Keep your Eyes on the Road:

AR HUDs for Automotive

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Introduction

The concept of a Heads-up Display (HUD) is not new. A HUD is a transparent display presenting visual information, so users continue to see their usual out the window viewpoints. There is still some debate over the first implementation of a HUD based on the definition of "Conventional HUD." Depending on how one defines a HUD, it was either North American Aviation in 1958 with the AJ-3 A-5 Vigilante or the Elliot flight Automation 1961 Blackburn Buccaneer. In either case, the HUD originated in defense aviation to centralize critical flight data within the pilot's field of vision. This approach sought to increase the pilot's scan efficiency while reducing "task saturation" and information overload. The HUD is a precursor technology to Augmented Reality (AR) HUD that we are starting to see in automotive systems requirements today.

1958 AJ-3 A-5 Vigilante

1961 Blackburn Buccaneer

1958 AJ-3 A-5 Vigilante

1961 Blackburn Buccaneer

AR HUD systems project information so that it appears integrated with the real-world environment, thereby giving the driver scan efficiency of their environment while reducing the cognitive load. AR HUD Technology is in rapid expansion mode currently and not yet fully implemented in production automobiles. The HUD market is poised for some significant growth. Valued at US$930 million in 2019 with expectations to rise to almost US$2.5 billion by 2026, the HUD industry can expect a compounded annual growth rate (CAGR) of 17.3% during 2020-2026 [(1)]. The AR market is set for even more explosive growth at 46.3% CAGR to reach US$89 billion by 2026 [(2)].

The goal for AR HUDs is to minimize distraction yet still provide critical data to enhance the driving experience. Advanced Driver Assistance Systems (ADAS) information like lane assist, adaptive cruise control, forward collision warning, pedestrian/cyclist detection, navigation hints, and alerts are already present in the 2021 production cars. However, 2D or 3D Point of Interests (POI) are not yet widely present in mass production. Mercedes-Benz will likely be the first OEM to offer the tech in the new S-Class sedan when the 2021 S-Class debuts in September, the brand's flagship sedan offers an AR HUD, among other tech upgrades [(3)]. Modern AR HUDs can enhance driver experience by implementing POI information on the windscreen and giving OEMs the ability to implement unique features that are not available anywhere on the market. To successfully build and implement an AR HUD system, it is crucial to understand how the system's main components come together. These parts are further defined and clarified below.

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1. Reports, V. (2020, July 24). Head up Display (HUD) market size is projected to REACH usd 2422.5 million by 2026 - Valuates Reports. Retrieved March 11, 2021, from https://www.prnewswire.co.uk/news-releases/head-up-display-hud-market-size-is-projected-to-reach-usd-2422-5-million-by-2026-valuates-reports-879069209.html

2. Reports, V. (2021, January). Global Augmented Reality Market - Market Research Report. Retrieved March 16, 2021, from https://www.kbvresearch.com/augmented-reality-market/

3. Gitlin, J. M. (2020, July 10). Augmented reality heads-up displays for cars are finally a real thing. Retrieved March 11, 2021, from https://arstechnica.com/cars/2020/07/augmented-reality-heads-up-displays-for-cars-are-finally-a-real-thing/

AR HUD Defined

AR Engine can be considered everything that a developer needs to dynamically place and draw arbitrary objects to the screen/display at the correct scale, orientation, and placement in the 3D scene relative to the driver. The details of those objects are not part of the AR engine itself. Those details would typically be content development of the HMI. The AR Engine assumes that the Lidar, Range, Camera Vision sends data to an AI system that then calculates the position and object type information, which is then forwarded to the HMI application, which uses the AR Engine to show the objects correctly in the scene. All of these components can be classified in several different ways; however, generally; the components of the AR Engine are as follows:

HUD Distortion Layer

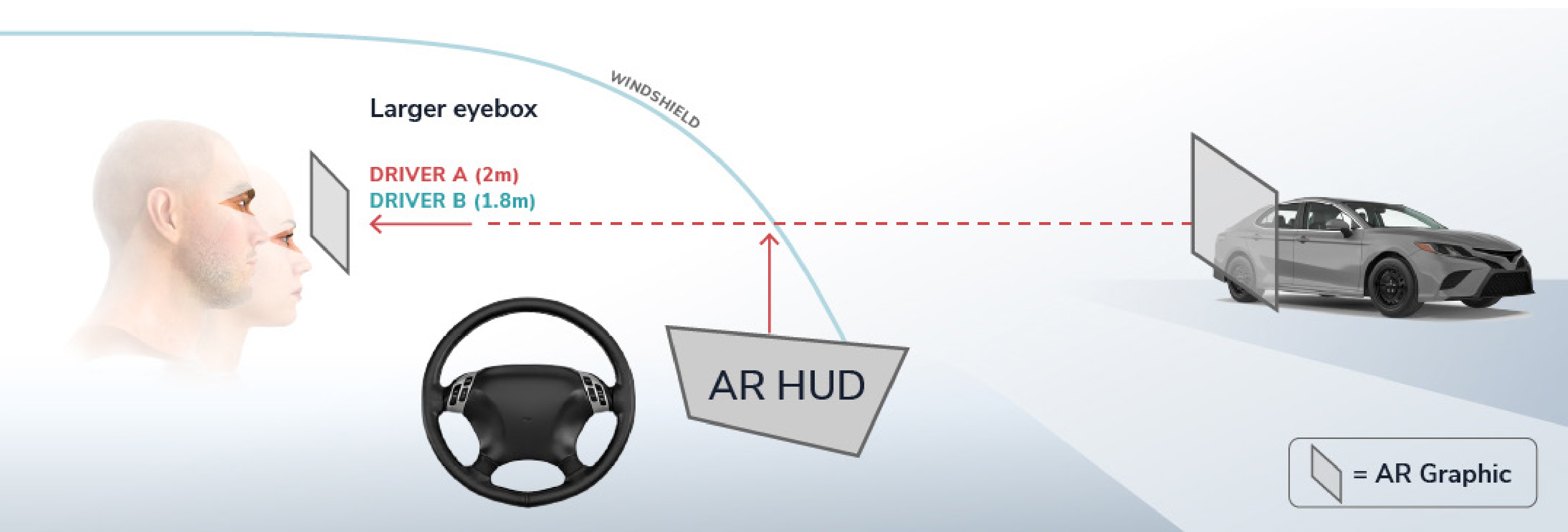
Spatial Calibration

HMI Visualization

The HUD Distortion Layer compensates for the collection of distortions caused by reflections by lenses, mirrors, windshields, and other elements. If head-tracking information is used, this is handled differently. If head tracking is used, this distortion layer may be dynamic based on viewer position. (Ex: Imagine how the windshield curve changes as you move your head close to the door.) This layer creates a large virtual screen floating out in front of the car.

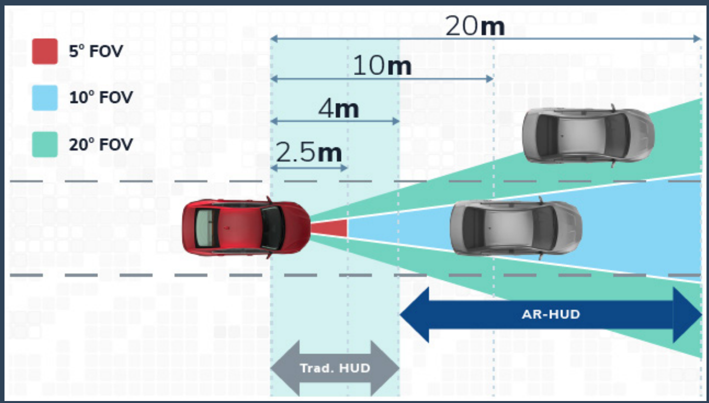
Spatial Calibration determines the matrix transform for a particular viewer position to a particular 3D location relative to the vehicle. As previously described, handling is typically different if head-tracking information is used. This would again be dynamically updated based on detected head position. Without head tracking, there may be a brief calibration sequence for each driver and seat position. Spatial Calibration is what modifies the camera matrix. For example, a marker that is supposed to be on the ground at 50 feet out and 10 feet to the side looks to the driver like it is at that location and, therefore, matches the real-world object it represents. Assuming head tracking is used, this anchoring will be stable while the driver moves their head (within limits), providing solid motion parallax cues to the object's real-world location and size. Data Processing accepts the constant stream of objects and positions and dynamically creates and destroys the 3D objects in the scene as needed. An AR application would need to present digital data onto objects in the real world. With meaningful tracking markers, this is a difficult problem. The implementation of neural networks would enable one to track and classify objects that the neural network has been training on. This position data could be passed to the HMI application handling the view transformation and drawing.

HMI Visualization is the last component of an AR HUD and provides the visual objects and effects that are displayed through the AR Engine. The HMI then uses that AR Engine data as inputs to give the visual front end the information to display the correct size, orientation, and location in the 3D scene to be shown on the screen or display. 3D content is created, positioned, oriented, and configured based on incoming AR Engine data. The details on the appearance of these are highly customizable customer-driven requirements. The HMI would usually not be processing raw data. That would go to the AI Engine, which processes the data and sends out the appropriate data for visualization in the HMI layer. The HMI layer would only get involved when the vehicle system decides that the HMI needs to show visual data in the 3D world. Then the HMI displays the appropriate content where and how it is instructed to do so.

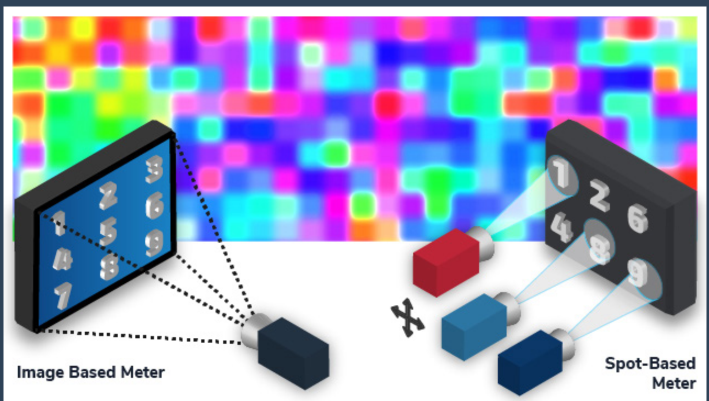


There is certainly no shortage of challenges in developing AR HUDs. There are many excellent papers in the market on these topics. The meaning of this paper is to be more of a general overview. Below is an abbreviated list for consideration in researching one's AR HUD development.

- **Field of View (FoV) projection requirements for AR HUD**
- **Ghosted images and misalignment during calibration of non-identical environments**
- **Driver viewpoint alignment compared to the 3D data displayed over the real-world objects**
- **Tracking objects positions and perspectives while objects are in motion and constantly entering and exiting the scene**
- **Updating data in real-time with no latency**
- **Object classification and tracking to determine hazards, warnings, and points of interest accurately**
- **Determination of data connections between AR Engine to HMI visuals**



Conventional HUD projection distances versus augmented reality HUD (AR-HUD) projection distances, Courtesy of AZO Optics



Evaluation across a HUD field of view can be performed point by point using a spot-based meter or at once using an image-based meter.

As research continues rapidly expanding into AR HUDs, expect this list to continue to grow. Some of the above data points are handled through the proper implementation of Neural Networks discussed further in this paper; some are managed through the use of safety-critical processes also discussed later in this paper. All must be carefully considered when developing an AR HUD for production.

Other Factors to Consider with AR HUDs

As it is related to AR HUDs, V2X is another topic that merits mention. Ideally, Vehicle-to-Everything (V2X) used in AR HUDs would produce almost real-time info presented on the windscreen for traffic assistance (ex. traffic jams, accidents notifications, icy road conditions) or infrastructure information (ex. traffic lights, tunnel lane closed, drawbridge pulled-up/down). There are several challenges here, such as continuous signals, data integrity, and of course, data security, all of which could easily be the topic of their own paper.

As automotive infrastructure continues to evolve and the adoption of EVs becomes more widely spread, it is worth noting that there is more space for the HUD hardware in electric cars. There would no longer be a combustion engine or related parts, and thus more space for the AR HUD system. Potentially more space than classic HUDs could be allocated early during the design process allowing for more processing power availability, hence further flexibility. Electric cars are usually equipped with the ADAS systems needed to support AR HUDs already. There would merely need to be the addition of a different method of detection and projection.

AI and the Role of Neural Networks

Neural Networks (NN) excel at problems that have been tremendously hard to solve in the computer vision domain, for example, Object Classification, Object Tracking, and Specialized Data Compression and Abstraction. Although it is easy for humans to see an object and understand that it is a "car" or a "human," it can be challenging to represent that abstraction for a computer. NN provides a mechanism for us to provide training data and an expected result and then "generate" an algorithm to solve the hard problems for us.

For the example of processing LIDAR data, one can design a neural network that takes a large LIDAR point cloud in as an input and provides 3D positional data as an output.

The next one could take training data and manually create the expected outputs. The goal is to train the neural network against the training data to have an algorithm that will work as specified in the training data. While this is indicative of the high-level view, it does oversimplify the training process. There are some key issues to take into account when training a NN. It is important not to over-train the network on the training data, such that it does not work on generic input data anymore. The training data should also be designed across a wide variance of inputs.

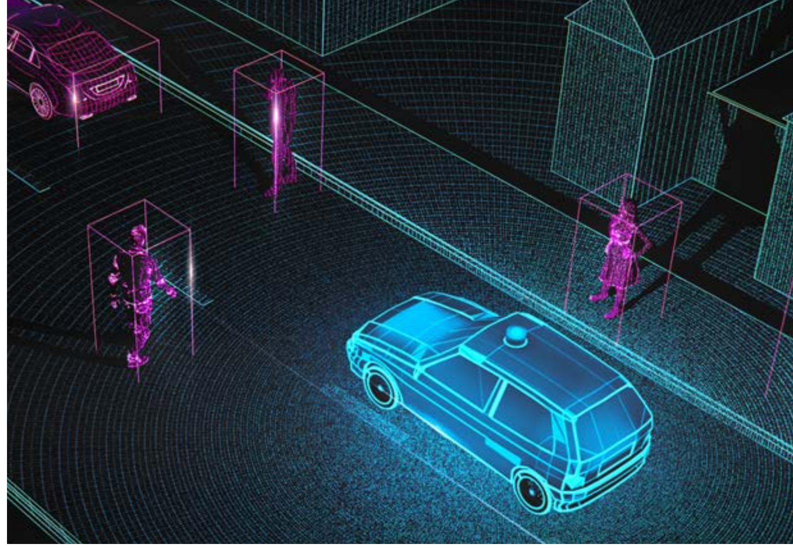
There is still constant research in the field of Neural Networks, especially when it comes to functional safety, and the field is always changing and growing. With hardware that is more powerful and has significantly faster computational cycles available, the execution of NN can easily be accelerated by existing hardware inside vehicles today, like the GPUs we are using for our HMI applications.

HMI Support 3D AR HUD Development

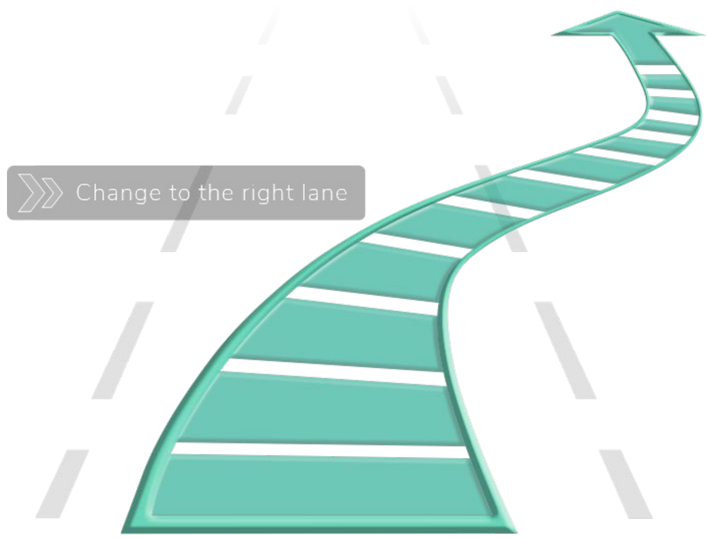
To visualize 3D AR HUD HMI, the development of 3D and 2D components is required. In selecting the HMI tools and framework, the built-in concept of 3D becomes a critical factor for AR HUDs. Flexibility and customizability are the keys to future proof your HMI development for many years to come. **GL Studio®**, for example, has native support for 3D content and full customizability to create reusable widgets that, when introduced in the scene, and controlled in real-time, display a full range of interactive 2D and 3D content. It also has the ability to make drag and drop object-oriented HMI Widgets that are easily reused in other projects without the need for programming once created. This level of flexibility is the key to future-proofing the AR HUD design, rapid development, long-term maintainability, and producing high-performing 3D HMI content. With **GL Studio®**, an AR HUD Widget set can be implemented to handle the following features with no programming:

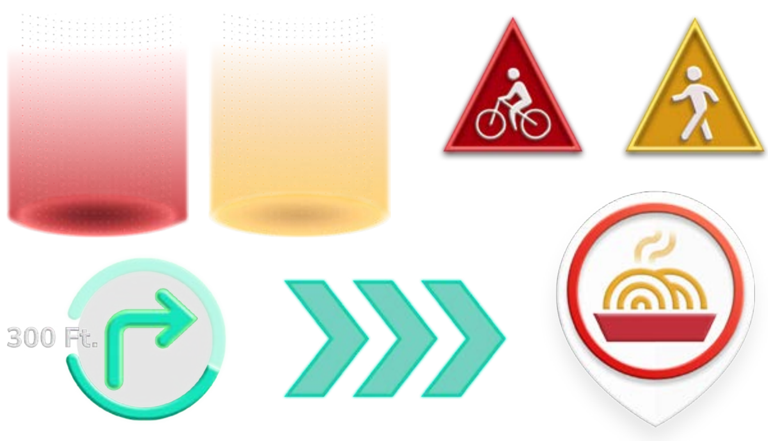
Examples of AR HUD Widgets

- **Direction Arrow**
- **Driving Routes**
- **Lane Change**
- **Object in Scene**
- **Adaptive Cruise Control**
- **Point of Interest**
- **Floating Text**
- **SC Instrumentation**
- **Any many other objects**



To control the visualized 3D AR HUD objects, each object type is created to process data inputs to display them with desired HMI appearance and effects that are then placed and made visible through data from the AR Engine. **GL Studio®** lets developers work with custom 3D and 2D data imported from a host of commercial design tools to develop different real-time widget features. This method lets developers create a highly customized look and feel, and once created, developers can build their customized behaviors and animations to control the 3D widgets as desired. When the component is completed, the new AR HUD HMI component can be saved as a reusable widget and even added to the **GL Studio®** toolbar in other projects for use by non-programmers.

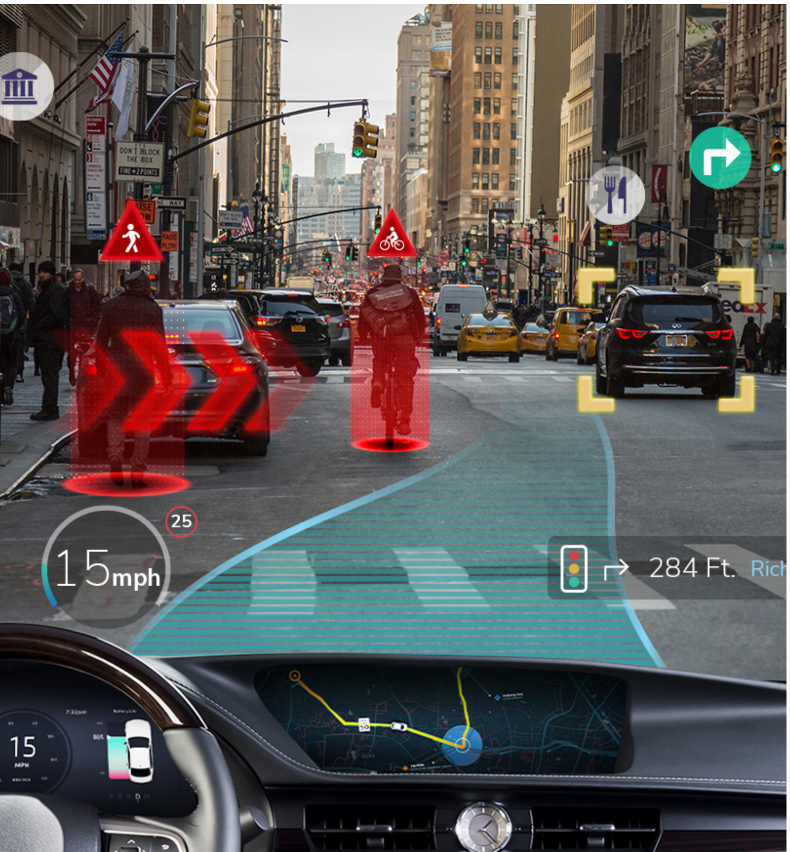




Does Functional Safety Play a Role?

The AR HUD is likely to support the transition between autonomous driving mode and driver control in the near future. There is expected to be a long intermediate period before the era of fully autonomous driving. The AR HUD will play a key role in supporting the move from autonomous driving mode to manual in displaying related information. FuSa consideration for HMI only comes into consideration so long as the vehicles are still manned or partially manned by way of take over events from autonomous capabilities. Functional Safety elements can certainly be included in the AR HUD, which can take precedence over the entire display to show only the critical data.

AR HUD technology is a relatively new concept; thus, it continues to be scrutinized, evaluated, and analyzed from the safety perspective. The first thing that must be done is the Hazard and Risk Analysis (HARA), where the output of the potential risks will be defined. Based on these risks, the proper Safety Goals will be formulated. Without formal HARA results for AR HUDs, we can topically define examples of potential hazards and risks. The most apparent perceived risk is that images displayed on the windscreen can cause a distraction for a driver. This means that flickering or too bright of an image in the low ambient light conditions can be a hazard or a risk. Another risk to consider may be that presented information on the windscreen might be misleading; thus, it may provoke a driver to perform undesired actions.



ADAS features are heavily developed, and year-by-year due to law regulations (given by EU commission, US DoT, NHTSA, or other national agencies), they become present in all car segments as standard equipment. ADAS notifications are currently conveyed to a driver via the Instrument Cluster, both through the visual warning and audible sounds. In the future, by the nature of their use case, we can see that AR HUDs will present safety-critical data for obstacle avoidance, forward collision warning, pedestrian recognition, along with other considerations. Therefore, it is crucial to ensure the integrity and reliability of displayed information on the windscreen. ASIL-D compliance in **GL Studio®** provides reliability and code integrity demanded by AR HUDs.

With a larger virtual image, increased display scene, and brightness, the AR HUD can overlap real objects that can potentially prevent the driver from the appropriate reaction. This point is where Functional Safety becomes a critical component of AR HUDs during both day and night conditions. It is expected that the AR HUD will slowly preempt Instrument Cluster functionalities and features. The Tesla Model 3, for example, does not have the classic Instrument Cluster or HUD, even though the consistency of displayed content (vehicle speed, telltales) falls under the functional safety scope.

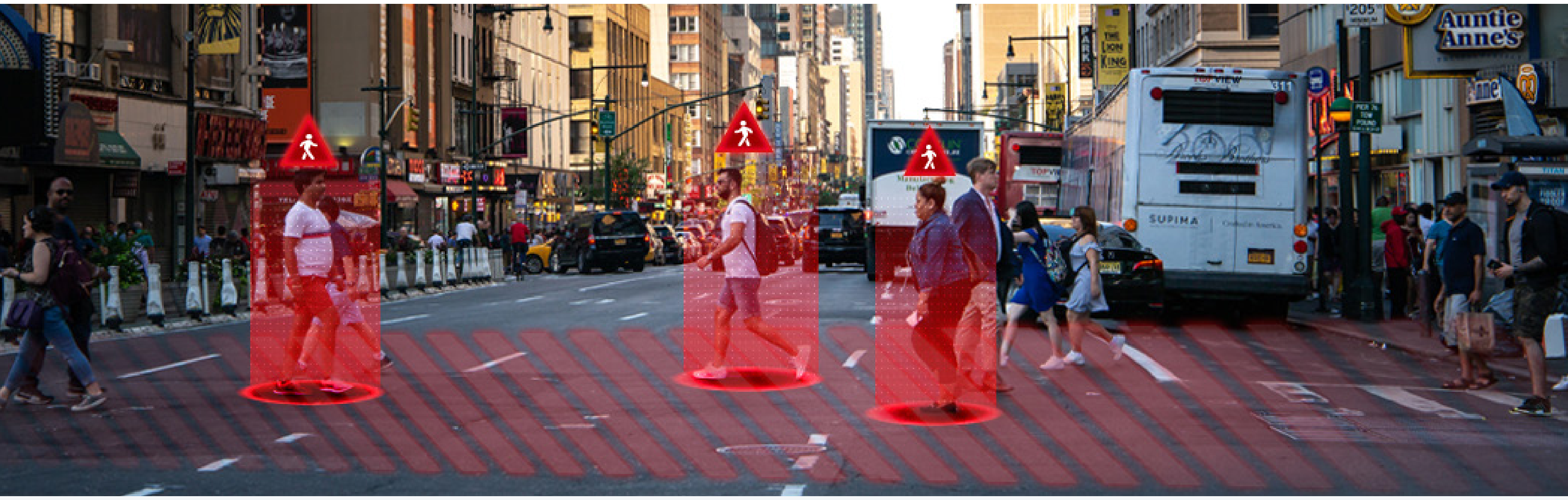
If Neural Network (NN) based algorithms are being used, two key aspects come up for functional safety, both the intent of the NN and the execution of the NN.

The intent of neural networks is a difficult problem to be solved and is aggressively being researched in the field today. NNs need to be well understood to address their accuracy and compare their results against expected results to solve this problem.

The execution of NNs can be solved by commercial tooling available today. **CoreAVI's VkCoreVX™** currently provides a certifiable inferencing engine for neural networks based on the **Khronos OpenVX™** standard and the Neural Network feature set from **OpenVX™**. Khronos also defined a "Neural Network Exchange Format" that would allow one to take neural networks developed in a NN tool like TensorFlow and export to a common exchange format that can be imported in **OpenVX™**.

Current NN-based frameworks are not designed with safety and mind, and **OpenVX™** provides a path to migrate existing work and designs to a safety-critical platform. Developers need to ensure that the software being used to execute the neural network is safe and meets existing functional safety standards. Software certification is a much better-understood problem and needs to be addressed by vendors going through developing a functionally safe code that meets safety requirements such as **CoreAVI's VkCoreVX™** and **DiSTI's GL Studio® SC**.

Considering the AR HUD and its relation to functional safety, remember that more complexity of displayed content, objects, equate to more difficulties to keep it safe and consistent. Selecting the appropriate tools for your framework is the key element to achieve success.



Conclusion

AR HUDs is a rapidly growing field being aggressively studied and implemented in proof of concepts. The goal is to provide the driver scan efficiency of their environment while reducing the cognitive load. "From hazard avoidance to location updates, AR technology can enhance the driving experience, adding speed and efficiency in the delivery of important information in real-time, adapting to the changing environment." [(4)] As Autonomous Vehicles become prevalent, this could all change; however, as long as there is a manual take-over event for vehicles, AR HUDs will play a key role in transferring data to the driver.

Displays are everywhere in the vehicle, and the data provided becomes more complex over time, requiring the need for HMI. The requirement for systems that calculate and provide that data also continues to grow.

Consumers of this technology continue to prefer the visually appealing graphical content displayed on the large physical screens. Moreover, not only the beauty of the content matter, but it has to be robust and reliable. To make it reliable from the safety perspective, special methods must be applied both on hardware and software levels. Strict safety measures are satisfied by both the SoC manufacturers and the software, both for Operating Systems and Graphic User Interface applications. As this paper highlights, there is a lot to consider in designing and developing an AR HUD system. At the top of the list needs to be the adoption of the proper commercial tools and implementation expertise that understand the challenges and how to de-risk and future-proof your technology for a successful, safe, and reliable Augmented Reality HUD system.

4. Elias @hariselias, H. (2020, October 09). How augmented reality (AR) HUD technology is hitting the road. Retrieved March 11, 2021, from https://techhq.com/2020/10/ar-huds-the-next-upgrade-for-connected-vehicles/

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Since 1997, Chris has focused on developing UI and HMI Software, starting at the U.S. Navy and University of Central Florida. Chris has worked at DiSTI since 1999 as a lead engineer or program manager for over 60 different programs, and eventually, the product manager for all DiSTI's UI development tools. Chris managed DiSTI's HMI/UI programs for Boeing, Hyundai, Jaguar Land Rover, Lockheed, NASA, Nissan Motors, Northrop Grumman, and The Space Ship Company, to name a few, and is currently DiSTI's VP of UX/UI Technology. He has successfully managed DiSTI's UX/UI business for over a decade, developing a global leadership position as experts in HMI/UI and Functional Safety. Chris holds bachelor degrees in Finance from UNCW and Computer Engineering from UCF, graduating with honors.

Yaroslav has a strong technical background in the embedded software development area. Since 2017, he has worked at GlobalLogic as the Associated Vice President of Engineering, managing a team of more than 500 highly professional engineers. Yaroslav leads many different programs in communications, embedded, industrial and automotive industries. He currently leads many advanced automotive programs in the area of Advanced Driver Assist Systems (ADAS), AR, and combined virtualized IVI/Cluster solutions for production.

Lucas Fryzek has been a software developer with CoreAVI for five years and has recently transitioned over to the role of Field Application Engineer (FAE). Lucas has extensive hands-on experience in developing embedded software systems deployable in DO-178C safety-critical environments. He has worked in tandem with many of CoreAVI's largest leading customers to deliver safety-critical solutions, including those specializing in the division of graphics workloads across multiple CPU cores. Lucas's experience with OpenGL SC and Vulkan APIs allows him to provide expert technical support and guidance to CoreAVI's customers and internal team.