

Towards a Design Space for External Communication of Autonomous Vehicles

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ABSTRACT

Autonomous vehicles are about to enter the mass market and with it a complex socio-technical system including vulnerable road users such as pedestrians and cyclists. Communication from autonomous vehicles to vulnerable road users can ease the introduction of and aids in understanding the intention of these. Various modalities and messages to communicate have been proposed and evaluated. However, a concise design space building on work from communication theory is yet to be presented. Therefore, we want to share our work on such a design space consisting of 4 dimensions: *Message Type, Modality, Locus, and Communication Participants*.

CCS CONCEPTS

• **Human-centered computing** → *HCI theory, concepts and models*.

ACM Reference Format:

Mark Colley and Enrico Rukzio. 2020. Towards a Design Space for External Communication of Autonomous Vehicles. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems, April 25–30, 2020, Honolulu, HI, USA*. ACM, New York, NY, USA, 4 pages. <https://doi.org/10.1145/3334480.3382844>

1 INTRODUCTION

Autonomous vehicles (AVs) are expected to change interaction between pedestrians and vehicles [14]. There is no need for a human driver to be present in AVs. Interpersonal communication for situations, in which people today rely on eye-contact or gestures [29] will therefore be even more challenging.

Recent research projects aim to overcome these upcoming challenges through external communication to vulnerable road users (VRUs) such as displays [15], LED strips [15, 23], movement patterns [39], projections [1], auditory or tactile cues [25], combinations thereof [25], and enhancement of the infrastructure [35].

Researcher struggle whether and when such communication is necessary [26] and which modality and technology to use given the numerous aforementioned opportunities.

We present a design space for such external communication of AVs based on research on communication theories of Berlo [7] and DeVito [11]. The proposed design space consists of 4 dimensions (Message Type, Modality, Locus, Communication Participants; see

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CHI '20 Extended Abstracts, April 25–30, 2020, Honolulu, HI, USA.

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ACM ISBN 978-1-4503-6819-3/20/04.

<https://doi.org/10.1145/3334480.3382844>

Sidebar and Section Dimensions and Values). Current work has been classified and research gaps are named. The design space shows that current external Human-Machine Interfaces (eHMIs) mainly are of instructional or advisory nature, answers e.g. for inquiries such as “Can I cross?” are unexplored.

2 BACKGROUND

This work builds on research in the fields *Design Spaces in HCI, Communication Theory, and External Communication of AVs*.

2.1 Design Spaces in HCI

In Human-Computer Interaction (HCI) research, taxonomies [16] and design spaces [18] allow for the exploration of potential interaction possibilities. They also aid in understanding current as well as upcoming technologies (e.g., shape changing interfaces [20] or external communication of AVs [25]). Especially taxonomies enable researchers to systematize knowledge about interaction techniques and input devices [16].

Therefore, creating a design space about external communication of AVs is a first step to understand current trends and to uncover unknown potential.

2.2 Communication Theory & Models

Communication theory is a multidisciplinary research field concerned with intra- and interpersonal communication. Starting in 1920, various models have been proposed. The three most commonly described models are *Linear, Interactional, and Transactional*. Shannon and Weaver introduced the first linear model in 1949 [34] with no feedback or response mechanisms. In interactional models, participants alternate positions as sender and receiver [33], e.g. Sender-Message-Channel-Receiver (SMCR) Model of Communication [7]. This model mainly has four components to describe communication: sender, message, channel, and receiver. Transactional models involve other factors such as cultural or social context in the communication concept [4], e.g. DeVito’s interactive model [11]. Compared to the SMCR-model, this model includes context, feedback, and noise as factors. Rothwell explains the concept of noise and divides it into four categories: (1) physical noise or external noise such as poorly heated rooms or startling sounds, (2) physiological noise such as sweaty palms or speech anxiety, (3) psychological noise means that your preconception alters the way one talks to another, e.g., with a foreigner or a child and (4) semantic noise which is using confusing or distracting word choices [31]. Additionally, there is the constructionist view on communication, as described by Lanham [21]. In this view, the meaning of a message is not solely dependent on the sender but also on the receiver. This

means that the knowledge and views of the receiver play an important role in unveiling the meaning of the sender. Trenholm [36] put this in the context of entire cultures: “communication is a process whereby people in groups, using the tools provided by their culture, create collective representations of reality”.

2.3 External Communication of AVs

An overview on vehicle-pedestrian interaction with both traditional and AVs is given by Rasouli and Tsotsos [30] with special regard to communication modalities and messages. Various aspects of external concepts of AVs have been investigated in literature: Rouchitsas and Alm [32] focus on empirical work in which a clear benefit from these concepts was found. Colley et al. [10] focused on the used modality in the concepts, evaluating 29 concepts in a thorough survey finding that visual concepts were most prevalent. Industrial concepts were analyzed by Bazilinskyy et al. [5] with focus on visual features such as color. These include projections and LED displays (Mercedes Benz F 015 [6]) or abstractions reminiscent of a face (VW Sedric [37]).

2.4 Differentiation to Other Design Spaces

Design spaces for various aspects of external communication of AVs have been proposed. Colley et al. [9] showed where external displays can be attached to a vehicle. Löcken et al. [22] classified the interaction concepts under investigation into four categories: visual only, visual plus acoustic, anthropomorphic, and concepts including infrastructure. This resembles the dimensions *Modality* and *Locus*. They further distinguished each category based on the complexity of the information presented. Mahadevan et al. [25] employed a method called PICTIVE [2] to elicit possibilities for external communication of AVs. They propose a design space with the dimensions *Cue category* (Visual, Auditory and Physical) and (not explicitly stated) *Locus* of the communication (Vehicle-only, Vehicle and Street, Vehicle and Pedestrian, Mixed). There are two concerns regarding this proposal and the classification: The physical cue seems mixed as “Car lowering/raising” is actually a visual stimulus. The nomenclature of physical could also be changed to tactile having a clear foundation in research on senses. *Mixed* locus allows for an ambiguous classification of proposals. We argue that this category should be removed to coerce a more strict classification. We therefore propose a novel design space.

3 DESIGN SPACE

The unique requirements for external communication of AVs call for structured analysis to identify challenges and opportunities for future interaction design, which is currently missing.

3.1 Process

According to the approach of morphological analysis, we combined relevant values of the dimensions in a multidimensional matrix, also called “Zwicky Box” [40]. This is an established tool for ideation and design space creation (e.g., [3, 18]). This matrix contains all possible combinations of parameters relevant for a given problem. Through classification of related work, it is possible to identify promising approaches as well as a lack of solutions. In the fourth step of the analysis [40], solutions are “closely analyzed and evaluated with

respect to the purposes”. This may involve dropping solutions or dimensions.

To simplify the design space, we excluded dimensions such as *Technology* or *Position on Locus*. While there are various technologies employed in today’s proposed concepts (displays [15], LED strips [15, 23], movement patterns [39], projections [1] auditory or tactile cues [25] as well as combinations thereof [25] and enhancement of the infrastructure [35]), this design space should not exclude upcoming technologies (e.g., aforementioned shape changing interfaces [20]).

For the *Position on Locus*, Colley et al. [9] presented a design space for external displays on cars. They proposed various example areas: bumper, grille, wheels, side mirrors, windows, license plate, on road projection, car body surfaces, and the lights. Eisma et al. [13] investigated the effect of position on crossing intention and eye-gaze using the levels *Roof*, *Windscreen*, *Grill*, *above the Wheels* and *Projection*. A generalized *Position on Locus* seems not possible nor desirable as the *Locus* is variable (Vehicle, Personal Device, and Infrastructure) and the shapes of vehicles for instance could change.

In the following, we describe the dimensions of the design space based on the SMCR model [7] and DeVito’s interactive model [11]. For the actual values see the sidebar.

- **D1 Message Type:** Instruction, Command, Advisory, Answer, Historical, and Predictive (see Buck [8])
- **D2 Modality:** Auditory, Visual, and Tactile/Physical
- **D3 Locus:** Vehicle, Personal Device, and Infrastructure (see Mahadevan et al. [25])
- **D4 Communication Participants:** one-to-one, one-to-many, many-to-one, and many-to-many (see Jensen and Helles [19])

3.2 Dimensions and Values

We found the *1. message* and *2. channel* to be variables that are modifiable for the external communication of AVs. The first dimension therefore is **D1 Message Type**. Most of the information currently sought from displays is of the answer kind [27]. We distinguish **D1 Message Type** in *Implicit* and *Explicit* [17, 38]. Implicit means “suggested but not communicated directly” [12]. “I’m about to start” [23] is therefore treated as an implicit message as it does not state that the pedestrian should wait. Communicating via movement is also considered to be implicit [26].

The second dimension is **D2 Modality**. For simplicity, the variants of **D2** are not further broken down (these representation can differ in semiotic terms: *symbolic*, *iconic*, and *indexical* [28]).

The third dimension **D3 Locus** is based on the work of Mahadevan et al. [25]. The fourth dimension **D4 Communication Participants** is based on the work from Löcken et al. [22], who raise the question of “scalability” of the communication concepts. We propose the level *one-to-one*, *one-to-many*, *many-to-one* and *many-to-many*, known from *social media research* [19]. *One-to-one* here stands for *one* AV communicates with *one* VRU. Mahadevan et al. [24] included this aspect by simulating multiple pedestrians.

This leads to a four-dimensional design space. We present two subsets in Figure 1 and Figure 2.

		Modality						
		Auditive	Visual	Tactile/ Physical	Olfactory	Gustatory	Vestibular	
Message type	Implicit	Instruction						
		Command						
		Advisory						
		Answer						
		Historical						
	Explicit	Instruction						
		Command						
		Advisory						
		Answer						
		Historical						

Figure 1: Matrix obtained by the morphological approach containing all parameter combinations of D1 and D2. Highlighted in gray are the combinations that make technically no sense.

		Communication Participants			
		One-to-one	One-to-many	Many-to-one	Many-to-many
Locus	Vehicle				
	Device				
	Infrastructure				

Figure 2: Matrix obtained by the morphological approach containing all parameter combinations of D3 and D4.

4 FIRST INSIGHTS

This work provides a literature based approach to a design space for external communication concepts of AVs. Based on the actual values of the dimensions, first insights can be drawn: To our knowledge, there is no related work that investigated *answers* (e.g., when a person asks via gesture if one can pass the street) or *historical* as a message type. It is, however, not clear whether such communication is useful and therefore requires further investigation. This design space also allows researchers to classify their work. While this is out of scope for this work, already interesting questions arise per concept: Is this concept intended for a one-to-one communication? Is it viable for one-to-many or many-to-many communication (referring to *scalability* [22])? The classification of the text “Cross” concept by Mahadevan et al. [25] is (according to this design space): **D1: Command; D2: Visual; D3: Vehicle; D4: (evaluated for) one-to-one.**

5 FUTURE WORK

We will discuss the current design space with other researcher in this area and will, if necessary, make relevant adjustments. A workshop on the design space will be held with experts in the field of communication research. Current external communication concepts will be classified according to the design space. Furthermore, we want to explore the design space and implement some of the potential communication possibilities.

ACKNOWLEDGMENTS

This work was conducted within the project ‘Interaction between automated vehicles and vulnerable road users’ (Intuitiver) funded by the Ministry of Science, Research and Arts of the State of Baden-Württemberg.

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