**Auto Head-Up Displays: “View-Through” for Drivers**

Head-up displays (HUD) are featuring more and more frequently in both current and future generation automobiles. One primary reason for this upward trend is that head-up displays are said to improve auto safety significantly. Another reason is that the installed cost of these instruments has dropped enough so that today, not only luxury vehicles are equipped with this device; HUDs now are finding their way into economy cars as well.

The HUD projects all relevant auto and traffic info “into”, not merely “onto”, the windshield. This allows the driver to maintain a view of the street scene, rather than requiring vision to be diverted to the instrument panel. The HUD “picture” is projected toward the driver’s forward field of view, 2.2 meters into the windshield. Information such as speed, autopilot data, all warning indicators, directions, etc., are displayed. The latest generation HUDs even show approaching traffic signs.

A head-up display consists basically of a light projector and a special kind of windshield made of two sheets of glass. The projector is built into the dashboard in front of the driver. Between the sheets is a special integrated layer that can receive and display the information sent by the projector. The control electronics sit in the engine compartment.

To guarantee full functionality, a system test during assembly is essential. A simple visual inspection is inadequate because varying environmental light conditions would negatively impact the results. Thus, the HUD cannot be calibrated properly.

![Camera test position - principle test scheme](image)

**Figure 1: Camera test position - principle test scheme**
Development goal

Therefore, in order to guarantee outstanding performance, Audi AG (Ingolstadt, Germany) and GEFASOFT GmbH (Regensburg, Germany) jointly developed a calibration routine including complex software. The goal of this effort was to provide a mechanical set up, based on CCD cameras, which can be used in-line during auto assembly. GEFASOFT took part in the software development for the CCD camera and the image processing tools, while other system partners developed the mechanical arm.

The test software is developed to be used in a production environment. Thus, a short cycle time is of paramount importance since the forward speed of the assembly line is not to be modified unless absolutely necessary.

As an integral part of the test, the software projects test images onto the windshield. Thus, both the projected image as well as the windshield itself can be analyzed for possible errors and defects.

As part of this process the image processing software must identify certain characteristics and evaluate them on an objective scale. Based on experience three test images are utilized for this purpose:
- Cut-Height-Image is used for alignment of the eye box. The eye box is the field of view for the driver without any cut-offs, that is, an area in which the driver cannot see the images.
- Height-Warping-Image makes use of a warping algorithm which modifies the image so that no image distortion occurs. This is accomplished via a warping matrix, as described below.
- Cut-Ghost-Image checks the warping results. A clear view without distortions is the result.

The test images are filed in the drive electronics of the HUD and can be recalled during assembly or even later if system recalibration is necessary.

All data gathered by the test system must lie within certain limits to be acceptable. The control-PC geometrical characteristics are given in millimeters, while the CCD camera output is shown as pixels. Consequently the camera needs to be calibrated by a high precision target. Also, the moving arm of the system needs to ensure a repeatable movement.

Figure 2: Image positions of the test camera in the eye box (shown in forward direction)
Head-up Display Algorithms

Based on a 1200 x 1600-pixel resolution GigE® CCD camera with an f=35 mm focal lens, the Cut-Height-Image is analyzed in the driver’s field of view (eye box). The image is projected in such a way that even large disturbances can be seen, as shown by positions 8 and 9 in the eye box in Figure 2. The adjustable mirror (Figure1) in the HUD is then aligned to produce minimal distortion. After this first step, warping mode can be applied.

![Image of warping matrix](image)

Figure 3: Height-Warping Image (courtesy of Audi AG)

The Height-Warping Image shown in Figure 3 is comprised of 189 (21 x 9) dots with the central dot highlighted. The central dot is known as the mass center point or center of gravity. The image processing algorithms calculate the “dot” out of the pixel cloud using sub-pixel resolution. Each dot is defined by its x-y coordinates as well as a “score-value” which characterizes each dot.

The test image can identify the following characteristics: rotation, translation, trapezoid, linear distortions and aspect ratios.

Proper dot numbering (scan order) is essential, since it is necessary to “design” lines according to a linear or parallel fit that is based on the mathematical scheme of minimizing least squares. Incorrectly calculated dots means the overall result also would be incorrect. Vector-based and always starting from the center point, the “nearest-neighbor” eight dots are searched until reaching the cut off or end of the viewing area.

All 189 dots are necessary to create the warping matrix based on interpolation. The matrix coefficients represent ΔX, ΔY and hexadecimal values in a fixed-point arithmetic. The Δ-values describe the actual theoretical variance. Also, a check sum is included. The mathematical algorithms were developed by Dr. Ing. Norbert Eichhorn of GEFASOFT; the software is based on commercially available tools from Cognex.

As Dr. Eichhorn points out:

“These algorithms provide the necessary level of thoroughness for processing the test information to achieve optimal results.”
Analysis of Cut-Ghost-Image

The Cut-Ghost-Image is similar to the Height-Warping-Image. In this image, three characteristics are determined: Cut, Ghost and Dynamic. Cut means the image is not full in the view of the eye box. An unwanted double line, a line with less intensity or a blurred line is called a Ghost. Dynamic compares the images received by the left and right eyes (eye box positions 2 and 3 in Figure 2), in order to provide the proper overall image blend. These images must meet certain requirements in order to be considered acceptable.

The complete test system, including mechanical arm, CCD cameras and test software, is positioned near the assembly line. When an auto under assembly reaches the test position, the arm moves into the chassis and the programmed test routine automatically checks and calibrates the Head Up Display in less than 60 seconds. The result is shown in Figure 4, which demonstrates the driver’s ease in gathering auto- and traffic-related information in dense traffic.

Figure 4: Drivers view in city traffic
Summary

Modern vehicles boast more safety-related features every year. These include various driver-assistance systems such as automated lighting and brake control. The goal, of course, is to reduce the number of accidents, along with the often tragic consequences that can be the result. The Head-up Display is another addition that will be incorporated in nearly every future vehicle and will provide even further safety-related benefits and ease of navigation.

As stated by Dipl. Ing. O. Zink, Project Director Production at Audi AG:

“Any accident prevented by an HUD means the system pays for itself.”

The advanced mathematical algorithms and state of the art CCD-camera technology from GEFASOFT calibrate all Audi vehicles manufactured with an HUD system. This is being done on the assembly line, 24 hours per day, every day. Currently, GEFASOFT is developing the latest version of its unique test software with new features for other automakers.

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