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3-D Displays for Use in the Vehicle Cockpit

With a three-dimensional display, information can be captured faster than on conventional screens. In the automotive sector, this results in a considerable increase in safety: Thanks to the depth effect of the display, drivers perceive important information – such as that from assistance systems or a traffic jam report – much more quickly. Bosch presents the basics of 3-D technology and demonstrates possible fields of application.

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VALUABLE DRIVER ASSISTANCE

A few years ago, cockpit displays were exclusive to the luxury car segment. Nowadays, they are a standard feature and core element for interaction via Human Machine Interface (HMI) in all vehicle classes in increasing number and size. Displays support the driver and other passengers by providing intuitive graphics and interaction concepts and are a valuable differentiation attribute for automakers. In a market field that is defined by high technology, 3-D displays are a must-have: They will help to define future cockpits to be more organized and intuitive and thus make driving safer. In the following, the basics of the technology are shown and an overview of use cases and best practices for HMI design is provided.

HUMAN DEPTH PERCEPTION

The human visual system provides a mental model of the 3-D world around us. The depth perception is helped by various cues. Monocular cues, like motion parallax, or perspective and pictorial information, like shadows or color gradients, help our visual system with depth information when only one eye is used, or when a regular 2-D display is viewed. Binocular cues provide depth information when viewing a scene with both eyes. The most important binocular cue is stereopsis. The effect of stereopsis is easily illustrated: If a person takes a pen and extends their hand holding the pen in front of a background (for example a display as illustrated in **FIGURE 1**), then alternately observes the pen with one eye opened while the other one is closed, they will perceive the pen "jumping" horizontally with respect to the background. If the distance to the background is small, the amount of horizontal shift is also small. Accordingly, the amount of shift depends on the depth difference between the pen and the background. This effect is called parallactic shift. It is caused by the distance between the eyes which results in a slightly different perspective of the object. The two images of the right and left eye (stereo image pair) finally merge into one image in the human visual system.

3-D displays consistently provide a technological solution for displaying stereo image pairs containing objects shifted in proportion to their relative depth in order to stimulate depth vision. In detail, they differ in terms of technological implementation.

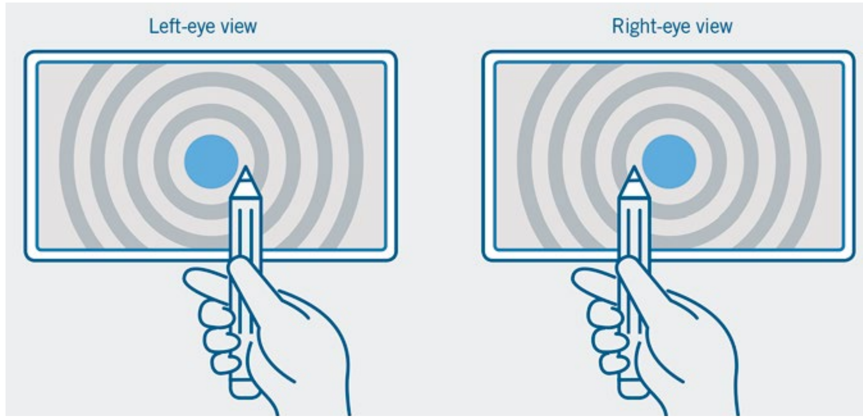

FIGURE 1 Parallactic shift between left- and right-eye views (© Bosch)

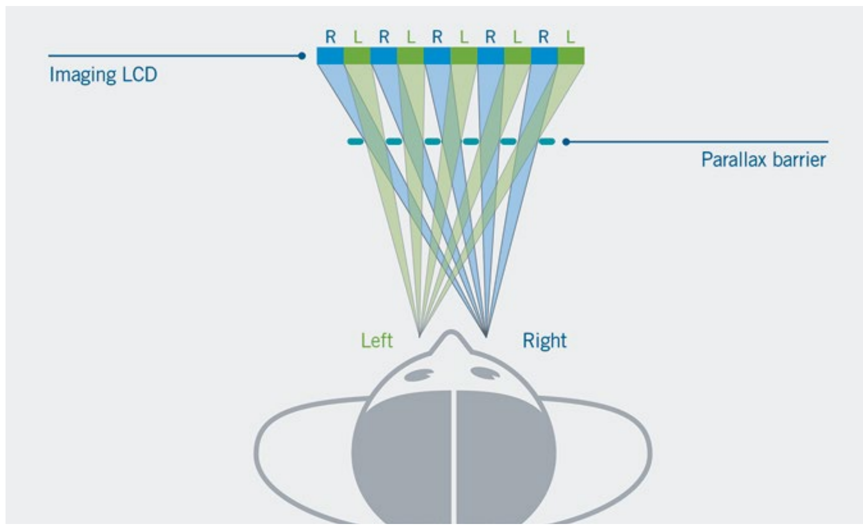

FIGURE 2 Autostereoscopic display based on parallax barrier (© Bosch)

AUTOSTEREOSCOPIC 3-D DISPLAYS

The simplest solution to stimulating depth vision is a conventional 3-D display that emits left and right views in combination with glasses that filter only one view to one eye. Obviously, the need for special eyewear is a huge disadvantage. Alternatives are autostereoscopic displays providing different views depending on the viewing angle. Often stereoscopic image pairs are created by means of parallax barrier technology, **FIGURE 2**. Such 3-D displays comprise a conventional imaging Liquid Crystal Display (LCD) with color filter, to which another monochromatic LCD panel (used as switchable parallax barrier) is optically bonded. The barrier LCD will show alternating transparent and light-blocking vertical stripes. This creates two interwoven viewing areas on the imaging LCD by the slightly different viewing directions of the right and left eyes toward the screen. On the imaging LCD, two nearly identical images are displayed, with objects shifted horizontally depending on their depth. This generates depth vision. A relative change of the observer's position in front of the display is corrected by a horizontal shift in the barrier pattern. For a high-quality display, the observer's eye position (that is, viewing direction) needs to be tracked by a spatially ultra-precise and real-time based eye-tracking system which, consequently, leads to sophisticated system requirements.

Apart from technological challenges, the major drawback of such systems is their optimization for only one tracked observer. An implementation in a cluster display, for example, results in an optimized performance for the driver, while the 3-D effect will not be recognized by passengers with different viewing angles of the display. Moreover, the dynamic parallax barrier often causes distracting optical artifacts such as image flickering which is visible to non-tracked observers. Another major disadvantage is the light-blocking working principle caused by the barrier which leads to very high power consumption to compensate for luminance losses.

MULTI-VIEW TECHNOLOGY FOR AUTOMOTIVE DISPLAYS

Advanced multi-view technology will help to overcome the drawbacks of eye tracking-based systems. Moreover, it

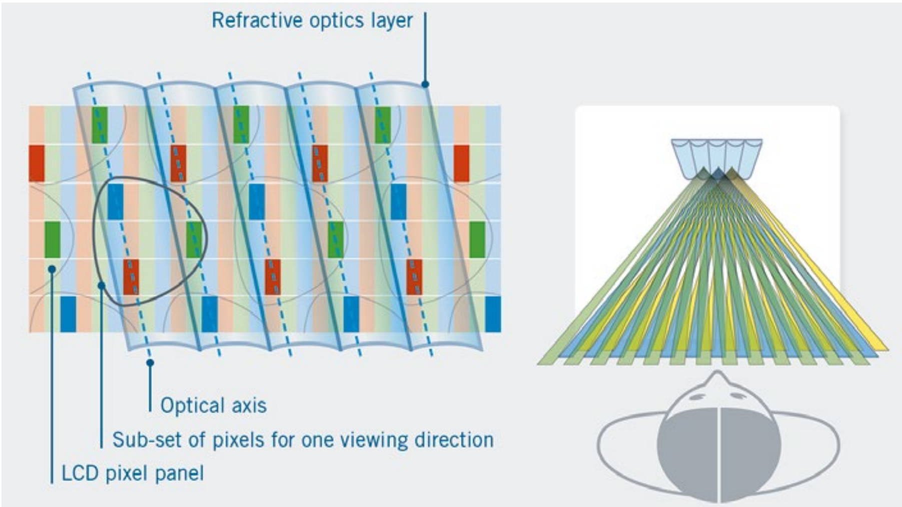

FIGURE 3 Autostereoscopic display based on multi-view technology (© Bosch)

makes use of the benefits of high-resolution displays by means of excess pixels to create depth, rather than using them to increase the resolution above a level that can no longer be resolved by the human eye. Recently, Bosch and Stream TV Networks Inc. entered into a partnership aimed at industrializing the company's high-quality multi-view display technology for the next generation of automotive 3-D displays.

Multi-view technology allows for head movement in front of the display while still providing a good and natural stereoscopic view. Hence, it works entirely without the need for an eye-tracking system. Consequently, it is not restricted to the number of observers. As illustrated in **FIGURE 3**, this technology applies a refractive optical layer on the LCD that provides a set of different views to the two eyes over a wide viewing angle. This refractive layer redistributes the light emitted by the LCD display in a horizontal direction rather than blocking light emission. The actual direction of light rays is determined by the location of the refractive structure with respect to the sub-pixels. Sub-pixels allocated to one optical axis are refracted in the same direction. This effect is used to create the different views, whereas the imaging information of one pixel (triple of R, G, B) is distributed spatially to non-neighboring sub-pixels (rendering). Since there are multiple degrees of freedom for combining sub-pixels into one view, a balanced combination of optical design and rendering algorithm is key to achieving a high-quality multi-view display characterized by natural depth vision.

SYSTEM CONCEPT FOR A MULTI-VIEW DISPLAY

A multi-view rendering function is required to drive the display. This function uses detailed knowledge of the optical layer to position the respective image data at the correct sub-pixel sets. The input to the rendering function consists of a regular RGB image that is "enriched" with a depth map, both provided by the HMI application. This way, the color is defined for every pixel, as well as its depth relative to the display. Colors are typically encoded in 24-bit color depth, whereas an 8-bit grayscale (corresponding to 256 discrete layers) is used for the depth map. One advantage is that only half of the vertical and horizontal native display resolution needs to be transmitted. **FIGURE 4** depicts the signal chain of the system.

This rendering function is a rather computing-intensive operation which can be seen as a large pixel pipeline that runs in real time. Therefore, it only introduces a short signal delay such as is needed to form a number of video lines. The rendering function is also responsible for final up-conversion to the native display resolution. It is typically implemented in a Field Programmable Gate Array (FPGA) or Application-specific Integrated Circuit (ASIC). Thanks to this solely hardware-based implementation, the central Graphics Processing Unit (GPU) system is not entrusted with the task and the function does not require external memories.

Use of the image and depth as an interface format allows easy adaptation of the degree of depth perceived by the viewer to account for individual depth preferences. By simply applying a gain factor to the depth signal, the amount of depth shown by the display is adapted from 0 to 100 %. This factor can be con-

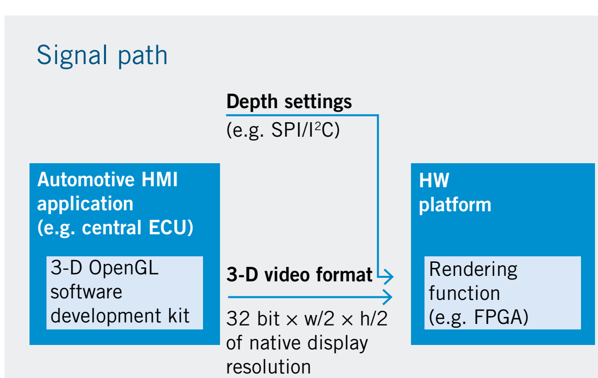

FIGURE 4 Simplified system concept in an automotive environment with central computing architecture (© Bosch)

Examplary system characteristics	
LCD technology	LTPS (Low-temperature Polycrystalline Silicon)
Diagonal and aspect ratio	12.3", 8 : 3, landscape
Pixel density	420 ppi
Native panel resolution	4800 pixel by 1800 lines
Transmitted HMI signal	2400 pixel by 900 lines
Luminance	> 800 cd/m²
Viewing distance	0.6–0.9 m

TABLE 1 Proposed specifications for an automotive display (© Bosch)

trolled by the driver or is automatically set by the system.

TABLE 1 lists the main parameters of a well-balanced display design developed by Bosch that shows a very good and proven visual performance for a cockpit application and which is feasible for automotive implementation.

CREATION OF 3-D HMI CONTENT

There are two fundamental options for creating content for multi-view systems: either by modeling a 3-D scene using multiple, spatially distributed cameras viewing from different directions followed by software-based rendering of the captured scene to the pixels, or – as used for the technology presented here – through generation of exactly one RGB image and its corresponding depth map.

A huge advantage of the latter method is that 2-D-based creative tools such as Adobe Photoshop or Adobe After Effects can be used to create content rather than relying on a setup of virtual (or even real) cameras. Hence, when creating prototyping content, it is possible to literally generate a "hand-drawn" depth map. Ideally, one can also start from scratch to use classic 3-D animation tools such as Autodesk 3ds Max. Such tools are able to generate depth information automatically. Moreover, they allow for already moving in a virtual 3-D world as later used for the production of serial HMIs. **FIGURE 5** demonstrates how the RGB image and its corresponding depth map have been generated by a 3-D tool from a 3-D scene.

Generation of prototype content is especially important in the early design phase. Instant validation of design concepts directly on the 3-D display with regards to the depth impression is possible – long before extensive development of serial HMIs starts. Also, popular real-time engines like Unity are supported by direct plug-and-play to the 3-D display. This makes it possible to close the gap between the design and validation phase and serial development as much as pos-

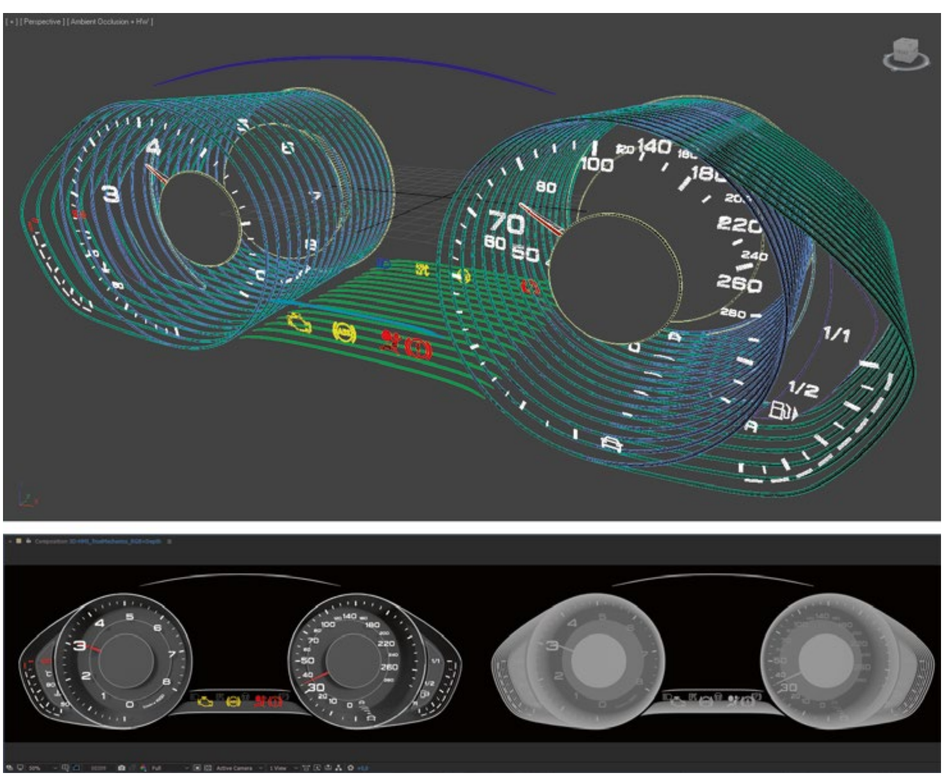

FIGURE 5 Tool chain for creating prototype 3-D HMI content using standard tools: scene of a virtual 3-D cluster (top, Autodesk 3ds Max) and RGB image and its depth map rendered out of the 3-D scene (botton, shown as After Effects Composition) (© Bosch, Adobe After Effects, Autodesk 3ds Max)

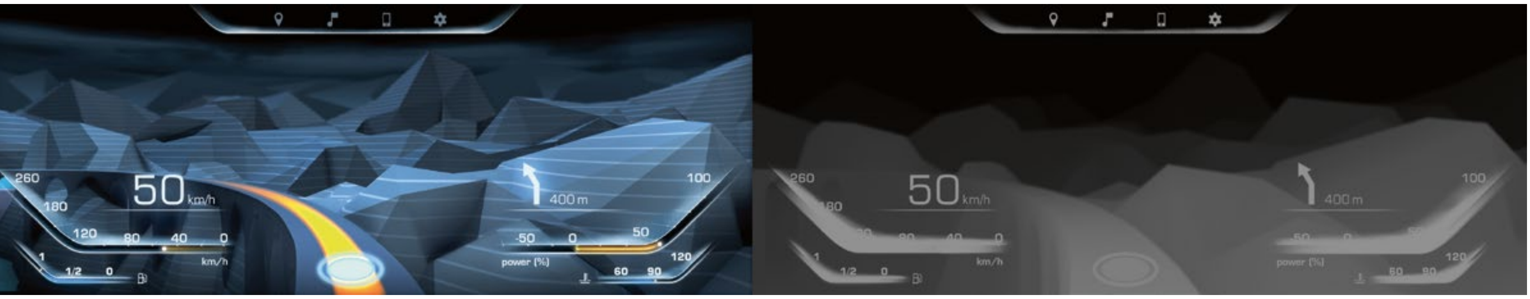

FIGURE 6 Structuring the 3-D HMIs into fore-, middle- and background (left) and layering of depths via grayscales (right) (© Bosch)

sible due to technically similar software tools used throughout the design process. Typically used development environments (for example Candera) are already able to deliver the required RGB image along with its depth map.

DESIGN RULES

When creating 3-D HMIs, experience has shown that it is not necessary to use all of the 256 available layers simultaneously. Instead, it is sufficient to structure the content within a few, clearly-separated layers to generate a convincing 3-D impression. Further refinement makes it possible to express objects with fading depth (showing truly three-dimensional objects). This is shown in **FIGURE 6** which demonstrates a 3-D scene where depth layers are clearly visible by distinguishable brightness levels of the grayscale image while the road nicely fades into the distance.

A well-proven method is to structure a 3-D scene into fore-, middle- and background levels – comparable to classic stage settings. In the foreground, prioritized driver information can be presented, for example, cruising speed, maneuvering or warning signs, whereas the middle ground is well suited to present layered information such as driver assistance systems (distance or lane assists), three-dimensional navigation maps, or elements of a cover flow. In the background, ambient or decorative design elements are used depending on the current context, for example, landscape sceneries such as mountains, sky or urban surroundings.

Apart from structuring content by depth layers, the use of pictorial depth cues is a well-proven method for achieving a pleasant depth impression in practice. Shadows, perspective views, change of brightness or color saturation levels depending on depth as well as systematic adding of blur support the creation of a natural and consistent depth impression fitting to mental models.

In contrast to rather static scenes, it is beneficial to use the 256 depth layers for animations or dynamic content. For example, this can be used for prioritization of information such as warning signs popping out continuously from the background to the foreground.

OUTLOOK

Consequently, 3-D displays in the cockpit are well suited for organizing driver-centered HMI content and supporting recognition of context-relevant information. In the future Bosch sees the possibility for 3-D displays to help improving driving safety by replacing 2-D-based digital side mirrors, providing an optimized depth estimation of the depicted surroundings. The system concept allows for easy combination of real and virtual content (mixed reality). This makes it possible to highlight objects in the mirror by means of image analysis in critical situations, for example.

Apart from the functional aspects, the enhanced user experience regularly exerts a special fascination on observers. Further, 3-D displays entertain passengers while enjoying a 3-D movie on long trips and are therefore a valuable addition to the equipment of autonomous vehicles.