Advanced Optical Methods to Ensure Safe Image Reproduction on Automotive Displays

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ABSTRACT

Modern cars are equipped with Camera Monitor Systems (CMS) - such as back-up camera systems or mirror replacement systems. These systems must achieve high safety levels. Today, only digital data are supervised. This paper introduces new methods for optical supervision of displays enabling "light-to-light" (camera to display output) protection.

1 INTRODUCTION

Modern cars and trucks are equipped with rear-view cameras. Side-view mirror replacements paved their way to early mass production. Such systems are called camera monitor systems (CMS, e.g. [1]); they provide obvious benefits in terms of safety. Fig. 1 bottom shows a typical rear-view (backup) CMS: The camera is connected via high speed data interface to a head unit, which modifies the image data (e.g. overlay of augmented information such as trajectories) and sends them to the vehicle display. If autonomous (robot) cars without steering wheel fail, they will stop and become obstacles. A remote operator (Fig. 1, top right) can login to the car system and perform remote control (like drones). Such connectivity, which bases on consumer electronics and systems like 5G networks, is far away from fulfilling ASIL requirements [1]. It is mandatory that CMS and remote operator systems are as safe as possible. We investigated and prototyped new approaches for safety of CMS with focus on supervision of displays.

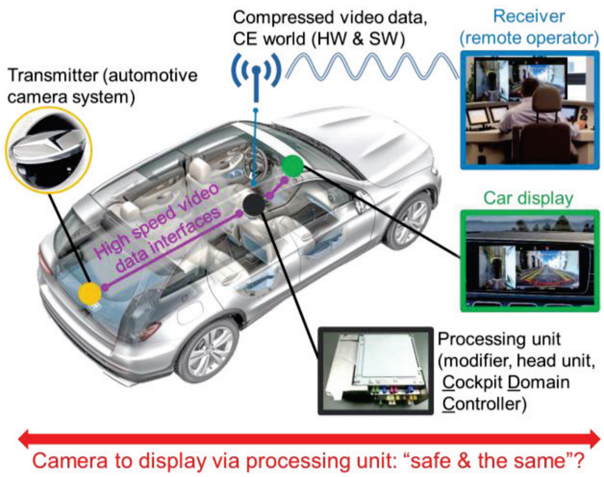

Fig. 1 System overview and challenges of Camera Monitor Systems (CMS) for in-car systems and wireless transmission to a remote operator

2 SAFE CMS CONCEPT

Our goal was to develop a set of methods from which an intended application with defined safety requirements can pick from. This is done via theoretical and practical methods which resulted in a fully functional demonstrator (details see [2]). We combined today's methods (pure data-based, Fig. 2, left, magenta) with new ones (Fig. 2, right, green). The focus of this paper is on optical display supervision ("light-to-light"):

- Acquisition of the optical output and comparison with the RGB input data to be reproduced using a model.
- This display model was derived from measurements of test patterns and HMI examples.

In this paper we present how a speedometer can be optically supervised by 8 photodiodes (§3) and monitoring of the display output by a camera (§4). The latter method can be used for both in-car and remote systems. The correlation between target and actual data is performed in a safety unit called APVSS.

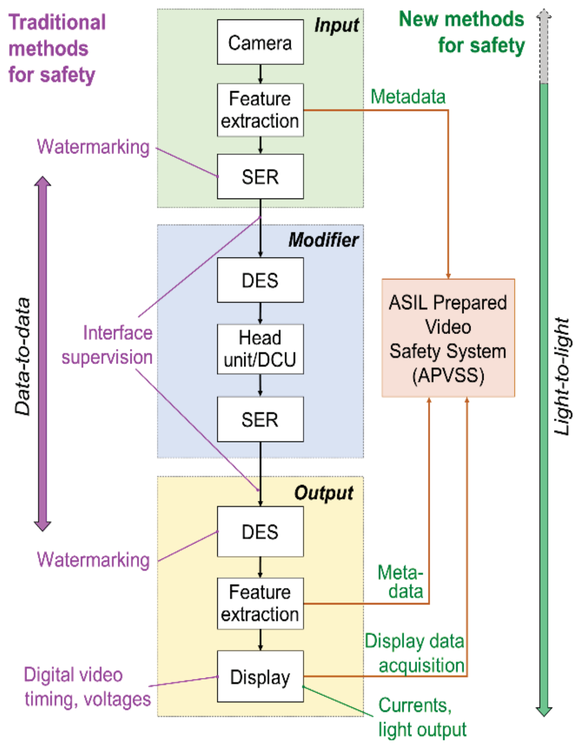

Fig. 2 Block diagram of today´s (left, magenta) and our advanced concept (right, green) for safety

3 MONITORING BY PHOTODIODES

The optical output of a display can be monitored by photodiodes, however with “low resolution” (~10 photodiodes vs. ~million camera pixel). Nevertheless, even a single photodiode can improve safety: Mounted in an invisible area (e.g. corner covered by a display plastic frame) a single photodiode can capture gray level and color reproduction and frame-freeze. The ultimate but most expensive solution is to equip every subpixel with a dedicated photodiode.

This paper presents a new method for optical control of a digital speedometer by photodiodes. Fig. 3 shows the basic principle:

- The front lens (left image) is used as a wedge light guide to capture the light output of the display.
- An intensity map (right image) was acquired via measurement depending on the horizontal and vertical distance of individual pixels.
- The measured intensity value of a photodiode is then correlated with the model output (RGB input, map …).
- The correlation provides a measure if the display output (actual value) corresponds to the target value. Corresponding actions (e.g. display OFF, warning) are performed in case of significant deviations by APVSS.

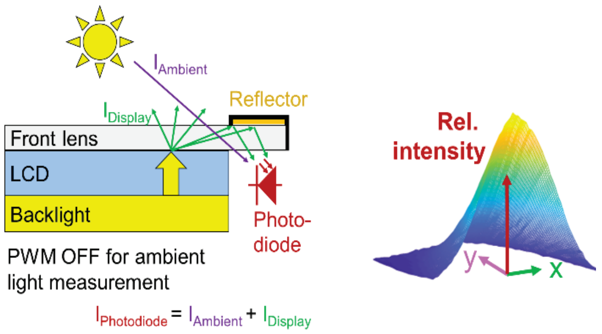

Fig. 3 Left: Measurement of the display‘s optical output via light guide principle for LCD (as shown) and OLEDs by photodiode; right: Calibration data of area intensity for model

Fig. 4 shows this approach applied to a speedometer. 8 photodiodes are placed at a corner of the display next to the speedometer location. To achieve significant differences of the intensities of those photodiodes at different vehicle speeds, an optimized visualization of the actual speed is used (see Fig. 4 for 0 km/h and Fig. 5 for 30, 50, 70 and 100 km/h).

Such a visualization is already implemented in cars but with the motivation of faster and safer reading of the actual speed by the driver and a higher perceived value of the automotive HMI. The photodiodes measure the intensity of the light emission of the pixels with respect to distance, individual gray levels and color. Ambient light is compensated by measuring the intensities of the photodiodes during LED PWM OFF.

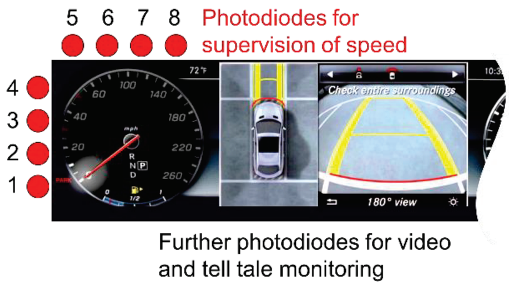

Fig. 4 Set-up of the photodiodes for speedometer

Fig. 5 Highlighted actual speed using torchlight illumination of numbers and circle segments

We measured the intensity of all photodiodes for narrow speed steps in order to determine the precision of this method. Fig. 6 shows the resulting intensities of the 8 photodiodes for 0, 30, 50, 70 and 100 km/h respectively. It is easy to see that each of these speeds can be identified by comparison of the relative intensities. For example, 30 km/h results in a high intensity of the photodiodes numbered as #3 and #4 because the “torch light” is closest by. The maximum intensities for 50 and 70 km/h are lower as the lit area is further away. This relatively inexpensive method allows the supervision of the actual optical display output in a way that the actual speed can be verified within a range of about ~5 km/h. Our prototype system was able to perform up to 5 acquisitions per second. This is definitively a significant progress as today there is no optical supervision of the display output, just digital interface data are safeguarded.

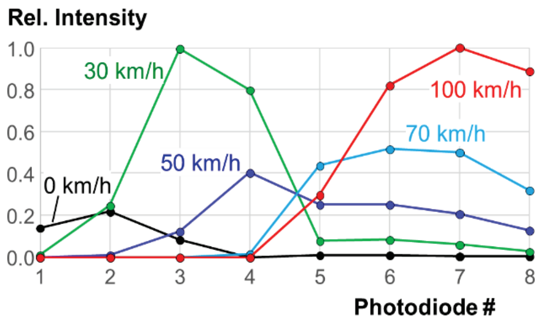

Fig. 6 Intensity for various speeds (see Fig. 5) acquired by photodiodes (see Fig. 4)

4 MONITORING A DISPLAY BY A CAMERA

Low volume use cases of CMS are not economically suitable for any larger modification or customization (see [2] for various methods) of the display. A typical example is the monitor of a remote operator who most likely uses a CE PC monitor. The supervision of in-car displays are possible as well. To supervise such highly safety-relevant displays, it is much more convenient to use a camera as clip-on as shown in Fig. 7. The correct image reproduction of the display including verification of operational data such as speed is checked by the camera (professional, CE grade also possible). The prototype system was tested using MATLAB [3] and programmed in PHYTHON with the use of OPENCV image processing library.

This approach offers high resolution and a vast number of possibilities in terms of computer vision algorithms to process and analyze the camera data and pass them for final decision making (e.g. display switched OFF) to the safety unit APVSS (see Fig. 2).

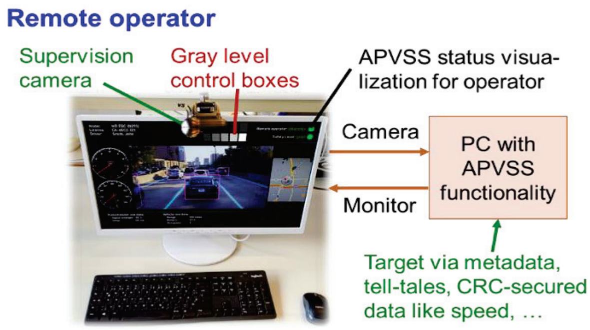

Fig. 7 Prototype setup to evaluate camera-based supervision of a remote operator´s monitor

4.1 Pre-processing

The supervising camera's raw data shows several degradations which need to be pre-processed. Examples are Moiré, distortions, mismatch of display luminance and camera sensitivity, and gray level reproduction. Fig. 8 shows an overview on the image pre-processing steps on the left. At first, the periodic Moiré-pattern is reduced by Fourier transform and band filtering. Another approach is playing with lens FOV, distance, or slightly defocusing.

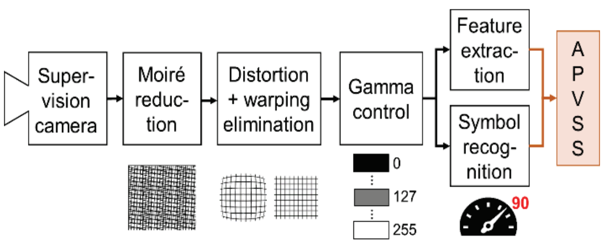

Fig. 8 Flowchart of display monitoring by a camera using image processing for safety monitoring

As the supervising camera is placed above or beneath the display, the image is geometrically distorted which is compensated and warping is applied as well. For calibration purposes, a grid can be used as well.

The last pre-processing step is gray scale reproduction (gamma) control. It is necessary to take the gray scale optical output characteristics of the camera and the gray scale input characteristics of the camera into account. This is performed in daily use by gray level control boxes (see Fig. 11 bottom center). If the display's use case does not allow visualization of such control boxes, pre-defined gray levels areas in the GUI can be used. To be able to adapt the transfer function to changing ambient light conditions, the system uses black areas as reference and perpetually determines the gray level reproduction.

As most cameras have 8-bit gray scale resolution, just grabbing one image would result in limited supervision performance. Solutions are 12-bit cameras or dual exposure of 8-bit cameras as described here. This is performed by acquisition of two subsequent images at different exposure times. Fig. 9 visualizes gradation curves for different exposure times. Longer exposed images present higher resolution at lower gray scale range and vice versa. The goal is to get two linear curves of different sensitivity to capture and resolve low and high luminance content. As an example, the cyan line (exposure time 1/64 s) is linear up to 0.35 of the relative maximum gray level; saturation is reached at 0.5. The red curve (exposure time 1/512 s) is mostly linear from 0.2 to 1.0 without reaching saturation.

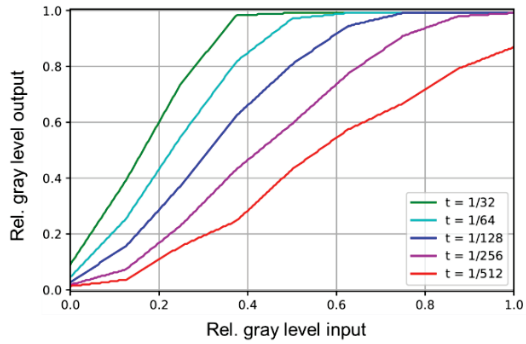

Fig. 9 Gradation curves for various exposure times

An example of the enhanced dynamic range is given in Fig. 10: A typical night scene of a rear-view camera is recorded at different exposure times. The blue and yellow dotted boxes mark the significant differences: A shorter exposed image (left) resolves high gray level areas much better than the image on the right taken at longer exposure time and vice-versa.

Fig. 10 Visibility of bright and dark objects using short (left) and long (right) exposure time

4.2 Safeguarding Display Reproduction

The typical automotive GUI display content is not monitored as a single unit, but in a modular approach, divided into individual regions of interest (ROI). Therefore, the most suitable image processing and analyzing method can be applied and optimized for each part of the display content (Fig. 8 right). We used a test image (Fig. 11) composed of typical automotive HMI components for optimization and evaluation of the monitoring and supervision methods. Three safety-relevant information groups are to be examined in detail: the speedometer needle (red), a rear-view camera video image and reference boxes (gray level, color) as well as textual and symbolic telltales (marked by dashed yellow box).

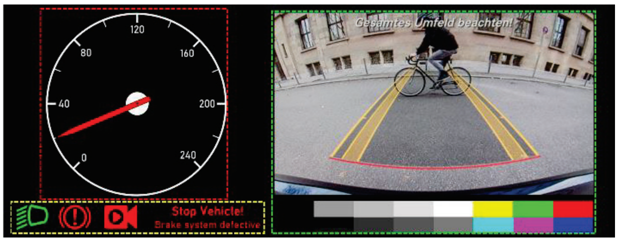

Fig. 11 Test image composed of typical automotive HMI components

The indicated speed is monitored by detecting and verifying the angular position of the speedometer needle using Hough transform and plotted as green line in Fig. 12 left. The right image proves that the angle is correctly detected despite bright reflections of ambient light.

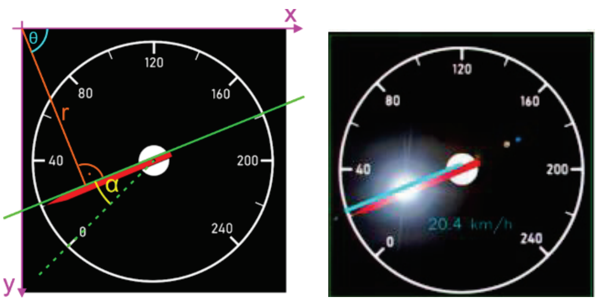

Fig. 12 Acquisition of the actual speed by extracting the speedometer needle angle

Text is often used for safety-relevant error messages. We applied image manipulations and standard optical character recognition (OCR), which however were relative slowly (duration 300 ms on standard PC).

Icon telltales (Fig. 11 bottom left) are extracted by object recognition algorithms (key point matching). Thereby, specific characteristics describing every telltale are pre-defined as templates. If a telltale is captured, the algorithm searches the ROI for those key points and checks for correct telltale reproduction.

The video content is supervised by feature comparison of the camera image and the digital data at the display's interface. 100+ segments (Fig. 13) are correlated for gray scale and color, both by mean value and histogram.

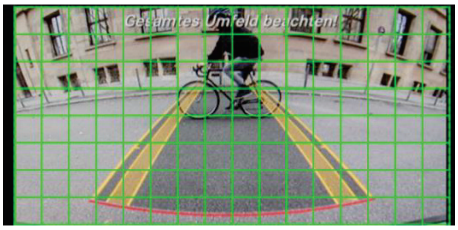

Fig. 13 Segmentation of the video image

Fig. 14 points out that the segmentation can detect even small gray scale reproduction deviations which could result in loss of essential details such as potholes or pedestrians with bright clothes at a bright background.

Fig. 14 Even minor gamma distortions (right) are detected as "faulty reproduction"

Reflections of ambient light are detected by the camera as well. However, using a black surface on the desk in front of the monitor significantly reduces specular reflections (geometric conditions shown in Fig. 7).

Using a standard PC with PYTHON and OPENCV framework we achieved the following processing durations: Capturing of one or two camera images lasts about 150 to 200 ms. Speed, telltales, and video image supervision requires typically 30 ms each. The longest duration was OCR with about 300 ms, so it is not performed for every loop.

Camera-based monitoring provides a reliable and precise way to verify optical display output beyond today's state-of-the-art safety methods (digital data).

5 SUMMARY

Safe and unaltered reproduction of speed and camera content of modern CMS is essential for automotive applications. We successfully developed and evaluated two new methods using a fully functional demonstrator:

- Supervision of speed by a few photodiodes
- Supervision of the image reproduction by a camera. This can be used in-car or for remote operators

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