Toward "Light-to-Light" Protection of Automotive Camera Monitor Systems

The use of CMS to replace rear- and side-view mirror functions in cars is gaining traction. However, implementing these systems safely requires a high level of performance monitoring to ensure that they work properly. The authors describe new methods toward full end-to-end or "light-to-light" performance monitoring.

by **Benjamin Axmann, Frank Langner, Chihao Xu, Karlheinz Blankenbach, Mirko Conrad, and Jan Bauer**

THE DEMAND FOR SAFETY-RELEVANT REQUIREMENTS IN automotive displays is on the rise. Camera monitoring systems (CMS), such as surround-view monitoring or mirror-replacement systems, are being designed to meet these new standards. Because future car designs trend toward a reduced view outside, the driver will need to rely more on video data screens inside the car. Over the past two years, the Video Safety research group at Mercedes-Benz, in cooperation with specialized universities and companies, has focused on display technology and supervision (in terms of performance monitoring and fault detection) to provide a new solution: light-to-light (L2L) supervision for CMS safeguarding.

To show how this group is meeting these future L2L needs, here we detail new methods that demonstrate enhanced safety in CMS systems. We then explore the research group's focus on two use cases (in cars and remote view video presentation on displays) to specify the general requirements for all automotive-relevant CMS systems. Finally, we describe our prototype effort and results.

Safety Framework

As an overview, we first provide a diagram of the work being done and how it has shaped the safety framework's development. **Fig. 1** shows how the two use cases[1] were superimposed onto one vehicle, such that camera data and other relevant information can be displayed on an in-vehicle display and a remote operator's workstation. To design in-vehicle CMS and remote operator systems as safely as possible, we used prototypes to investigate and demonstrate new approaches to safeguard them. Current automotive displays have only interface and tell-tale supervision (besides supply voltage) for the instrument cluster. With our new mechanisms in place, we can detect failures such as delays, wrong text messages, and missing objects. In addition, we are able to detect optical performance issues with the display—including incorrect luminance and contrast—that are not recognizable by a human observer.

Ensuring functional safety, such as mitigating risks resulting from failures of electric/electronic (E/E) systems, is a key issue in developing road vehicles. Engineering for functional safety is guided by the international standard for functional safety of electrical and electronic systems that are installed in serial production road vehicles (ISO 26262). The risk level originating from a system is classified using automotive safety integrity levels (ASIL).[2] To safeguard an automotive CMS, the actual system architecture, which can be modeled as a set of input (I), modifier (M), output (O), and video data transmission (T) components (**Fig. 2, left**), must be extended by additional components to detect or mitigate faults and control failures. Such ASIL Prepared Video Safety System

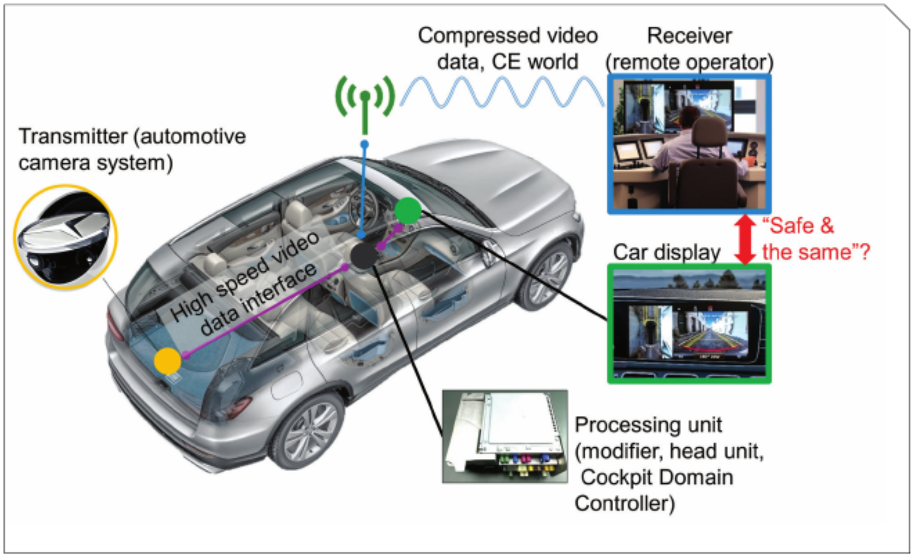


Fig. 1.

System overview of a passenger car with onboard camera monitoring systems and a future use case for automated vehicles and fleet operations control.

(APVSS) components (**Fig. 2 right**) can be integrated into the existing I, M, O, or T components or realized separately.

Malfunctioning system components or an incorrect transmission can lead to the unintended modification of images such that the displayed video stream critically deviates from the video stream captured by the camera. The APVSS should detect and handle such malfunctions. ISO 26262 calls first for a systematic analysis of each system component's potential failure modes (FMs), and second, for the systematic incorporation of safety mechanisms to detect and address corresponding faults and resulting failures. To provide the required systematic approach, we identified and analyzed more than 30 FMs for output components realized by displays.[3–5] For example, display FMs comprise image corruption; image distortion; frozen image; delayed image; erroneous zoom factor; erroneous image orientation, color, contrast, and brightness; image artifacts; erroneous augmentation and marking; and modification and loss of essential information.[4]

We collected existing and newly proposed safety mechanisms (SMs) utilized to detect display faults and failures. Some of these safety mechanisms can be implemented locally in the display (e.g., current or voltage monitoring of display panel components with low temporal resolution), but others must be distributed across multiple components, such as video watermarking.

To evaluate SMs' fault coverage and to rationalize the selection of suitable SMs for a given CMS, we created a matrix array with the FMs as rows and the SMs as columns. The capability of a safety mechanism SM_x to detect failure mode FM_y was written in the corresponding element. If known, the diagnostic coverage (i.e., the percentage of detected faults) has been stored as well.[4]

For a CMS to be developed, such a structured documentation of SMs at the engineer's disposal can be used to devise suitable and efficient safety mechanisms and identify FMs that cannot be detected efficiently. The SMs outlined here aim to provide L2L protection with reduced important gaps regarding FM coverage. The SMs' efficient technical implementation across multiple CMS benefits from a standardized safety architecture using local and global APVSS components (**Fig. 2**). In such a standardized architecture, the local SMs of the I, M, and O components collect status or fault information and transmit them to a global APVSS component. This global APVSS controller could be a separate component or be integrated into one of the other components.

Feature Extraction

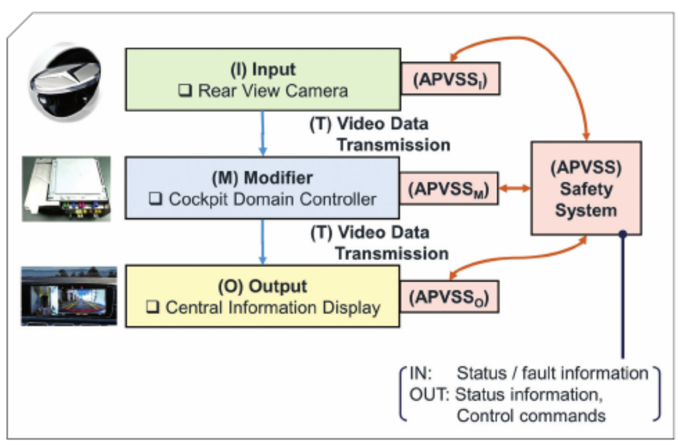
Next, as part of our L2L solution, we work on feature extraction to contribute to safety measures. In particular, a safeguarding algorithm is used, and its purpose is to detect safety hazards so that warnings can be given and countermeasures taken. The perception of the image at the end/output of a video transmission path (before display) shall be equivalent to the source image at the input of the video transmission path. Possible malfunction of image processing or transmission faults causing false perception shall be detected by the algorithm. So as not to alter existing transmission hardware, a negligible data overhead may be inserted into the transmission. The algorithm's outcome shall specify the perceptual distance between the transmission path's input and output.

Thus, features are to be defined and extracted from a source image so that they may be transmitted as metadata. These data shall not be modified in the transmission path, whereas the image itself may be processed or modified. At the path's output, the features for the output image are extracted in the same way as for the source image. The distance between both feature sets can be determined, indicating a failure, warning, or unacceptable distance.

Inspired by the human visual system, an image's contrast stimuli qualify to be selected as features. A histogram of gradients (HoG) helps

Fig. 2.

Generic model of a video data transmission and processing system with local and global safety system components. APVSS: ASIL Prepared Video Safety System.



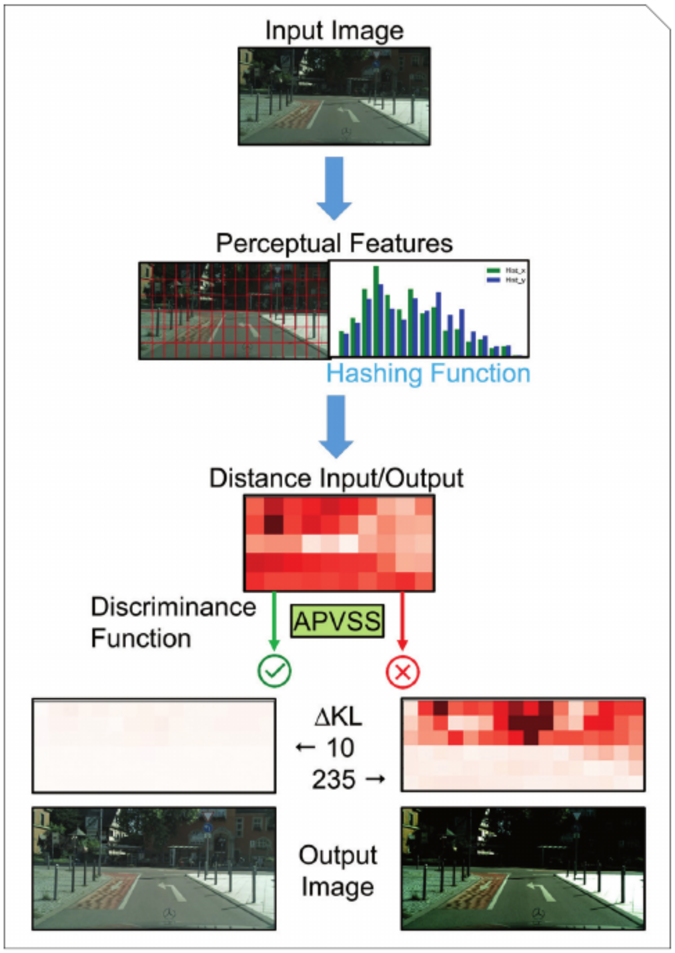


Fig. 3.

Feature extraction (hashing) for comparing (top) the input's image quality and (bottom) the processed output image. A Kullback-Leibler (KL) divergence indicates a non-acceptable loss of details. APVSS: ASIL Prepared Video Safety System.

drastically reduce the amount of data.[6] For a more stringent discrimination, an image may be divided into several patches so that multiple HoGs are yielded for each image. The amount of data compared to the image data is still negligible (below one permille). The Kullback-Leibler (KL) divergence has been proven to deliver a reliable perceptual distance value between two HoGs so that a threshold may be set for APV.

Fig. 3 shows the flowchart: The KL divergence (center, hashing function) of an input (source) image (top) is extracted. This provides the "distance" of an input–output image. The distance decides whether the output image is acceptable (bottom left) or not (bottom right). Properly processed contrast enhancement preserves the relevant information and results in better recognition of "darker" parts (center top), where the total KL divergence is low and acceptable. Opposite to that, image modifications, which result in significant losses of details (bottom right), lead to a high KL divergence, which is far from acceptable. The threshold for the acceptance may be empirically determined by user tests. We performed many tests with different test images and image-processing methods to prove the KL divergence function for automotive images.

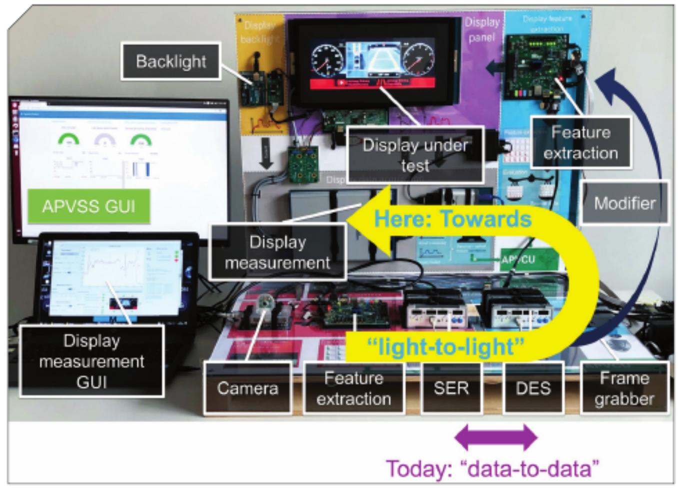


Fig. 4.

APVSS (ASIL Prepared Video Safety System) demonstrator. GUI: graphic user interface; DES: deserializer; and SER: serializer.

Display Supervision by Photodiodes, Row Current, and Camera

Today's methods for supervision of displays rely only on "data-to-data" supervision (**see Fig. 4**). It is assumed that the automotive display either works properly, or the user would notice a faulty reproduction. To improve the display's supervision, its optical output (toward L2L) should be compared to the intended reproduction. We evaluated several methods using prototypes and theoretical approaches, such as using a photodiode in every subpixel.[6] We focus here on the combination of optical measurements by photodiodes and row current.

The measurement data (actual) of eight photodiodes (placed at the display edges[7]) and time-resolved row current are compared with a model (target) of the display that are based on many tests and typical images. The left side of **Fig. 5** shows an example of a distorted reproduced (top) and reference image (bottom). The display measurement graphic user interface (GUI, **Fig. 4** bottom left) on the right visualizes the methods of the optical and current data acquisition. The actual measured (red) and target (blue) current are displayed in an oscilloscope-like manner. It is clearly visible for a degradation of the gray-level (GL) reproduction that the measured current deviates significantly from the target waveform generated by the model. Distortions in GL reproduction (too bright or dark) result in loss of significant and safety-relevant details from the camera image.

The optical comparison for the photodiodes is visualized in a traffic-light style. All correlations and other measurement values such as supply voltage and backlight performance are shown additionally as numbers. We performed evaluations with many images (mostly automotive HMIs) to test and improve our new methods. All data are reported to the APVSS (**Fig. 4**) for further actions. The optical and current method are easy to implement, cost-effective, and can bring automotive displays to a higher safety level.

We also developed supervision of a remote operator's CE monitor (**Fig. 1** top) by a camera; this approach is also applicable to

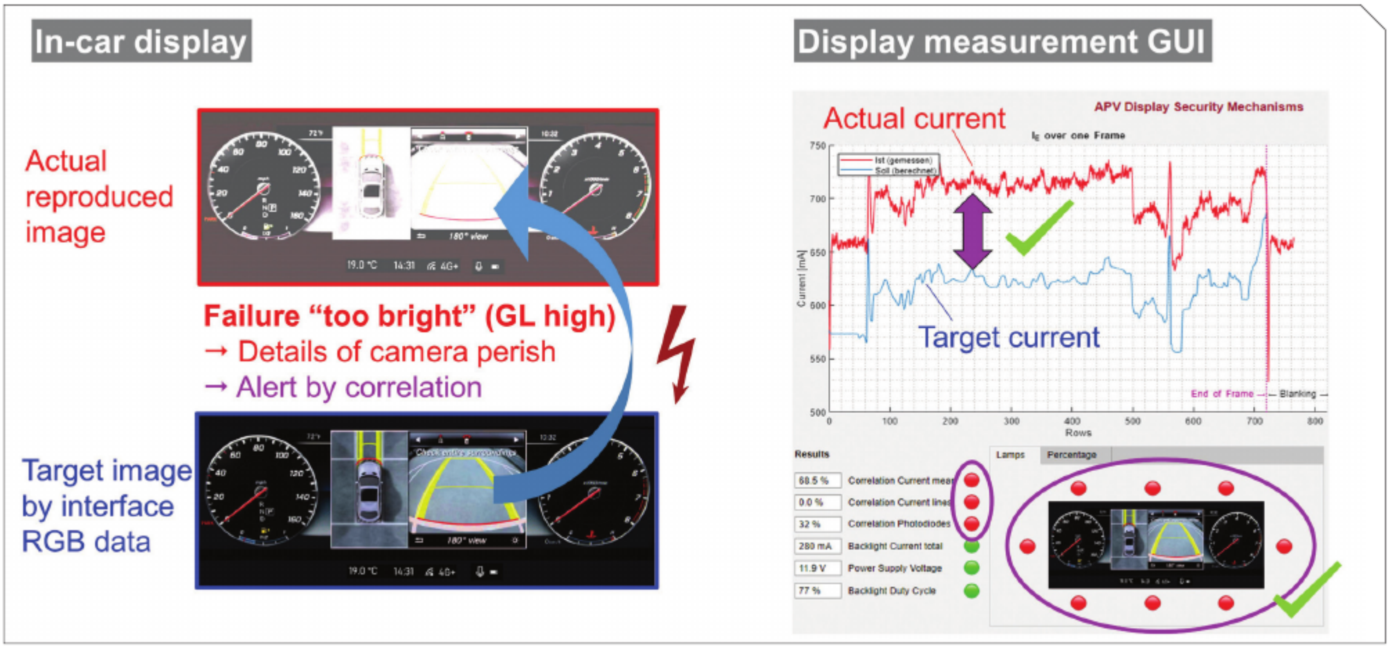


Fig. 5.

Visualizing a faulty reproduced and original image (left) and the user interface (right) for display supervision. The display's degraded reproduction is detected by current and photodiode measurements. RGB: red, green, and blue; GL: gray level.

in-car displays. The captured display "picture" is analyzed with image-processing methods to judge image quality and operational data. "Traditional" (data-to-data) CMS methods of in-car systems (**Fig. 6**) are inapplicable for remote supervision, as consumer hardware and software and transmission (e.g., lossy image compression) must be used.

Summary

A safe and unaltered reproduction of camera content is essential for modern automotive CMS applications. Our goal was to extend the coverage of the safeguarding mechanisms to enable a full L2L protection (see **Fig. 6**). A key element is the APVSS, which was developed and evaluated successfully in our project. As a first step, we developed a generic functional safety framework for possible failures with respect to their levels of criticality and detection methods. Those methods were proved for the most relevant cases: in-car CMS and the camera-based supervision

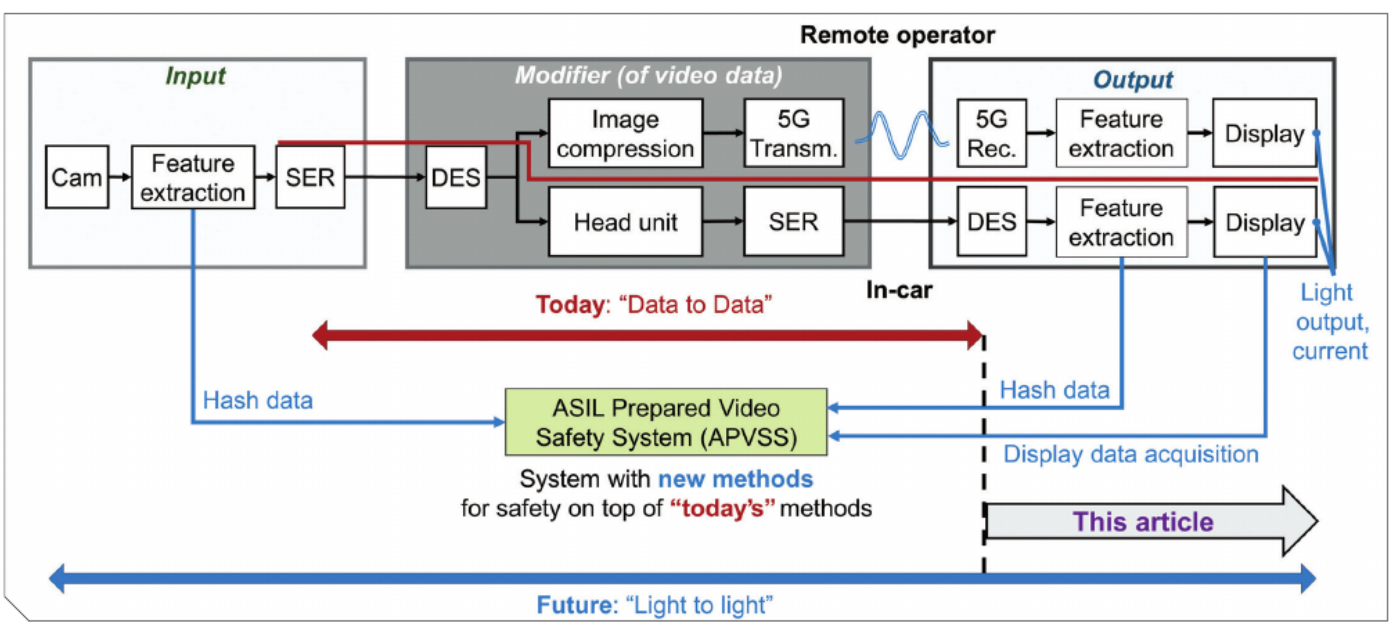


Fig. 6.

Automotive camera monitoring system: From today's data-only supervision to future systems with image feature and optical display supervision.

of the monitor of remote operators. This high-resolution optical safeguard method is beyond today's state of the art. We evaluated our prototype setup for supervising the speed, text, tell-tales, and video reproduction of an in-car camera. The latter one is the most safety-relevant topic and is challenging in correlating actual and target data. The method is part of the overall ASIL-prepared video framework to facilitate the functional safety engineering of CMSs.

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