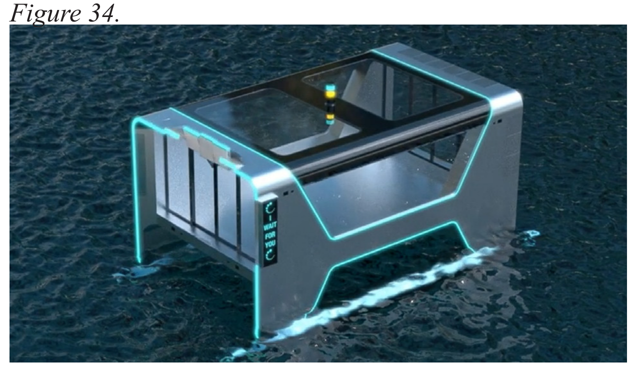
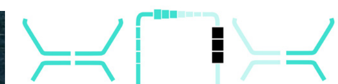


Figure 35.



13 The secondary user goes first, while the ferry waits for them to pass.
The quarter closest to the user pulses turquoise. The top panels move sequentially. The corner panels rotate, transforming into a screen and displaying a message: I WAIT FOR YOU. A loading symbol is displayed.

The legibility of the displays depends on a number of factors, such as of viewing distance, size of the text, typeface, etc. We have used the text fonts Helvetica Neue Bold for the top panels and Helvetica Neue Condensed Bold for on the side panels since Helvetica is a widely recognized typeface and is rated as very legible. The condensed font was chosen for the side panels to fit the text within its dimensions. The letters on the top panels are around 30cm high, while the side panels are around 15cm high. The maximum viewable distance of the top panel is 84m, normal readability is 34m, and maximum impact is 17m. Further, the same viewing distances for the side panels are 46m, 18m, and 9m [26]. Because of this, only on those distances or smaller, it makes sense to display text on screen, as other scenarios would make the screens illegible. Light and movement however can be seen from much further distances (depending on the light intensity used) and should therefore be used accordingly.

DISCUSSION

Urban waterways are characterised by mixed traffic with highly diverse knowledge about the rules of the sea and often questionable safety culture. Therefore, urban autonomous passenger ferries need to be able to communicate their state, perception, future intent and advice to nearby ships, boats, kayakers and bystanders. This is important to ensure an efficient traffic flow and to prevent deadlocks, dangerous situations, and accidents. In this pictorial, we have proposed an eHMI design for the next generation of urban autonomous ferries that can efficiently communicate with the environment in which they operate.

In the domain of AVs, a range of creative eHMI solutions have been developed by different car manufacturers. At some point, the AV industry needs to converge towards a common standard for eHMIs. The nearby cars, pedestrians, and bystanders should not have to learn numerous ways of understanding the state and intention of the AV. The same holds for autonomous ships and ferries. However, eHMIs have to a very little extent been explored for autonomous ships, with one exception [19]. The proposed solution is therefore one of the first contributions to eHMI for autonomous ships and the first to implement movement as a way of communicating its state and intention.

The proposed eHMI offers a flexible platform for exploring various solutions and communication forms. However, to implement the design and to finetune the way messages are communicated, many rounds of design iterations and user evaluations are necessary. The design space of eHMI is large and can take countless shapes and forms. It must be understandable for its users.

Limitations

One of the limitations of the proposed solution is that it is only useful for nearby ships, boats, kayaks and bystanders at a relatively close distance (less than 100 metres). It is not suitable for open ocean or coastal waters, but only for urban waterways, such as rivers, canals, harbour basins, etc. For these areas of operation, other means of communication need to be developed, such as those proposed by Alsos et al. [1].

This pictorial's main limitation is that the eHMIs have only been evaluated as 3D animations. The next steps are to implement prototypes in VR and perform a user evaluation, then to implement a working eHMI prototype, install it on a test ferry and perform a user evaluation where ships, boats, kayakers, and other secondary users report on its effectiveness. In addition, current evaluation has only been done on preliminary design concepts, and not the final design. Future studies could address these limitations by using more comprehensive evaluation approaches that incorporate multiple measures and methods.

Another limitation is the omission of non-visual modalities, e.g. auditory. This eHMI design focuses on visual communication and as such does not use the potential benefits of sound (horns, music, voice commands, alarms, sirens). The feedback gained from the evaluation suggests that some of the message concepts were confusing or not clear enough for users, which could result in users having to spend more time learning how to interpret the messages. This could be a potential limitation of the proposed concept, as users should ideally be able to quickly and easily understand the state and intention of UAPs without having to spend a significant amount of time learning how to interpret the messages.

On the other hand, surveys with closed questions using predefined interpretations provided clear and unambiguous response options, making it easier to analyze and compare responses. They can also help to ensure that all participants are interpreting the questions in the same way. However, they may not capture the full range of possible responses or interpretations and may limit the depth of understanding that can be gained. Closed questions also do not fully capture the complexity or context of concepts such as automation transparency.

Potential

The eHMI designs presented in this paper are some of the earliest examples developed for urban waterborne transport. We see this as a beginning that will evolve as UAPs become a part of cityscapes around the world. The use of eHMIs in UAPs might eventually develop into a standard.

Improvement in technology is sure to accelerate the change in perspective when it comes to autonomous vehicles. Users will get more used to interacting with artificial intelligence while the manufacturers will get more input on what communication channels are more effective than others. Finally, the essence of the eHMI must succeed in clearly getting a message across to the user. Whilst the topic of eHMI's for autonomous ships is fairly unexplored, we hope this work may catch the attention of maritime designs and encourage them to research the topic further.

The maritime industry is conservative. It has a traditional set of directives and is sensitive to any possible changes in regulations. Consequently, we must challenge maritime regulations in order to advance the standards for eHMI for autonomous ships. Future research should explore new eHMIs and validate them in a real-world context.

It is imperative that designers, researchers, regulatory bodies, and users openly discuss the optimal answer, leaving no outcomes unanswered. The advantages of implementing an eHMI are certain, and several experiments have been conducted demonstrating that users feel safer and more confident. Therefore, we believe that eHMIs are an important element in successful autonomous transport solutions in general, and especially for autonomous ferries.

CONCLUSION

As autonomous passenger ferries start sailing urban waterways, there is a need for user interfaces which can communicate the vessels' status and future intention, not only to their operators and passengers, but also to nearby ships, boats, kayakers, and bystanders, who are not always are familiar with standard maritime rules. By including an eHMI which can communicate the ferry's status, perception, future intention and advice, it will be easier for secondary users to understand how to relate to the ferry.

In this pictorial, we have as a result of a user-centred design process, proposed an eHMI for ZWIPP, a small autonomous passenger ferry for urban waterways. The eHMI can communicate 13 messages through a combination of (1) screens to display words and symbols in the front and on the corners, (2) moving panels of the ferry's superstructure, and (3) light signals along the superstructure. This work can inform designers of autonomous vehicles and ships, in particular urban autonomous passenger ferries.

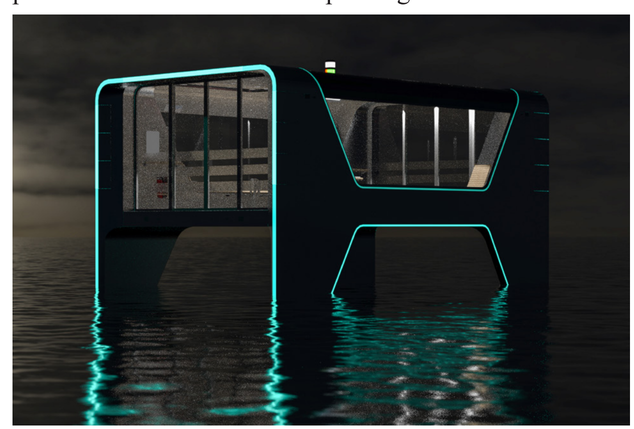


Figure 36.

ACKNOWLEDGEMENTS

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