Introducing a road interaction-focused approach towards autonomous driving cargo bikes as a new urban mobility offer

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Abstract – **The project AuRa (autonomes Rad, engl. autonomous bicycle) is motivated by the real-world problem of availability and accessibility of bicycles in bike-sharing schemes in urban environments. Autonomous driving offers completely new possibilities to overcome it. With autonomous cargo-bikes as an efficient and ecological mobility solution, we can take a big step towards mobility transition. However, one of the major challenges they will be facing is the ability to interact with other road users as the most vulnerable – pedestrians. Yet, especially in terms of bikes, few studies investigated the timely topic of interaction concepts for autonomous vehicles. With our research in progress, we aim to contribute to research on the interaction of humans and autonomous cargo-bikes and gain findings helpings us design a communication interface for the autonomous bike. To this end, we designed a road interaction-focused approach involving three scientific sections: computer science, design engineering, and environmental psychology. This paper is introducing the overall interdisciplinary approach design including a series of studies for developing an interaction concept via visual and auditive signaling for the autonomous bike. It presents the current research state and some first findings of the research practice.**

Keywords – **autonomous bicycle, interaction design, non-verbal communication, signaling urban, environment.**

I. Introduction

Bike-sharing is a good alternative for urban and climate-friendly mobility of the future - however, there are considerable obstacles to its use from the user's and operator's point of view. A frequent point of criticism is the distribution of bikes. They either take up many and sometimes large parking spaces and then must be redistributed again at great expense. A solution for this could lie in the technology of autonomous driving [1]. It is recently mainly focused on cars due to the expenses and technical requirements, but due to technological advances, it became a viable opportunity for smaller vehicles like cargo bikes. Autonomous cargo bikes would enable a green and smaller way of mobility that can highly reduce air pollution, energy consumption, space occupancy, and simultaneously allow the transportation of goods. We focus our research on the novel project AuRa aiming to realize this kind of mobility offer. As a brand-new development, the project faces lots of challenges for its successful implementation as ensuring safe operation in autonomous mode. Including the interaction with other entities in public space like pedestrians, cyclists and car drivers is a critical point. It is important to fulfill the need for mutual communication between the autonomous bike and others for them to feel safe and accept the vehicle as a good model for sustainable transport. To tackle this issue a sophisticated communication interface must be designed for the AuRa-bike. The goal for safe urban riding ability and communication interface for the autonomous bike is a small and energy-efficient signaling concept, showing vehicle intentions in daily traffic scenarios. To function it needs exterior devices (transmitter) and a defined range (language set) of signals including auditive and visual signals (communication tools) to be transmitted by the devices. There is a diversity of possible solutions but at the same time a list of requirements and limitations, concerning legal regulations, technical feasibility, design, and ergonomics. The challenge is finding the right combination for the project AuRa. For this goal, by uniting three scientific sections we designed a road interaction-focused approach for investigating communication concepts, defining technical requirements, prototyping, and collecting usability data.

II. State of the art

The research regarding interaction concepts for autonomous vehicles, especially in terms of bikes, has received not much attention yet in the scientific community. With our approach, we strive to contribute to human-computer interaction research regarding autonomous cargo bikes as a new urban mobility offer. To find a suitable selection of communication strategies that can be tested in our approach, broad literature research for innovations and tendencies in the field of human-technology interaction regarding urban autonomous driving and robotics was con-ducted. The empirical studies that were collected to gather

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abroad range of tested communication strategies and fields of application dealt with autonomous cars ([2],[3],[4],[5]), non-humanoid robots ([6],[7],[8]), and other small autonomous vehicles ([2],[9]). A large part of these studies use either light signals [10] and/or displays, lights are often used to communicate the status of the subject ([7],[8]), while displays are also used to show symbols or features such as eyes [11]. Only one study uses a projector on a car [2]. About half of the studies also use sound as a support, although these can also be divided into language ([4],[2]) and non-language ([3],[6]). In addition to that, the interaction of conventional cyclists with their environment was analyzed. Communication can be formal like traffic signs and signals of vehicles, but also unformal as to non-verbal signals by traffic participants. For unprotected road users like cyclists and pedestrians, non-verbal communication is essential to increase their visibility and make their movements predictable to other traffic participants. About sound signaling, as for electric vehicles, it must be mentioned that from 2021 electric vehicles have to produce noise if not driving faster than 20km/h. This system is called AVAS (acoustic vehicle alerting system) [12].

The autonomous bike will not be driving in the street but only on designated cycle paths. Considering that, we selected different typically critical traffic scenarios considering parallel literature research with a focus on accident statistics of cyclists and pedestrians. In line with this, we considered the results of the "Statistisches Bundesamt" 2018 [13] concerning cycle accidents on the road as well as traffic accidents involving personal injury. We deduced different categories from literature research in traffic psychology which included crossing a road, sudden emergence as well as sudden and unexpected reactions ([14],[15],[16],[17]). Based on these findings, we inferred five critical traffic scenarios according to requirements for communication: "autonomous mode: on", "turn Left/Right", "stop", "speeding up", "slowing down".

III. Approach

The contribution of this approach is in research about the interaction of humans and autonomous cargo-bikes via visual and auditive signaling. To this end, we designed the process including primary research (focus groups), an expert panel (including ideation stage and prototyping), and series of usability studies (questionnaire, mixed-reality-experiment, and simulation) to be of use for development of the AuRa-bike. Our research is in progress and we already conducted 3 of the 5 studies of this approach. Table 1 outlines the roadmap of our approach and where we are right now.

A. Focus groups (primary research)

In 2018 three focus groups were carried out to find out what first impression the autonomous cargo bike-sharing system has on people. In these focus groups with cyclists and car drivers that took place in Magdeburg and Berlin, the interaction of the bike with other traffic participants was discussed. Everyone agreed that the bike must be visible for all traffic participants, including car drivers.

Table 1. Roadmap

Date	Method	Description
Early 2019	Focus Group	Impressions and opinions on the bicycle with-out communication tools
Late 2019	Expert panel	Technical and legal restrictions, technical possibilities, ergonomics requirements
Early 2020	Pre-test	Evaluation of the digital, prototypical communication tools using images and sound clips
Late 2020	Study 1	Evaluation of the communication tools in an360 degree mixed reality simulator; focus on the need of pedestrians
	Study 2	Evaluation of the communication tools in an driving simulator; focus on the need of car driver

Some people had the idea of attaching a safety flag to the bike like children's bikes sometimes have. It was also important for everyone to mark the autonomous cargo bike as being autonomous. The language independency of the communication strategies was discussed since communication should be clear to everyone. Some people mentioned the wish of having an unobtrusive driving noise for the bike. These focus groups gave a few directions for how the communication strategies should be designed. But they also showed that implementing innovative vehicles to traffic raises many questions that must be studied scientifically.

B. Expert panel

During the process of generating the first set of designs for the external human-machine interface, we had to define technical and legal restrictions, ergonomics requirements, and take care of the technical feasibility. This includes general aspects of safety, efficiency, design and aesthetics, power consumption and supply, weight, and stability of the additional hardware. To include all groups of traffic participants and their needs, the combination of visual and auditive signals is highly recommended [18].

Auditive signals can either be voice or other sounds. The transmitter is usually a speaker to be adapted to the vehicle. The communication tool can be a tone, bell, horn, or another random sound. It can also be voice output, words, or whole sentences. A strong disadvantage of voice is the language barrier [2]. Since this would be a safety issue, voices were excluded from our study. In our study we decided to explore the question about subject user perception: should the bike sound like a conventional cargo bike or should it sound like a futuristic vehicle while operating?

For the visual communication symbols, words, street signs, emoticons, and gestures have been tested in former studies. The transmitter is usually a lighting device like an LED, display, or a rotating beacon. Depending on the position of the pedestrian it may be difficult for visual messages to be visible [19]. Since we want the bike to be very visible and safety flags were also discussed in the focus groups, we wanted to test our transmitters not only attached to the front box but also a tower [9]. We had to limit the size of possible screens attached to the bike, depending on the specific mounting position on the bike e.g. smaller screens at a tower as on the front or side of the bike.

Another important aspect was to keep the authenticity of the manual driving when the user directly controls the bike as usual. This includes thoughtful placement in order not to reduce the view and freedom of movement of the driver. Furthermore, keeping a stable driving characteristic during autonomous mode is necessary to support the cruise control of the bike. One of its tasks is always to keep the bike stable and allow the path planning module to utilize even sharp corners and higher curbstones. This in mind, we dismissed any possibility of the use of projectors.

- Digital prototyping

Depending on earlier literature research, the ideation stage, and the ergonomics and technical feasibility analysis we gained a clear idea about what kind of concepts (transmitters and communication tools) we want to test for each scenario. Two auditive signals per scenario were selected. These subdivide into conventional and “futuristic” autonomous vehicle sounds. Within the procedure of selecting an appropriate transmitter of visual signals, three channels have been selected: an LED light, a rotating beacon, and a display respectively placed on the tower or the bike’s box. Concerning the visual signs, shapes, colors, and symbols were selected for each scenario.

Depending on the early stage of the design process we selected the prototyping techniques sketching and producing digital prototypes (Fig. 1) in 3D software (Siemens NX and Catia V5). They gave us more flexibility in visualizing our alternatives realistically enough to explain complex design details.

Fig. 1. Design and technical models

C. Pre-test

To measure and quantify the efficiency of the offered alternative designs and pinpoint where to focus our improvement efforts on our future work we run a usability research session including an online-questionnaire and two live experiments. Collecting quantitative and qualitative usability data will help us reaching our goals. We planned to manipulate differences in performance, user cognitive perception, and interaction with the alternative design concepts. We evaluate each design using a predefined set of measures including performance measures and self-reported measures, which are relevant [20].

To narrow down the potential designs of communication strategies for a subsequent 3D simulation study, we conducted our pilot study comparing around 60 alternative designs for the five defined scenarios. Quantitative data was collected through an online questionnaire in German language with the software SoSci Survey [21]. We tested the impact of our design concepts on students at the Otto-von-Guericke University Magdeburg. This pilot study gave us a first overview of how potential users can be involved in the development and design process to find out about preferences.

The sample (N = 66) was acquired via Max Lab (Magdeburg Experimental Laboratory of Economic Research) in three sessions on February 19th, 20th, and 21st 2020. The average age of both groups was M_{age}=24.18.

For the auditive signaling the findings show that the participants preferred the classical over the modern sounds. The findings for the visual signaling in percentages indicate how many participants chose a design to be their favorite, compared to the alternatives. According to the first scenario, the group in which no tower was presented, a blue WiFi-symbol combined with the script “Autonom” (Engl. autonomous) was rated the most comprehensible signal with 79.4 %. In the tower-group, the display indicating a blue “A” obtained the best ranking (28,1%). Regarding the attention scenario, in the no-tower-group the script “Achtung!!!” (Engl. attention) was rated as most fitting with 33.3 %. The tower-group rated the red LED as most adequate (31.3 %). In the third scenario (signaling direction), both groups rated an orange bike and a human represented in green combined with arrows indicating their direction respectively as most fitting (no-tower-group = 64.7 %, tower-group = 68.8 %). The no-tower-group rated a red LED as well as a Stop-sign as most comprehensible in the fourth scenario (31.3 %). In the tower-group, a Stop-sign was the one mostly chosen (54.8 %). In the last, driveaway scenario, the no-tower-group rated a green arrow with a speed indicator as most comprehensible (36.4 %). The tower-group rated the WiFi-symbol as most fitting with 51.6 %. Future work will improve the best-ranked designs, develop additional features, and further investigate their impact on users.

D. Study 1 (mixed-reality-experiment)

Since we cannot ensure, that the participants could put themselves in the situation during the online questionnaire, we plan to use the results in the preparation of a complex mixed-reality-experiment in a mixed-reality laboratory Elbedome [22] in September 2020. This next planned step will certainly provide important results as to which concepts are understood in more realistic settings. In this way, we will try to reach a more representative sample and higher immersion. It is important to mention that the sample will be again with German-speaking participants, but this time – citizens of Magdeburg. Furthermore, our first sample consisted of students only. Although students are an easy to access group, their perception might not generalize toward the broader public. Therefore, we strike a more diverse set of participants in this study.

E. Study 2 (simulation)

In a driving simulator, we plan to evaluate the communication tools with the focus on the need for car drivers. We still need to define a lot of details and questions around the concrete design concepts we let in the experiment.

IV. Discussion and outlook

The development of a sophisticated communication interface for the autonomous bicycle regarding users to ensure the easy and user-friendly operation is a long interdisciplinary process we started. A series of studies need to be conducted to design and improve this responsible task. Currently, we are in the middle of our research approach. We work in progress and prepare our first complex live-experiment in the mixed-reality laboratory [22] in September 2020. Due to the huge size compared to classic projection systems, this laboratory is suitable for the demonstration and interactive prototype visualization on a scale of 1:1 with a 360°panorama and floor projection surface, which makes it possible to move realistically and to scale in virtual worlds. In our next contribution, we plan to share and discuss our qualitative findings from this upcoming research practice.

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