White Paper

Augmented reality head-up displays: HMI impacts of different field-of-views on user experience

Visteon

Augmented reality head-up display HMI impacts of different field-of-views on user experience

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1 Retrospective

Head-up display (HUD) technology in aviation has been known about since the 1940s. It keeps the pilot's
attention focused outside of the cockpit and supports aircraft control by information visualization within the pilot's main sight line on a transparent combiner. What has been worked out for pilots, also worked for drivers. "The Oldsmobile 1988 Cutlass Supreme Indianapolis Pace Car and limited edition replica cars were the world's first production automobiles equipped with a HUD" (Source: GM). In 2001, GM featured the first color windshield HUD (W-HUD) with the Corvette.

With the introduction of less expensive combiner HUDs (C-HUD), as an alternative to W-HUD technology in 2005 by PSA, one can observe a rising market demand and penetration of both HUD technologies up to this date. Whereas a W-HUD uses the windshield for picture reflection, the C-HUD utilizes a transparent screen that works as a reflection plane in front of the windshield. The value of both technologies are subjectively and objectively measurable – high subjective acceptance, reduction of driver distraction due to less eye accommodation, eye adaption, information pick up time, and sight deviations, amongst others (Milicic, 2009).

Depending on optics, technology, and available package, simple C-HUDs can present information up to 2m in front of the driver's line of sight. W-HUDs are also able to present information in a typical distance of 2.5m. In future, automakers will offer augmented reality HUDs (AR-HUD), pushing the limit for their virtual image position above 7m. Following these technology trends and our customers' demands, Visteon's advanced technology group is additionally developing this innovative technology.

This paper will focus on the properties that influence drivers' HUD experience. From the end-user's perspective a general question is: What is the benefit of AR-HUD technology compared with conventional HUD solutions? From designers' perspective, what could be the requirements in designing HMI for cars with AR-HUD technology?

Next to the virtual image position, there are a number of additional aspects to consider such as differences in location of the image within the size of the field-of-view (FoV), human factor requirements, and the design of the HMI, which means to define what information is shown where, when and how.

The C-HUD image position can be perceived within the combiner and positioned on the top of the instrument panel. Since the combiner is transparent, the picture seems to float above the instrument cluster in front of the lower windshield area. Look-down angles can vary between -2° to -5°. The C-HUD FoV of 3°x1° up to 6°x2.5° is relatively small.

Free of the physical and visible combiner restrictions, the W-HUD image position can be located higher - which means a smaller viewing angle. The position of the W-HUD picture is floating above the bonnet, in front of the street. With a FoV from 4°x2° up to 10°x2.5° drivers subjectively perceive almost double the width of the virtual image. This picture can cover critical traffic environments outside of the windshield.

AR-HUD images can feature FoVs of up to 17°x6.5°. Their look-down angle can achieve 0° - which means the image center can be perceived in front of the horizon. Based on the most frequent use cases this represents a theoretical value, since the most useful assistance depictions while driving is needed in between the horizon and the hood. This can be achieved with a look-down angle of 1°. Even the fact that the virtual image is optically perceived only at 7m does not hinder the driver to bring this information in context with objects that are much further away. The human eye's accommodation (near-far-adjustment) is adjusted to infinite above 4m meters and the human brain is the greatest "tool" to make sense out of presented visual information.

Both conventional HUD solutions - C-HUD and W-HUD - can feature driver information and ADAS representations within the primary sight line. Nevertheless, C-HUD and W-HUD depictions are not fully augmenting reality one is driving through. In other words, these two technologies are showing concise information in a different location. Navigation routing symbols for instance need to be cognitively processed by the driver and applied into the actual situation. This procedure affords milliseconds of time and attention resources (Morita, National Traffic Safety and Environment Laboratory).

In order to reduce cognitive workload while driving, AR-HUD systems could make a difference to reduce distraction and make driving safer. Driver information, assistance and attention management can be shown not only in drivers' line of sight, but also matching the real traffic environment – a true augmented experience. Navigation routing for instance can directly point into streets, obstacles can be directly highlighted, and adaptive cruise control can be directly brought into context within the FoV. The ideation of possible functional use cases and their benefits is a huge topic within HMI design experience but might be too much to be listed within this publication. Also the ongoing technical efforts to increase the FoV up to the size where the whole windshield might become an AR-HUD display in future.

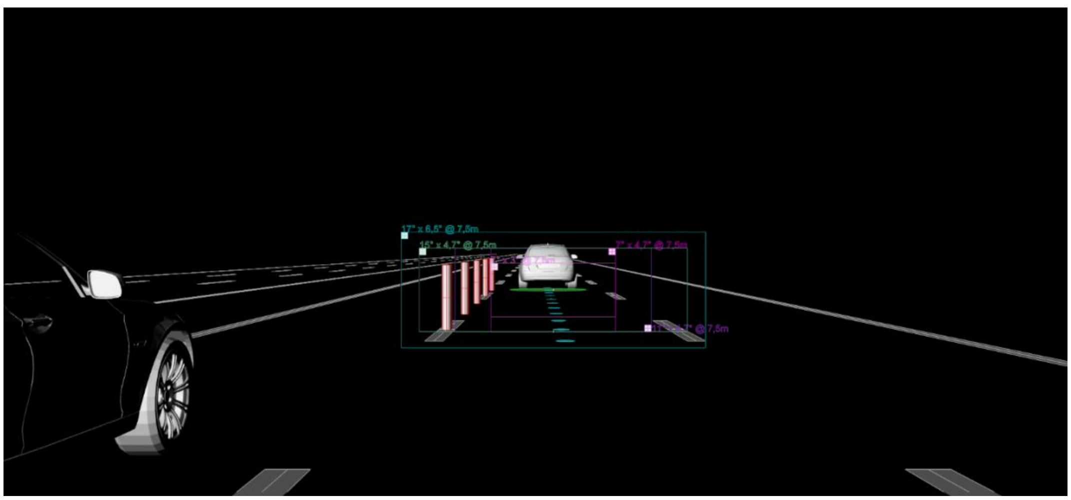
2 Prospective Challenges

To achieve a believable AR-HUD experience, additional technology to the optical and mechanical setup is necessary.

1. Eye tracking in order to calculate the right perspective in 3D of the AR HUD picture.

2. An outside oriented camera that constantly analysis and interprets the traffic situation
3. Background system data available from activated functions e.g. routing.
4. Merging data and picture rendering. It is obvious, that the whole system chain consisting of data acquisition, and data conversion will lead to latency times resulting in perceived picture deviations from the optimum. To keep error ratio low and provide an outstanding HMI experience represents a challenge for us designers.

Interesting for automakers with AR-HUD intentions are simulations to formulate general requirements for AR-HUD development. Specific simulations can analyze subjective deviation tolerances for examples based on most common customer use cases. These use cases are “Blind Spot Detection (BSD)”, “Adaptive Cruise Control (ACC)”, and “Navigation Routing (NavR)”. The designs of the selected functional representations for the three cases were kept constant to concentrate only on displacements of these depictions within the FoV. All three use cases were built and rendered in 3D, respecting the optical properties of the AR-HUD system. Picture 1 shows BSD (red poles), ACC (green ellipse), and NavR (blue dotted line) without any special deviation of the virtual objects relative to the real environment as optimal reference.



Picture 1: Field of views and use case reference

Variables within this sample set were five different FoVs in order to find out if the specific use cases can be displayed within the given FoV.

- 17°x6.5° @ 7.5m
- 15°x4.7° @ 7.5m
- 11°x4.7° @ 7.5m
- 7°x4.7° @ 7.5m
- 7°x3° @ 7.5m

Research Questions

1. What is the subjective deviation tolerance for “BSD” HMI depictions?
2. What is the subjective deviation tolerance for “ACC” HMI depictons?
3. What is the subjective deviation tolerance for “NavR” HMI depictions?

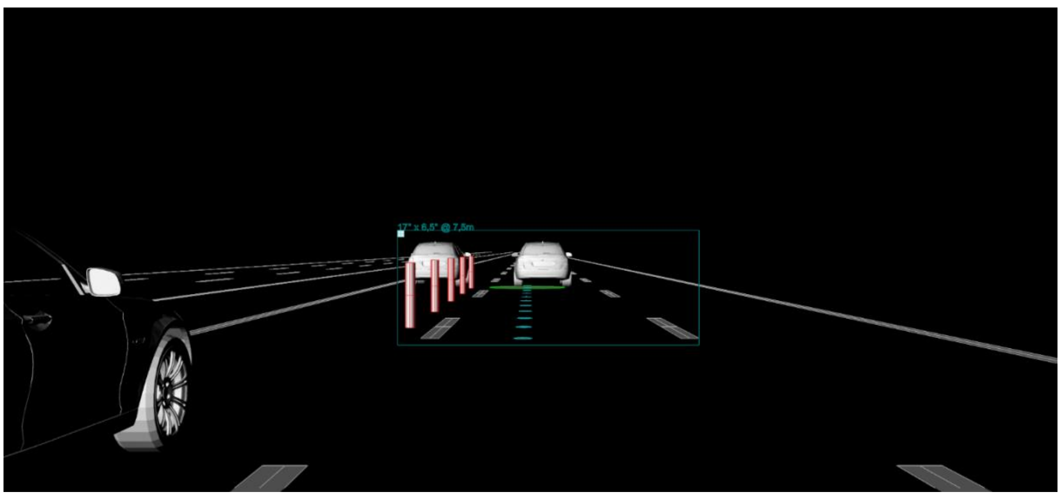
Our simulation setup should also help to answer the following research questions which represent quantitative data for ADAS system requirements and AR-HUD customer recommendations.

4. What is the objective minimal distance for ACC depictions per FoV?
5. What is the objective minimal distance for depictions pointing in intersections per FoV?

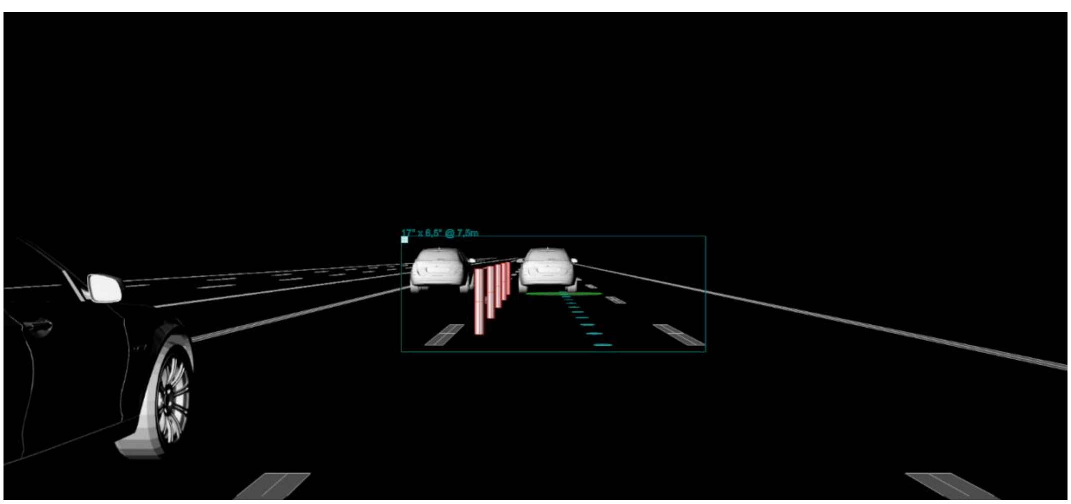
3 Findings

3.1 Subjective Tolerance

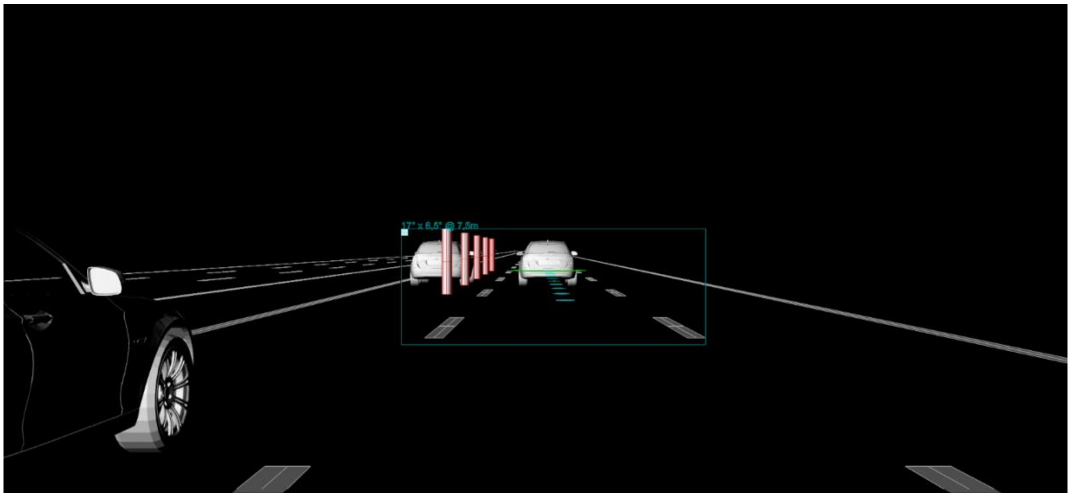
Visteon's experts from quality, engineering and HMI design rated the deviations based on static simulations. Ratings were given for all customer use cases. The maximum subjective tolerance of +/- 0.5m is acceptable for left-right (lateral) and up-down (vertical) picture deviations. This means, that the picture in each functional context could still be assigned to the active function and offered acceptable situational awareness or advice. The driver would accept a mismatch of less than one quarter of a standard driving lane in Europe (see Pictures 2, 3, 4 and 5).



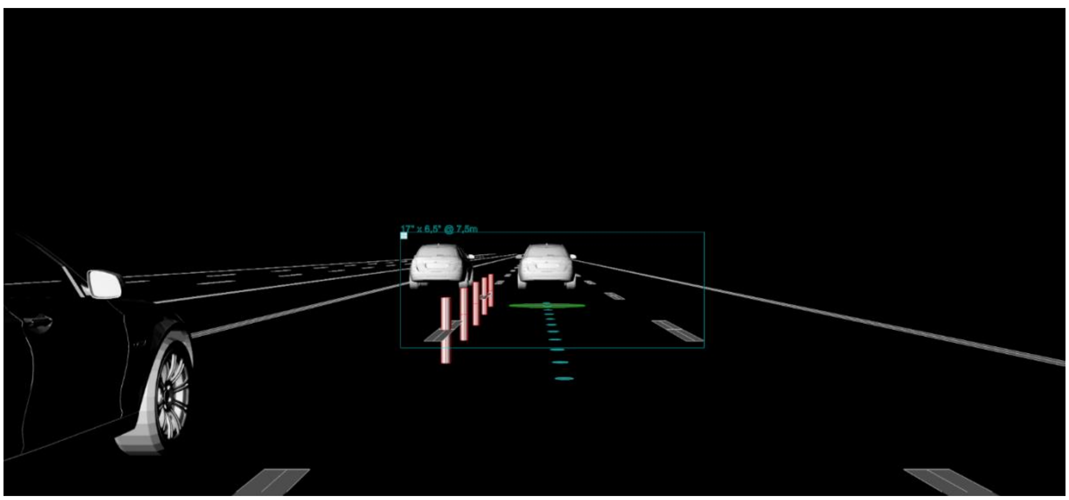
Picture 2: Deviation to left 0.5m



Picture 3: Deviation to right 0.5m

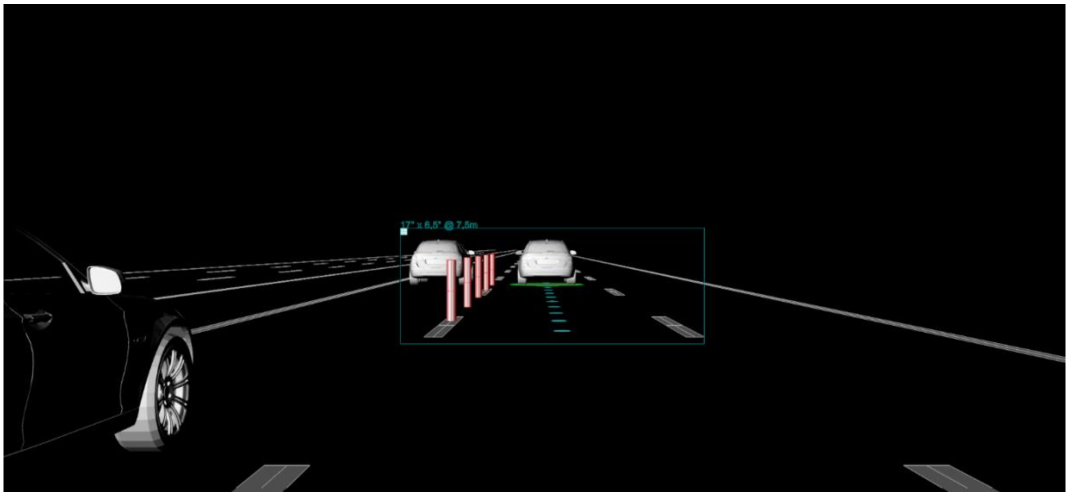


Picture 4: Deviation up 0.5m

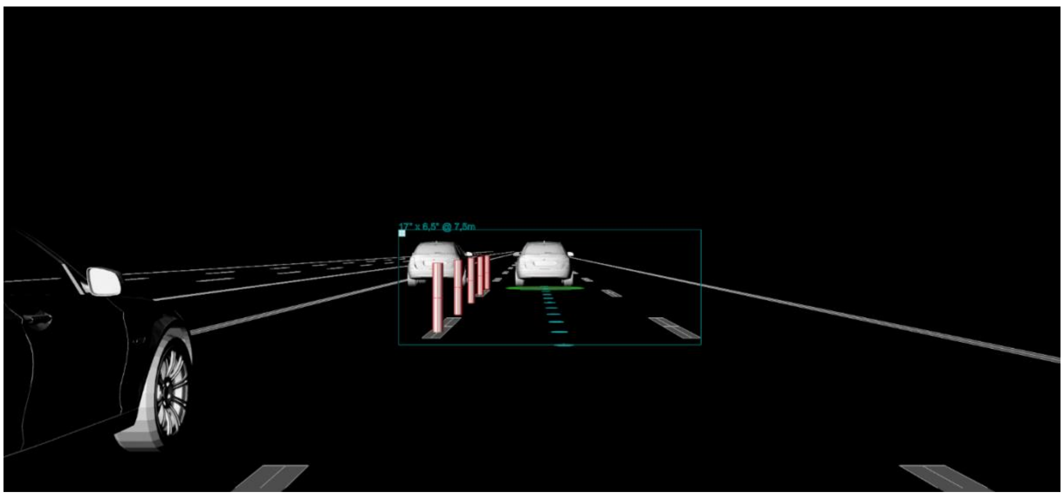


Picture 5: Deviation down 0.5m

An even bigger tolerance of bigger than +/- 1m in driving direction (longitudinal) was evaluated for all customer functions. This insight could lead to the technical property of an AR-HUD system that may vary in dimensional tolerance. Released CPU power for longitudinal calculations could be used to reduce vertical and lateral errors (Pictures 6 and 7).



Picture 6: Deviation deep 1.0m



Picture 7: Deviation near 1.0m

3.2 Recommendations on Field-of-View

With regards on the different FoV sizes, the two smallest ones cannot be recommended for the used customer functions. The missing real estate while driving could lead to the experience that virtual objects are popping in and out of the line of sight (keyhole effect). The three bigger ones offer enough real estate for virtual objects to cover a wider range in front of on the traffic environment, thus virtual objects can be longer visible within the FoV (Picture 1).

3.3 Minimal Activation Speed of ACC

An oversimplified relationship is: the bigger the vertical viewing angle of the FoV, the nearer virtual ACC objects can be placed, and the lower ACC speed activation can be realized.

ACC activation speed is the minimal speed where the ACC system can be turned on. The most automakers offer ACC activation above 30 km/h only. Respecting the popular recommended safety distance (safety distance (m) = speed (km/h) / 2) drivers normally maintain a safety distance of 15m while driving 30 km/h. Our analysis shows the following minimal distances, and minimal activation speeds for ACC:

- 17°x6.5°: 12.7m (lowest ACC activation speed = 25 km/h)
- 15°x4.7°; 11°x4.7°; 7°x4.7°: 15.3m (lowest ACC activation speed = 30 km/h)
- 7°x3° : 18.8m (lowest ACC activation speed = 40 km/h)

This means for Visteon customers, if they would like to maintain their ACC activation strategy, and an elliptical ACC representation, they cannot decide to use an AR-HUD with the smallest FoV. The only way to overcome this restriction would be to use a different HMI representation.

Picture 8: ACC depictions with biggest FoV possible over 25 km/h

3.4 Minimal Distance for Arrows Pointing into Intersections

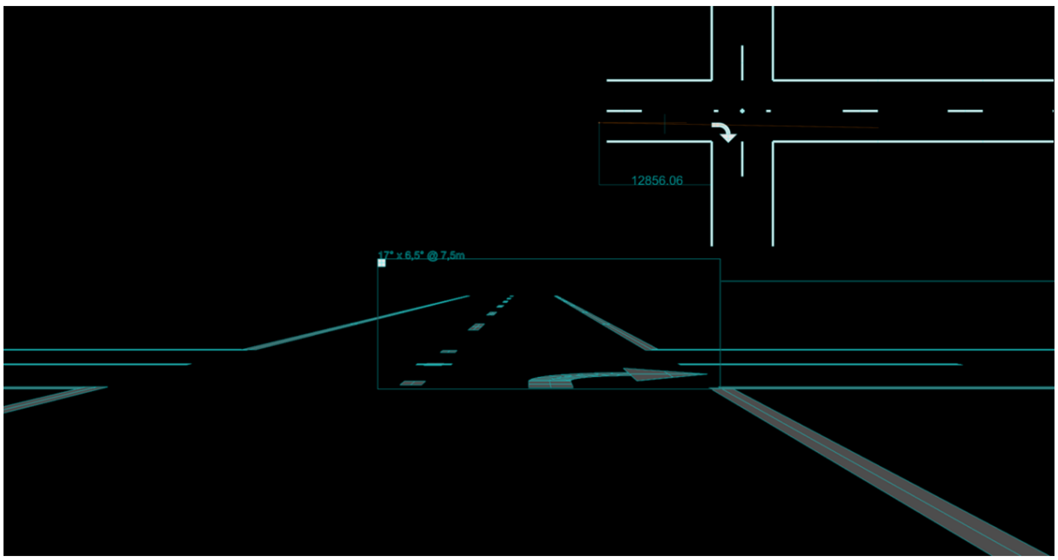
Regarding the navigation routing arrows from the driver's point of view, one can hypothesize that the bigger and wider a FoV is, the longer and nearer one can feature an arrow into a dedicated street. When we assume a city speed limit of 50 km/h, the car covers a distance of 13.88 m per second. A FoV of 17° x 6.5° @ 7.5 m offers visible routing information until a distance of 12.72 m from the eye box, and under a second to reach the crossing street. This value is extraordinary good since the upcoming event to turn stays long enough within the sight line. With a FoV of 15° x 4.7°; 11° x 4.7°; and 7° x 4.7° @ 7.5 m the AR system can still display information until 15.27 m from the eye box. The crossing road is just 1.1 seconds away.

With the smallest FoV of 7°x3° information cannot be shown under a distance of 18.82 m. The driver has 1.4 seconds to drive without routing information. This experience might lead to not acceptable HMI in high density traffic environments such as city driving. We would not prefer the smallest FoV against the bigger solutions.

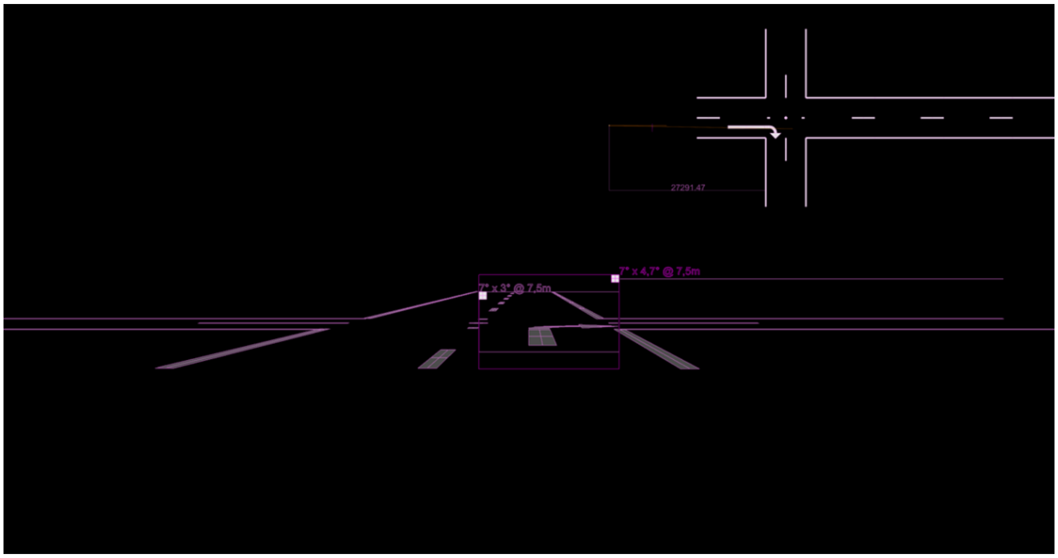
3.5 Minimal Distance for Depictions Pointing in Intersections

A wide and high FoV supports AR-HUD information to be shown long enough and spatially precise enough to drivers preparing for maneuvers. Our analysis shows the following minimum distances for navigation arrows pointing into streets. Especially the width of the FoV is relevant here.

- 17°x6.5° : 12.8m (Picture 9)
- 15°x4.7° : 15.14m
- 11°x4.7° : 18.86m
- 7°x4.7° : 27.29m (Picture 10)
- 7°x3° : 27.29m



Picture 9: NavR with Biggest FoV in 12.8m distance



Picture 10: NavR with smallest FoV in 27m distance

4 Conclusion

Static 3D simulations have contributed to benchmarked different use cases within different FoVs. Subjective deviation tolerances have helped to formulate target settings for AR-HUD system development. Objective data helped to identify if the system can meet functional feasibility for ADAS. We propose to repeat this testing in a dynamic driving context with a working prototype. From here we can conduct usability testing on dedicated use cases that might need specific HMI design improvements. As the potential for the complete windshield to act as a display becomes a reality, designers must carefully balance the amount of augmented information presented to the driver to avoid cognitive overload.

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As human-machine interaction (HMI) and technical design manager in Visteon's European design experience group, Dr. Alexander van Laack is responsible for developing strategies for the use of specialized, automotive-related HMI concepts. In his role, he leads driving simulated user experience research initiatives and is responsible for HMI and user experience concept implementation. Dr. van Laack has more than eight years of automotive experience. He previously held a position as research engineer at Ford Research and Advanced Engineering developing methodologies to measure user experience and quality perception of interiors and HMIs. Dr. van Laack has a master's degree in business administration and engineering, as well as a PhD in engineering, from the RWTH University of Aachen in Germany.

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About Visteon

Visteon is a global company that designs, engineers and manufactures innovative cockpit electronics products and connected car solutions for most of the world's major vehicle manufacturers. Visteon is a leading provider of instrument clusters, head-up displays, information displays, infotainment, audio systems, telematics and SmartCore™ cockpit domain controllers. Visteon also supplies embedded multimedia and smartphone connectivity software solutions to the global automotive industry. Headquartered in Van Buren Township, Michigan, Visteon has approximately 10,000 employees at more than 40 facilities in 18 countries. Visteon had sales of $3.25 billion in 2015. Learn more at www.visteon.com.

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