Making emergent technologies more tangible - Effects of presentation form on user perceptions in the context of automated mobility

By Frederica Janotta*

One of the main challenges of investigating consumers' perceptions and acceptance of emergent technologies is that respondents have not had any experience with them. This posits the question of how such technologies can be effectively presented to consumers both in the context of research and in measures to foster acceptance. Using automated driving as a case study, this paper presents results from a comparative study of three presentation forms (vignette, real-world video, computer-generated VR) of a ride in an automated vehicle in an empirical study with 103 participants. Results from quantitative analyses show that both real-world videos and the VR simulation outperform textual descriptions in terms of visualisation capability and user experience. Unexpectedly, the VR simulation does not perform significantly better at creating mental images of automated driving than a vignette. Recommendations are offered regarding the choice of a suitable presentation form in empirical research in relation to study objectives.

1. Introduction

In recent years, intelligent agents such as chatbots, service robots or automated vehicles have increasingly attracted interest in the academic community (van Doorn et al. 2017; Huang and Rust 2018). Automated mobility, in particular, is set to transform the way we travel, work and live dramatically (Quarles et al. 2021). Being able to anticipate and adapt to complex situations, fully automated vehicles are expected to provide safer and more efficient mobility. Beyond that, driving automation will enable consumers to socialise, work, and relax while travelling and will increase mobility for the physically or visually impaired (Sanbonmatsu et al. 2018). Thus, over the past decade, there has been an increasing interest in how consumers will respond to automated mobility offerings, including privately owned automated vehicles, autonomous shuttle busses or unmanned drones (Jing et al. 2020). However, one of the main challenges of investigating consumers' responses to such emergent technologies is that respondents have not been able to experience them yet (Bjørner 2015). While advanced driver-assistance systems (ADAS) have been available in modern vehicles for several years, full driving automation is still under development[1] and is currently not expected to be available on the market before 2030 (Quarles et al. 2021). Thus, evaluating technologies for automated mobility with potential users in real-world environments is highly challenging, as it is linked with high costs and high potential risks for study participants (Gerber et al. 2019). To address these challenges, researchers have used various forms of visualising these technologies and making them more tangible to respondents, ranging from textual descriptions to simulated representations in virtual reality (VR) to allow for more reliable evaluations in the context of empirical studies.

However, to date, little is known about how different forms of technology representation in the context of empirical research shape respondents' imagination and perceptions of emergent technologies (Mara et al. 2021). Only recently, researchers have begun to systematically investigate the efficacy of different presentation forms

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1 The Society of Automotive Engineers (SAE) distinguishes six levels of vehicle automation based on the capabilities of the automated driving system. At the highest level (full automation) the vehicle is able to perform all driving functions under all circumstances (SAE International 2018). In this paper, "automated vehicles" refer to fully automated vehicles where no human intervention is required.

in visualising emergent technologies and their potential influence on consumer perceptions (e.g. Hoggenmueller et al. 2021; Mara et al. 2021). The review of previous studies shows that very few provide a systematic comparison of dynamic visualisation forms such as VR and video representations, and findings regarding the efficacy of different presentation forms remain inconclusive. Thus, this research comparatively assesses how well text-based scenario descriptions paired with static images (vignettes), real-world videos and computer-generated VR simulations are suited for visualising the experience of a ride in an automated vehicle. To this end, a quantitative study was implemented, which aimed to answer the following research question: How do different presentation forms (vignette, real-world video, computer-generated VR simulation) of an emergent technology differ in terms of their ability to create mental images of the experience of automated driving in respondents' minds?

This study offers important insights and methodological recommendations for research concerned with consumers' perceptions and experience in the context of emergent technology. First, it presents one of the first comparative studies of different presentation forms of an automated ride for the purpose of user-centered research. In the context of highly complex emergent technologies such as automated driving, it is imperative to make experiences with these technologies more tangible to consumers using mediated representations, to ensure a consistent basis for their evaluations and judgment in empirical studies (Mara et al. 2021). In this regard, the findings provide important insights into the efficacy of different presentation forms in visualising emergent technologies. While the choice of a suitable presentation form should take into account study objectives, advantages and drawbacks of presentation forms as well as potential effects on study participants, our results indicate that real-world videos may be more suitable in mediating the experience of complex service offerings such as automated driving than VR simulations, as the video created the most vivid mental images in respondents and was rated most favourably in terms of realism, simplicity, and clarity. Second, from a methodological perspective, this study offers recommendations for future research on choosing suitable presentation forms for empirical studies focusing on experiential aspects of emergent technologies. While this study focused on automated mobility offerings, the recommendations provided may be transferred to research investigating consumers' perceptions of and experiences with other emergent technologies, such as smart products or service robots. Finally, from a practical perspective, this research provides indications as to how stakeholders can make emergent technologies more comprehensible to consumers within the scope of efforts to pave the way for successful market introduction.

2. Review of related literature

One of the main challenges of analysing consumers' responses to emergent technologies is that they are not implemented yet and thus, very few consumers have interacted with them (Venverloo et al. 2020; Mara et al. 2021). While, in theory, it is preferable to investigate aspects related to the evaluation of new technologies in real-world settings (Pariota et al. 2017), this is often difficult to achieve. This is perhaps most evident in the case of automated driving: From a practical perspective, driving an automated vehicle in traffic raises serious safety and liability issues (Gerber et al. 2019). From an empirical standpoint, real traffic environments do not comply with the strict protocols of experimental research. A recent review of 75 studies focussing on consumer responses to automated driving shows that studies providing real driving experience or a simulated ride experience were scarce (10.7% and 4.0% of studies, respectively), while 85.3% of studies were conducted online and only included explanations of automated driving (Jing et al. 2020). While providing valuable insights into consumers' perceptions and determinants of user acceptance, one major limitation of such studies is that respondents have different conceptions of the focal technology and possible interactions with it (Mara et al. 2021). Thus, participants' responses are primarily based on preconceived information, potentially confounding results (Patterson et al. 2017). In the context of emergent, automated technologies, various studies have tried to overcome this limitation by employing different presentation forms of the focal technology, providing participants with a clearer understanding and imagination of the experience of interacting with it.

2.1. Presentation forms used in current research

2.1.1. Vignettes

To ensure a common understanding of the respective technology among respondents, research often resorted to providing a definition and/or usage scenario, sometimes accompanied by static images, as part of the questionnaire. Such vignettes are widely used in research to present respondents with a hypothetical scenario as a basis for assessment without having first-hand experience (Alexander and Becker 1978; Baccarella et al. 2020). In the context of automated mobility offerings, studies have applied textual descriptions to examine determinants of consumer adoption of privately owned automated vehicles (e.g. Baccarella et al. 2020), automated public transport, i.e. shuttle busses (e.g. Kaye et al. 2020), as well as autonomous commercial airplanes (e.g. Rice et al. 2019) and remotely-piloted air taxis (e.g. Winter et al. 2020). In one study, text vignettes were even used as an initial stimulus to investigate affective reactions to automated driving (Hohenberger et al. 2016). Similarly, focusing on consumer responses to humanoid service robots, other studies have employed descriptions of human-robot interactions supplemented by visual images as a basis for the empirical investigation (e.g. Jörling et al. 2019; Letheren et al. 2021).

Despite the prevalence of this approach, some limitations remain. Specifically, some authors noted that verbal descriptions and static images of highly complex emergent technologies, such as automated driving, might not suffice in providing a common understanding for participants (Liu et al. 2019). Therefore, it is frequently recommended to provide respondents with more extensive visual information, e.g. through simulations or videos (Mara et al. 2021).

2.1.2. Simulations

Another commonly used presentation form in user research on emergent technologies is simulations. Most simulations display computer-generated virtual environments (Flohr et al. 2020), which can easily be manipulated by researchers to alternate individual variables while keeping everything else constant (Pan and Hamilton 2018), thus maximising experimental control. In the context of research on automated mobility offerings, various simulation platforms are being used, including CAVE-like setups, driving simulators, and VR headsets (so-called head-mounted displays, HMD) (Hoggenmueller et al. 2021), while research on human-robot interactions typically resorted to the use of HMDs (e.g. Babel et al. 2022). One key feature of such VR headsets is their ability to visually isolate the user from the real world while enabling 3D vision and dynamic updates of the visual scene following head movements (Pan and Hamilton 2018).

In the context of humanoid robots, several studies have employed VR simulations as a proxy for real human-robot interactions. For example, Herzog et al. (2022) used a VR simulation to evaluate how the human-likeness of a service robot impacts rule compliance and emotions of public transport users. Similarly, other studies assessed consumer responses to service robots with the help of VR scenarios, highlighting the flexibility and benefits of VR simulations in overcoming current hardware limitations of automated technology (Babel et al. 2022; Pozharliev et al. 2021).

Despite the apparent benefits of VR simulations, in the context of automated mobility, this presentation form has mostly been applied to investigate human-machine interface design (cf. Riegler et al. 2021) but has rarely been used in research focusing on general perceptions and acceptance. Several studies used VR scenarios to examine trust in automated driving (e.g. Wintersberger et al. 2021; Ha et al. 2020). Similarly, Venverloo et al. (2020) used a VR simulation to investigate participants' risk perceptions and adoption intentions toward autonomous boats as a proxy for autonomous vehicles. The authors stress the benefits of VR for studies aiming to investigate acceptance factors of emergent technologies and how they will be appropriated.

2.1.3. Videos

Compared to computer-generated environments, real-world videos can ensure higher visual realism and familiarity (Gerber et al. 2019). Notably, real-world videos can represent not only the subject of investigation but also a rich context at a higher level of realism (Flohr et al. 2020). This is particularly helpful in scenarios where context and environment are highly complex and dynamic, such as driving scenarios.

Several previous studies included videos to provide a common understanding of the features and experience of fully automated driving. However, the videos differed significantly in terms of their content and level of abstraction. While not all studies report details on the specific videos used (e.g. Koul and Eydgahi 2018), some videos depicted a specific prototype rather than a close-to-reality usage situation. For example, to provide participants with a better understanding of the technology using a real-life example, Böhm et al. (2017) included a stimulus video of the autonomous Mercedes F015 prototype in their survey. Similarly, focusing on human-robot interactions, Song and Kim (2021) employed videos of SoftBank's humanoid robot "Pepper".

Contents of video stimuli also varied according to the respective study's aim. For example, one study used short video clips to illustrate benefits and advantages of the technology to investigate their role in the formation of opinions about automated vehicles (Chikaraishi et al. 2020). Erskine et al. (2020) used videos that informed subjects about the capabilities of automated vehicles distinguishing three levels of automation to examine corresponding differences in consumer attitudes. Videos have also been employed to showcase concrete usage situations. For example, Mende et al. (2019) showed videos of interactions with humanoid service robots to visualise service encounters in medical, educational and dining contexts.

Videos have also been used in qualitative studies as an initial stimulus before conducting interviews or group discussions. For example, Song and Kim (2021) relied on a video clip of an interaction with a service robot in a retail setting to examine user responses. Similarly, in the context of automated driving, Bjørner (2015) showed videos of driving scenarios prior to conducting interviews to explore user acceptance and perceived driving pleasure. The author concludes that video examples help provide study participants with a better conceptual understanding of what the technology under study can accomplish, suggesting that videos are well suited for visualising complex technologies in the context of research.

2.2. Comparative studies on impacts of different presentation forms[2]

In the context of user studies evaluating emergent technologies, only few studies systematically examined the effects of different presentation modes on respondents' understanding and perception of the focal technology. For example, Hoggenmueller et al. (2021) examine the impact of different presentation modes on participants' perceptions of an external human-machine interface (eHMI) in the context of automated driving. Comparing a virtually displayed real-world environment, computer-generated VR and a real-world video, they find that these modes do not yield significant differences in user experience ratings of the eHMI. Interestingly, however, qualitative data indicate that respondents focused on different experiential aspects in each of the presentation forms. In the context of service robots, Mara et al. (2021) compare four modes of presentation with varying degrees of immersion potential (2D videos, 3D videos, VR, live interaction) and investigate how they influence user perceptions of the robot. Results show the highest perceived immediacy, i.e., directness and perceived lack of mediation, in the live interaction, with slightly lower values for the VR condition, but no significant difference between the two. Unsurprisingly, the live interaction led to significantly higher perceived immediacy than the 3D and 2D video conditions.

Another stream of research that is concerned with questions of visualisation is stated preference surveys and choice experiments (Patterson et al. 2017). In this context, it is recognized that different alternatives need to be presented to study participants in a way that enhances respondents' understanding of choice options (Louviere et al. 2000). Vriens et al. (1998) identified the use of graphic visualisations in addition to textual descriptions as a promising method to improve respondents' understanding of the subject of study. Furthermore, visualisations have been found to enhance the realism of choice alternatives and thus increase the reliability of measurements compared to text-only conditions (Orzechowski et al. 2005).

In the context of choice experiments, several studies that have employed virtual environments for visualisation purposes find that they are superior to static image presentations in helping people evaluate complex data. In particular, results indicate that VR visualisations can reduce choice error and bias, compared to static images (Bateman et al. 2009; Matthews et al. 2017). Bateman et al. (2009) conjecture that the greater 'evaluability' of the VR presentation reduces respondent judgement error. This is corroborated by further studies suggesting that VR presentations increase participants' understanding of the scenarios presented to them (Farooq et al. 2018). Similarly, Fiore et al. (2009) conclude that responses following a VR visualisation reflect beliefs that are closer to the truth. Focusing on wildfire management policies, the authors find that the higher immersion potential of virtual environments helps in generating subjective beliefs that are closer to actual risks compared to standard 2D images.

Some studies, however, indicate that graphic depictions can substantially influence respondents' perceptions and, thus, should be carefully considered before being incorporated into experimental designs (Jansen et al. 2009). In particular, several studies suggest that visual representations can bias responses in the sense that certain characteristics appear to be more important to respondents' overall evaluation when shown visually than when presented in written format (Vriens et al. 1998; Jansen et al. 2009). Other studies, however, do not find that visualisations affect the relative importance of attributes (Arentze et al. 2003; Patterson et al. 2017), nor reduce error variance (Arentze et al. 2003) in choice experiments. Arentze et al. (2003) therefore conclude that the development effort of graphical material is not compensated by better quality data.

Given these inconclusive findings, the present study further examines the potential impact of presentation forms on respondents' perceptions of emergent technologies. In particular, considering the high cost of computer-based virtual environments, it seems warranted to investigate whether the ability of more immersive presentation forms to visualise dynamic scenarios can justify the costs associated with creating them (Vriens et al. 1998).

3. Hypothesis development

Building on the previously described advantages and limitations of various forms of technology representation, this research comparatively assesses how well real-world videos and computer-generated VR simulations presented via HMD are suited for visualising the experience of a ride in an automated vehicle, compared to a vignette, i.e. a text-based scenario description supplemented by static pictures, as a baseline.

The included presentation forms can be distinguished by the degree of immersion which they achieve, i.e. their immersion potential (Mara et al. 2021; Peukert et al. 2019). In general, the term immersion describes the extent to

2 See Table D.1 in Appendix D for an overview of previous comparative studies.

which a virtual environment is "capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses" (Slater and Wilbur 1997, p. 604). According to this definition, technical systems vary in terms of the degree of isolation from reality (inclusiveness), the number and magnitude of stimulation of different sensory channels (extensiveness), the field of view delivered by the medium (surrounding), and the extent to which the system is able to create naturalistic environments in terms of resolution, fidelity and richness (vividness) (Peukert et al. 2019).

With their 360-degree field of view and their ability to shut out the physical surroundings of study participants, VR simulations shown via HMD arguably outperform real-world videos presented on a 2D screen in terms of immersion potential (Pan and Hamilton 2018). In line with previous research (Mara et al. 2021; Peukert et al. 2019; Fiore et al. 2009), it is therefore assumed that the VR presentation entails higher immersion potential than the real-world video, which is presented on a simple desktop screen. Featuring only a textual description and still images of the scenario, the vignette condition is considered to provide the lowest immersion potential. Due to these differences in immersion potential, it is hypothesised that the three presentation forms vary in terms of the vividness of mental imagery created in respondents' minds, their user experience and their visualisation capability.

Perceived vividness of mental imagery is defined as the degree to which a stimulus is able to evoke lively images in a consumer's mind (Vazquez 2019) and refers to the quality of mental imagery created in terms of clarity, intensity and distinctiveness (MacInnis and Price 1987). It relates to the extent to which participants feel that a representation of the focal technology evokes lively and detailed mental images (Keller and Block 1997). Previous research indicates that the rich, dynamic stimuli of a virtual experience with an object produce more vivid images in the participant's mind than static pictures or text (Harz et al. 2022; Schlosser 2006). In general, VR simulations can achieve a very realistic and engaging visualisation, mainly due to their ability to showcase a 360-degree-view from a first-person perspective, evoking the impression that the participant is in fact surrounded by the virtual environment (Harz et al. 2022; Pan and Hamilton 2018). Previous studies indicate that this immersive aspect of VR in particular facilitates the formation of mental images, suggesting the superiority of computer-generated VR even when compared to dynamic, real-world images (Fiore et al. 2009; Mara et al. 2021). Building on these insights, it is expected that the VR simulation will elicit more vivid mental imagery than both the real-world video and the textual description of the vignette, while the video is expected to elicit more vivid mental images than the vignette.

H1: Presentation forms with higher immersion potential generate more vivid mental images of the automated driving experience than presentation forms with less immersion potential. Specifically, real-world videos will generate more vivid mental imagery than the vignette (H1a), and the VR simulation will generate more vivid mental imagery than both real-world videos (H1b) and the vignette (H1c).

This study specifically focuses on the ability of the presentation forms to mediate the experience of a ride in an automated vehicle in a realistic and pleasant way. Therefore, to examine respondents' subjective experience with the respective presentation form and evaluate aspects of usability, perceived visual realism and overall aesthetic appeal, the three presentation forms were assessed in terms of their user experience. Following previous research, it is expected that the high immersion achieved in VR positively influences user experience (Brade et al. 2017). Previous studies indicate that, compared to less or non-immersive displays, highly immersive displays evoke more positive affective responses and a higher sense of presence, which are positively linked to user experience (Wienrich et al. 2018; Pallavicini et al. 2019). Therefore, it is hypothesised that the VR simulation will be rated more favourably in terms of its user experience than real-world videos and the vignette. Additionally, the video is expected to provide a more pleasant user experience than the vignette.

H2: Presentation forms with higher immersion potential will be rated more favourably in terms of their user experience than presentation forms with less immersion potential. Specifically, real-world videos will be rated more favourably than the vignette (H2a), and the VR simulation will be rated more favourably than both real-world videos (H2b) and the vignette (H2c).

The main goal of technology representations in the context of empirical research is to ensure a realistic visualisation of the focal technology to enable more reliable evaluations by respondents (Farooq et al. 2018). Following Harz et al. (2022), we investigate visualisation capability, which refers to the ability of a presentation form to visualise new products and environments in a comprehensive manner to allow for a deeper understanding and a clearer vision in the respondent's mind. The authors suggest that VR has a higher visualisation capability than alternative multimedia visualisation approaches, which can be attributed to VR's simulation scope, similarity to reality, and immersion (Harz et al. 2022). Compared to the immersive depictions of the vehicle and the surrounding environment achieved in VR, viewing a flat representation of the same objects and environments on a screen may create a lower similarity to reality in terms of the actual experience (Hoggenmueller et al. 2021; Fiore et al. 2009). In line with this reasoning, it is expected that participants will perceive the VR simulation to have a higher visualisation capability than the real-world video and the vignette. Additionally, as dynamic stimuli have a higher ability to visualise new technologies and related usage scenarios than static pictures or text (Roggeveen et al. 2015), it is expected that the video condition will be rated more favourably in terms of its capability to visualise automated driving than the text vignette.

H3: *Presentation forms with higher immersion potential will be rated more favourably in terms of their capability to visualise automated driving than presentation forms with less immersion potential. Specifically, real-world videos will be rated more favourably than the vignette (H3a), and the VR simulation will be rated more favourably than both real-world videos (H3b) and the vignette (H3c).*

4. Empirical study

4.1. Study design & participants

A between-subjects design was adopted to assess how respondents evaluate different forms of technology presentations (vignette, real-world video, VR simulation) in terms of their ability to visualise a ride experience in an automated vehicle. Data was collected using an online questionnaire comprised of 7-point Likert scale items as well as one open-ended question. If necessary, survey items were adapted to fit the context of the study. A small pilot test (n=13) was run to check the comprehensibility of the questionnaire, after which the phrasing of certain items was adjusted to ensure clarity. Two attention checks asked participants to select a specific response option on the Likert scale.

Participants were recruited on the university campus as well as via announcements in local news outlets, to reach a diverse audience. The call for participation stated that the study would pertain to attitudes towards automated driving. A monetary incentive was offered to boost the overall participation rate. Following previous research (e.g. Mara et al. 2021; Brade et al. 2017), we aimed for n > 30 participants per experimental condition. Overall, 109 participants were recruited, six of which had to be excluded from the analysis due to failed attention checks, leaving a sample of n=103.

4.2. Forms of presentation

The driving scenario was the same across all three presentation forms. Study participants were put in the perspective of a passenger taking a ride in an automated vehicle. To create the video, a ride in a seemingly fully automated vehicle was recorded in a natural traffic environment from the perspective of a passenger in the driver's seat. The scenario showed an 8-minute-drive and included a variety of everyday driving manoeuvres encountered in urban and suburban traffic as well as different driving speeds. Throughout the scenario, other vehicles pass by on the oncoming lane, and pedestrians can be seen on sidewalks. It is visible that the vehicle performs all driving tasks autonomously. The video was presented to participants in full-screen mode on a 24-inch full HD screen.

To develop a matching VR simulation, a professional service firm specialising in 3D modelling and simulation design was commissioned. The pre-recorded video was provided as a reference. The 3D designer used an existing VR scenario as a basis and, in an iterative process, adjusted it to match the video. Both the video and the simulation did not include an audio track. Participants experienced the VR simulation using HTC VIVE Pro VR headgear (for system specifications, see Appendix B).

Finally, a detailed description of the same driving scene was written to create the text-based scenario included as a baseline in the study, accompanied by screenshots from the video. Care was taken to provide an objective description of the driving situation. Appendix A provides the text description and screenshots of the presentation forms used.

4.3. Study procedure

Upon arrival, participants were informed about the study procedure and were asked to fill in the pre-assessment questionnaire, which included a brief description of fully automated vehicles. Subsequently, they were presented with the driving scenario. In the vignette condition, participants were asked to read the scenario description on an additional screen. Similarly, the real-world video was presented on an additional screen. In the VR condition, participants were asked to put on HTC VIVE Pro headgear to experience the simulation. Finally, participants completed the second part of the questionnaire comprised of items measuring their perception of vividness of mental imagery (α=0.92; Miller et al. 2000), user experience (α=0.85; Schrepp et al. 2017), and visualisation capability of the presentation form (α=0.93, self-developed). Measurement scales are provided in Appendix C. Additionally, one open-ended question asked participants to freely comment on those aspects of the presentation form that had stood out most to them.

5. Results

5.1. Sample characteristics

The sample had a mean age of 32.22 years (SD = 14.63, min = 19, max = 73); 57 participants were female (55%).

17.5% of participants drove a car daily, 61.1% weekly, while 21.4% indicated using a car only sporadically.

Participants were randomly assigned to the treatment groups, leading to three groups of roughly the same size ($n_{text} = 36$, $n_{video} = 34$, $n_{simulation} = 33$).

5.2. Control questions

To account for differences in risk perceptions potentially caused by varying levels of detail between the different visualisation forms, we included two control questions, which asked participants to rate the riskiness and safety of the driving situation depicted in the scenario. As intended, perceptions of riskiness and safety did not differ significantly between conditions (for riskiness: $M_{text} = 4.97$, $M_{video} = 5.03$, $M_{simulation} = 5.15$, $p = 0.913$; for safety: $M_{text} = 5.50$, $M_{video} = 5.03$, $M_{simulation} = 4.76$, $p = 0.127$).

5.3. Evaluation of presentation forms

A one-way ANCOVA was conducted to compare the effect of presentation form on the vividness of mental imagery elicited by the vignette, real-world video and VR simulation, while controlling for frequency of car usage. There was a significant effect of presentation form on vividness of mental imagery at the $p < .05$ level for the three conditions [$F(2, 99) = 5.851$, $p = 0.004$]. Post hoc comparisons using the Tukey test indicated that the mean score for the real-world video condition (M = 5.13, SD = 0.93) was significantly higher than the text condition (M = 4.27, SD = 1.3; p = 0.004). Additionally, the video condition evoked a marginally significant increase in vividness of mental imagery compared to the VR condition (M = 4.49, SD = 1.21; p = 0.053). Interestingly, the VR condition did not significantly differ from the text condition (p = 0.721). These results only partly support our hypotheses. Specifically, while these results suggest that real-world videos evoke more vivid imagery than textual descriptions (H1a), as expected, they indicate that the VR simulation does not perform significantly better at creating vivid mental images of automated driving than videos (H1b) or the vignette (H1c).

In the same way, a one-way ANCOVA was conducted to compare the three presentation forms in terms of user experience, controlling for frequency of car usage. User experience differed significantly between the three conditions [$F(2, 99) = 4.075$, $p = 0.02$]. Post hoc comparisons showed that the mean score for the video condition (M = 5.33, SD = 0.94) was significantly higher than the text condition (M = 4.71, SD = 1.16; p = 0.017), confirming H2a. However, the VR simulation condition (M = 5.11, SD = 0.91) did not significantly differ from the text and real-world video conditions (p = 0.229 and p = 0.649, respectively), which leads us to dismiss H2b and H2c.

Finally, a third one-way ANCOVA examined how the presentation forms were evaluated overall in terms of their visualisation capability, controlling for frequency of car usage. The evaluation differed significantly between conditions [$F(2, 99) = 4.358$, $p = 0.015$]. Post hoc comparisons revealed that the mean score for the video condition (M = 4.88, SD = 1.25) was significantly higher than the text condition (M = 3.94, SD = 1.72; p = 0.04), confirming H3a. Similarly, the VR simulation condition (M = 4.9, SD = 1.65; p = 0.036) was evaluated significantly more positive than the text condition (H3c). There was no significant difference between the video and VR conditions (p = 0.997, H3b). Again, these results only partly support our hypotheses.

Additionally, a closer look was taken at the individual items (semantic differentials) used to measure vividness of mental imagery and user experience. Interestingly, the real-world video received higher scores on all imagery scale items, indicating that the video consistently evoked more vivid mental images than the VR simulation. The comparison of mean scores for individual items of the user experience scale revealed that while the real-world video was rated more favourably in terms of realism ($M_{Video}= 5.21$, $M_{VR} = 4.33$), simplicity ($M_{Video} = 5.94$, $M_{VR} = 5.7$), clarity ($M_{Video} = 5.65$, $M_{VR} = 4.73$), pleasantness ($M_{Video} = 5.09$, $M_{VR} = 4.39$) and overall value ($M_{Video} = 5.47$, $M_{VR} = 5.24$), the VR simulation received noticeably higher scores in terms of excitement ($M_{Video} = 4.74$, $M_{VR} = 5.18$) and interestingness ($M_{Video} = 5.15$, $M_{VR} = 5.85$). *Fig. 1* illustrates these observations.

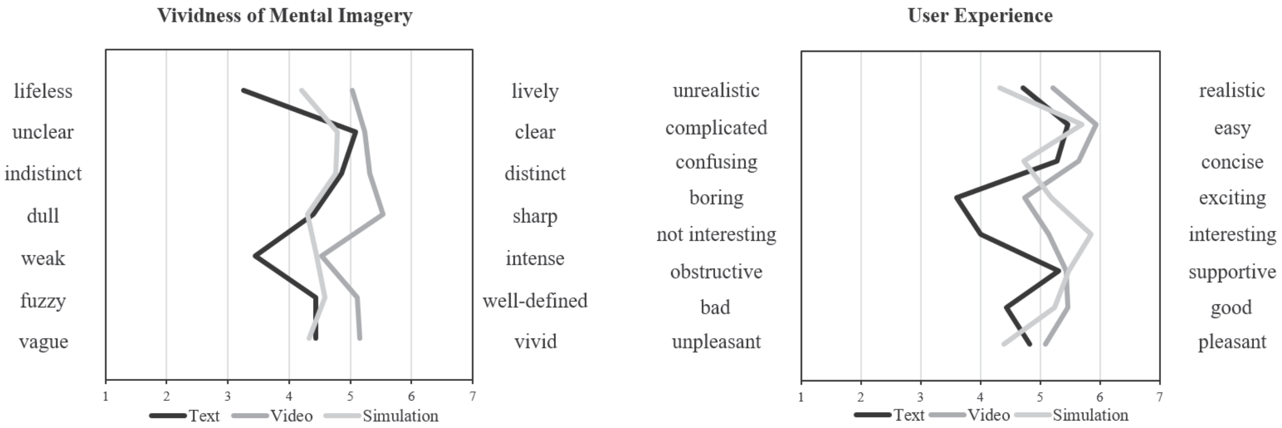

Fig. 1: Comparison of mean values for individual items of vividness of mental imagery and user experience.

6. Discussion

6.1. Evaluation of presentation forms

Results demonstrate that, of the three presentation forms included, real-world **videos** evoke the most lively, sharp and vivid mental imagery of automated driving in respondents. Additionally, the comparison of mean scores for individual items of the user experience scale showed that the video was rated most favourably in terms of realism, simplicity and clarity. Qualitative comments from the open question confirmed this finding, as participants commented favourably on image quality (e.g. P68: *"Image quality was top notch!"*), visual clarity (e.g. P69: *"Picture was sharp throughout."*) and realism of the video scenario (e.g. P58: *"Route was known to me, which I found quite positive. That made it more realistic."*). These findings correspond to previous research, which showed that real-world images outperformed computer-generated graphics in terms of realism (Gerber et al. 2019; Yeo et al. 2020). It was striking, however, that in the real-world video condition, open comments focused mostly on the specific driving behaviour displayed by the vehicle. Even though in recording the ride, care was taken to ensure that traffic regulations and speed limits were observed at all times while maintaining a cautious driving style, as is to be expected of automated vehicles, some study participants criticised the fact that the vehicle drove slower on rural roads and sometimes faster in towns than they would have considered appropriate, as stated by P16: *"I would not drive only 70km/h outside the city and would be very annoyed by other drivers driving this slowly for no apparent reason."*. This observation contrasts previous research, which reported that participants were less aware of vehicle speed and behaviour towards other road users in a video representation, compared to a VR scenario (Hoggenmueller et al. 2021). Similarly, other behaviours displayed by the vehicle were criticised: *"The distance to pedestrians crossing the street should have been greater."* (P52). It may be that the higher familiarity with the driving situation as depicted in the real-world video led to more critical evaluations of the scenario and displayed driving behaviour in this condition.

Results of the analyses further showed that the **VR simulation** was rated considerably lower in terms of its ability to stimulate lively mental images of automated driving than the real-world video, although only marginally significant. This finding was unexpected, as previous research indicates that the rich, dynamic stimuli of VR increase vividness of mental imagery elicited (Schlosser 2006). However, it seems possible that the evoking of mental images was limited due to restrictions of the VR simulation. Some authors point out that despite the advanced state of the technology, study participants sometimes perceive simulations as game- or cartoon-like, which may prompt them to feel detached from the virtual environment and, in turn, may elicit less lively mental imagery (Hoggenmueller et al. 2021; Hutchins et al. 2019). Some of the open comments also related to this aspect, for example, P84 commented: *"It looked like a video game to me, which did not make it feel like a real experience"*. Additionally, scores for individual items of the user experience scale showed that the VR simulation was rated less favourably with regard to simplicity and pleasantness than the real-world video. This observation was corroborated by participants commenting on the blurriness of the display: *"Interior of the car was a bit blurry from time to time. Movements felt a bit jerky."* (P90). Similarly, the experience of movement lag and cyber sickness is another problem frequently encountered in the context of VR simulations (Calogiuri et al. 2018), which may lead to less favourable evaluations (Hoggenmueller et al. 2021). In the present study, six participants commented on experiencing movement lag (e.g. P95: *"The simulation did not run smoothly in some parts"*), while two participants mentioned a slight motion sickness due to blurriness of the image, e.g. P86: *"I was glad when I could take off the VR glasses, otherwise I would have felt sick. Sudden turns and blurry images led to dizziness."*. Lastly, it should be noted that, while the VR simulation received a lower score in the overall user experience, it was perceived as more interesting and exciting than the video – this "wow factor" of immersive VR displays (Pan and Hamilton 2018, p. 398) has been found to have positive effects on participants' enjoyment and engagement during data collection in previous research (Brade et al. 2017).

Finally, the results reveal that the **vignette** was perceived as the least suitable presentation form for visualising a ride experience in an automated vehicle: The mean value of 3.94 for visualisation capability indicates a rather critical evaluation by respondents. Similarly, with a mean value of 4.27, the vignette did not seem to evoke particularly lively mental images in respondents. This finding corresponds with studies reporting that textual descriptions of ADAS did not perform as well in visualising functionalities and human-machine interactions as a simulator experience (Rahman et al. 2017). While vignettes have been used extensively in research, their suitability in the context of automated driving research therefore seems limited (Nastjuk et al. 2020). Even though textual descriptions may help foster a basic understanding of emergent technologies, they do not suffice in making them more tangible for consumers (Liu et al. 2019). Interestingly though, open comments in the vignette condition were quite positive overall. In particular, it was highlighted that the vehicle reacted correctly to different driving situations, for example: *"It was good that the vehicle recognised different environments and adjusted the speed accordingly."* (P11). Even though the vignette described the same driving behaviour that was displayed in the other conditions, including vehicle speed, no critical comments were made about these aspects.

6.2. Implications for study design in the context of emergent technologies

Overall, the findings of this research indicate that the included presentation forms differ significantly in terms of their ability to create mental images of the focal technology, their user experience and their visualisation capability. Additionally, open comments suggest that participants focus on different aspects of the scene as well as behaviours displayed by protagonists in the scenarios – in this case, the driving behaviour of the focal automated vehicle – depending on the presentation form used. These findings suggest that choice of presentation forms should take into account potential effects on study participants, advantages and drawbacks of presentation forms as well as study objectives. While by no means conclusive, the following recommendations provide indications for future research regarding the choice and design of suitable presentation forms for visualising emergent technologies for the purpose of empirical research.

Open comments indicated that, even though most participants inferred it was not an actual self-driving vehicle, the real-world video condition was perceived as very realistic due to the naturalistic environment. While VR offers high immersion, 3D environments used in VR simulations often lack visual richness and realism compared to real-world videos (Gerber et al. 2019). Additionally, real-world videos can represent not only the subject of investigation, e.g. the automated vehicle, but also a more detailed context at a higher level of realism (Flohr et al. 2020). This may be beneficial in cases where not only a specific object, like a product or prototype, is to be evaluated, but rather an experience, which requires more contextual information.

In contrast, due to limits in computing power, simulations typically include only a limited number of animations (Venverloo et al. 2020). Because of this, the investigation of more complex scenarios, such as urban traffic, may be difficult in VR. Additionally, it may not be advisable to use VR in very dynamic scenarios due to substantial confounding effects of simulator sickness. Thus, videos may be easier to implement in many cases when the goal is to simulate dynamic situations, such as automated driving, rather than building and using comparable computer-generated environments (Yeo et al. 2020).

Linked to this, however, when using real-world videos, researchers need to consider unintended and potentially confounding effects of the environment and the behaviour of other actors. When videos are created in real environments, undesired confounds may occur and may adversely affect respondents' perceptions (Flohr et al. 2020; Orzechowski et al. 2005). Qualitative data in this study also indicated that aspects beyond the vehicle itself influenced participants' perceptions. In contrast, computer-generated simulations allow for high controllability and enable the use of carefully crafted scenarios, thus limiting unwanted confounding effects (Gerber et al. 2019).

As qualitative comments showed, representations in complex VR scenarios may lead participants to express feedback directed at peculiarities and visual fidelity of the presentation (e.g. textures, glitches or blurry elements). Similarly, in previous research, VR led participants to focus more closely on the presentation of computer-generated other human beings in the scenario, with whom they felt to be sharing the experience in the context of shared automated mobility (Hoggenmueller et al. 2021). This indicates that elements of the VR experience may distract participants from a holistic evaluation of the scenario being shown. Therefore, it seems that VR simulations are better suited for the assessment of less complex scenarios and technology representations, or for evaluations of prototypes that require more focused attention.

Here, the high immersion and engagement achieved in VR may help participants focus on the main subject of investigation without distractions from environmental factors or other actors.

Linked to this, however, it should be considered that while HMDs allow users to be fully immersed in VR, they also 'cut off' participants from the real environment surrounding them, thus making it difficult to conduct studies that involve interactions with real objects (Pan and Hamilton 2018). In the context of automated driving research, this implies that it is impossible to study realistic behaviour during an automated ride without additional hardware (i.e. hand-held controllers) and considerable additional development effort, as the HMD makes it very difficult for study participants to engage in other, non-driving related tasks involving hand-held objects such as personal smartphones or laptops.

In general, it should be noted that VR simulations are typically rather costly and require specialised hard- and software as well as substantial time and skill to create the simulated environment (Flohr et al. 2020). In addition to that, the data collection using VR is cumbersome compared to browser-based surveys including textual descriptions or videos. Because videos do not require specialised equipment to display them, they can easily be incorporated into online surveys, thus facilitating data collections with larger samples and lower costs. Additionally, they can easily be shared between research groups and institutions to conduct comparable studies (Pan and Hamilton 2018). Therefore, compared to VR simulations, real-world videos may be preferable in terms of reproducibility and cost-efficiency.

Finally, vignettes arguably represent the most convenient, time- and cost-efficient way of presenting emergent technologies to consumers. However, it has been pointed out that textual descriptions may only help foster a basic understanding of emergent technologies but do not suffice in making them more comprehensible to potential users (Liu et al. 2019). Still, in studies that aim to examine general attitudes and acceptance factors with regard to a specific technology, it may be sufficient to provide a textual description accompanied by pictures. However, close attention should be paid so that descriptions do not include evaluative statements about the technology, to minimise the potential influence on participants' evaluations (Nastjuk et al. 2020).

6.3. Practical Implications

This research provides implications regarding how emergent, automated technologies and related service offerings should be communicated and advertised to make them more comprehensible to potential future users and the general public. In particular, this study reveals that the real-world video representation was rated the most supportive in imagining a ride experience in an automated vehicle. Thus, videos seem to be a promising presentation form to familiarise consumers with automated mobility offerings. Previous research shows that an increase in information and knowledge about technologies such as automated driving or artificial intelligence increase trust and usage intentions (Ayoub et al. 2021; Bedué and Fritzsche 2021). Therefore, depending on objectives, videos can be enriched with explanations and information to help consumers understand the benefits and limitations of the focal technology. Additionally, videos can easily be distributed through various channels to reach a large audience in a resource-efficient way, making them a valuable medium for informational campaigns. In contrast, VR simulations may be a promising presentation form in the context of informational events, thanks to their "wow"-factor and ability to leave a lasting impression on users. Properly implemented in public information campaigns, a mix of different presentation forms may therefore assist in paving the way for the successful introduction of automated technology and related service offerings.

7. Limitations and future research

While the results of this exploratory study provide relevant insights regarding the perception of different presentation forms of emergent technologies, this research is not without limitations.

First, while participants received a small monetary compensation to stimulate participation in this study, personal interest in automated vehicles may have triggered participation and thus resulted in a sample with an above-average interest in new technologies. Additionally, despite efforts to recruit a heterogeneous group of participants with respect to demographic characteristics, the comparatively small sample size limits the generalizability of the reported findings. Future research should therefore seek to include larger and more diverse samples.

Second, the selected presentation forms were subject to limitations. While the vignette was adapted to the scenario shown in the video and the simulation, the text description inevitably contained less detailed information about contextual factors than the other conditions. Similarly, it seems possible that further variables could have influenced participants' evaluations of the chosen presentation forms. For example, some authors report higher values of enjoyment elicited by VR environments compared to less immersive presentation forms (e.g. Brade et al. 2017), which could have biased the assessment of user experience or visualisation capability. Future studies should seek to control for such effects.

Third, this study did not compare mediated presentation forms with an actual driving scenario. As such, the question of whether the effects found in empirical studies relying on mediated experiences are transferable to respondents' perceptions and evaluations following real-world driving experiences remains unclear. A comparison of mediated and actual experiences with automated driving could thus help in identifying systematic bias in empirical studies (Mara et al. 2021). Additionally, future research should seek to examine potential moderating effects of personal characteristics such as affinity towards technology.

Finally, this research did not investigate the effects of presentation forms on users' evaluations and acceptance of emergent technologies. Extant research suggests that experience can enhance consumers' trust and acceptance of automated technology (e.g. Moták et al. 2017). However, while preliminary evidence indicates that even mediated experiences, e.g. through simulations, may yield changes in trust in automation (e.g. Gold et al. 2015; Wintersberger et al. 2021), to the best of our knowledge, no attempts have been made to systematically investigate whether such mediated experiences can effectively influence attitudes and acceptance of a technology as complex as automated driving. With regard to measures aimed at promoting acceptance, this might be an interesting avenue for future research.

8. Conclusion

It is difficult to experience and evaluate a technology that is not fully implemented yet. Thus, study participants often rely on imaginations when asked about their perceptions of and intentions to use emergent technologies. By systematically investigating the effect of different forms of technology representation in a comparative study, focusing on the use case of automated driving, this research adds to the methodological discussion of making emergent technologies tangible for study participants and provides recommendations for future research. Specifically, results indicate that real-world videos may be more suitable in mediating the experience of complex service offerings such as automated driving than VR simulations. Although not conclusive, the recommendations given provide directions with regard to the choice of a suitable visualisation considering advantages and drawbacks of different presentation forms as well as research objectives.

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Appendix A

Table A.1: Presentation forms

Presentation forms used

Text scenario

Imagine you are taking a ride in a fully automated vehicle. Please put yourself in the following situation: You are sitting in the driver's seat of the vehicle, but your hands are not on the steering wheel.

The vehicle drives through an urban environment at approx. 50km/h without your intervention. Other vehicles are approaching and passing by on the opposite lane. The vehicle crosses a green traffic light. Along the road, you see a park and residential houses as you pass. The road widens and splits into two lanes. The vehicle recognizes this and merges into the right lane. You are now approaching an intersection where the traffic light is just changing to red. The vehicle brakes and stops. Pedestrians and cars in the crossing lane pass through the intersection.

After the traffic light turns green, the vehicle drives off autonomously and turns right at the intersection. The road you are now on leads out of the city. The vehicle passes another green traffic light, then turns into a roundabout and takes the first exit. You are now on a rural road with tree lined up along the road. The vehicle accelerates to around 70km/h.

Presentation forms used

After a few minutes of driving, you enter a smaller town and the vehicle automatically slows down to about 50km/h. On the sidewalks along the road, pedestrians are walking by. At the next intersection, the car slows down and finally turns right. The road now narrows and the vehicle is only driving at 30km/h. During the entire journey, the vehicle drives autonomously and you do not need to intervene in the driving action.

VR simulation scenario (screenshot)

Real-world video scenario (screenshot)

Appendix B

Table B.1: System specifications

Graphics	NVIDIA GeForce RTX 2080 Ti
Video Memory	11GB GDDR6
System memory (RAM)	64 GB
Processor model	Intel Core i9-9900K
CPU	3.6 GHz, 8 cores

The virtual environment was developed by a professional service provider specialized in 3D modeling and simulation design using Unreal Engine Version 4.25. Scenario shown using HTC Vive Pro headgear.

Appendix C

Table C.1: Constructs and Measurement Items

Authors (Year)	Constructs and Measurement Items
Adapted from Miller et al. (2000)	**Perceived Vividness of Imagery** How would you rate the mental image of automated driving you got based on the simulation/video/text? ■ lifeless / lifelike ■ unclear / clear ■ indistinct / distinct ■ dull / sharp ■ weak / intense ■ fuzzy / well-defined ■ vague / vivid
Adapted from Schrepp et al. (2017)	**User Experience** How do you evaluate your experience with the visualisation of automated driving provided by the simulation/video/text? ■ unrealistic / realistic ■ complicated / easy ■ confusing / concise ■ boring / exciting ■ not interesting / interesting ■ obstructive / supportive ■ bad / good ■ unpleasant / pleasant
Self-developed	**Visualisation Capability** VC1: The visualisation has helped me to better imagine automated vehicles. VC2: The visualisation has given me a clearer idea of what automated driving could be like VC3: The visualisation helped me to better imagine myself in the situation of driving in an automated vehicle. VC4: The visualisation gave me a realistic picture of automated driving. VC5: I find the presentation form well-suited for visualising automated driving.
Self-developed	**Control questions** The driving situation shown seemed risky to me. The driving situation shown seemed safe to me.

Appendix D

Table D.1: Previous comparative studies

Reference	Topic	Research type	Presentation forms compared	Study design	Sample	Method of analysis	Relevant findings
Arentze et al. (2003)	Choice of transport mode for work trips	Stated choice experiment	Text and pictures Text only	Between subjects	n=346	Multinomial logit model	Pictorial material added to a verbal description of attributes does not have an impact on error variance or attribute weights.
Bateman et al. (2009)	Evaluation of options for coastal land use	Choice experiment	Numeric information only VR VR & Numeric information	Between subjects	n=288	Random effects probit model	Respondents consider changes in coastal land use more significant when the information is conveyed to them in numeric form alone than when they are additionally or solely presented with VR. Compared to the standard presentation of numeric information, providing VR presentations of changes significantly reduces respondents' valuation of losses. VR presentation led to a reduction in error variance.
Farooq et al. (2018)	Preferences related to automated vehicles and related infrastructure changes	Stated preference experiment	VR Text only Images	Within subjects	n=42	Multinomial logit model	VR presentation increases preferences for autonomous vehicle scenarios compared to text-only and image condition. The VR scenario improved understanding, and increased consistency of preferences.
Fiore et al. (2009)	Evaluation of wild fire management policies	Choice experiment	VR 2D images (2 pictures) 2D images (52 pictures)	Between subjects	n=45	Latent choice model	VR treatment generated subjective beliefs that are closer to actual risks compared to the picture treatments.
Hoggenmueller et al. (2021)	Evaluation of external human-machine interface in the context of automated vehicles	User study	Real-world VR Computer-generated VR Real-world video	Between subjects	n=42	Analysis of variance (ANOVA)	Engagement ratings are high for RW-VR and CG-VR, and slightly above middle rating for RW-Video. Ecological validity is highest for RW-VR, with high values for CG-VR and RW-Video. No significant differences between the different prototype representations in UX ratings of the eHMI.

Reference	Topic	Research type	Presentation forms compared	Study design	Sample	Method of analysis	Relevant findings
Jansen et al. (2009)	Housing preferences	Conjoint analysis	Study 1: Text only Text and color images Text and black-and-white impression Study 2: Text and photo-collages Text and photo-collages on request	Study 1: Within subjects Study 2: Between subjects	Study 1: n=28 Study 2: n=107	Part-worth utility models Multinomial/ Binominal logit model	Impact of architectural style on choice is larger when images are included in the presentation method. Presentation modes affected the perceived importance of the attributes: attributes shown on images were deemed to be more important.
Mara et al. (2021)	Evaluation of humanoid robots	User study	2D video 3D video VR Live demonstration	Between subjects	n=119	Analysis of variance (ANOVA)	Live HRI increased immediacy compared to video conditions. No significant differences between the live HRI and the VR condition, and between the 2D and 3D video. Live HRI condition led to highest perceived human likeness. No significant differences between live HRI and 3D video or 2D video as well as between VR and 3D or 2D. No significant influence of presentation mode on perceived eeriness, likability, or purchase intentions.
Matthews et al. (2017)	Evaluation of coastal erosion management policies	Choice experiment	Computer-generated video Text with pictures	Between subjects	n=1062	Mixed-logit choice model T-tests Mann-Whitney-U test	Video treatment reduced choice error when compared with static images. Video group indicated higher enjoyment. Video treatment improved likeliness to complete the first survey and increased retention of respondents in retests.
Orzechowski et al. (2005)	Housing preferences	Conjoint analysis	VR Text only	Between subjects	n=64	Multinomial logit model Modified Chow test	No significant difference in terms of internal and external validity. Presentation mode did not significantly influence housing preferences. The VR condition had a lower associated error variance. Evidence of better face validity of the price attribute for the verbal description format.
Patterson et al. (2017)	Neighborhood choice	Choice experiment	VR Text only	Between subjects	n=368	Multinomial logit models and mixed-logit models	Presentation mode did not lead to differences in perceived importance of attributes. Participants were more focused in the VR condition.
Rizzi et al. (2012)	Estimated value of travel time savings in varying traffic conditions	Stated-preference choice experiment	Computer-generated images Text only	Between subjects	n=481	Mixed-logit choice model	Images significantly influenced perceived differences between travel times: in surveys with images, VTTS for congested travel times were significantly higher than for free-flow travel times. In surveys without images, VTTS were the same in both travel conditions.
Vriens et al. (1998)	Car radio preferences	Conjoint analysis	Text and pictures Text only	Within subjects	n=160	Part-worth models Analysis of variance (ANOVA)	Results indicate that design attributes have higher relative importance in the pictorial mode compared to text only condition. Preliminary evidence that the verbal representation produces higher predictive accuracy compared to pictorial mode.

Keywords: automated driving, virtual reality, videos, visualisation capability