Automotive Night Vision Systems – Status and Development Trends

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Abstract

First generation Night Vision Enhancement Systems with image presentation in the dashboard have been introduced on the market some years ago [1]. Far Infrared and Near Infrared systems are currently competing technologies. The systems present a Camera-picture in the dashboard, in the center console area or on the windscreen. While Japanese systems prefer to present the camera picture via Head-up Display (HUD) in the windscreen, European car-makers prefer the presentation in the dashboard region with a graphic LCD screen. Ergonomic investigations have shown that the reconfigurable LC display located in the instrument cluster was found to meet best the requirements of a quick and distraction-free reading. A precondition for a quick recognition and identification of relevant obstacles is a high-contrast and brilliant picture quality. Meanwhile, the next generation has been introduced on the market in 2009. Due to technical progress in picture processing this 2nd generation makes an object classification for pedestrians and cyclists and warns the driver. The third generation will use a contact analogue HUD to warn the driver with icons projected onto the wind screen.

Kurzfassung

Systeme zur Nachtsicht-Verbesserung der ersten Generation mit Informationsdarstellung in der Instrumententafel wurden vor einigen Jahren in den Markt eingeführt [1]. Fern-Infrarot- und Nah-Infrarot-Systeme konkurrieren seit ihrer Einführung im Markt. Beide Systeme zeigen ein Kamerabild im Kombiinstrument, in der Mittelkonsole oder in der Windschutzscheibe. Während japanische Fahrzeughersteller die Bilddarstellung als Head-up Display (HUD) bevorzugen, stellen europäische Fahrzeughersteller die Information bevorzugt in der Instrumententafel auf einem Graphikdisplay dar. Ergonomische Untersuchungen haben gezeigt, dass ein frei programmierbarer Bildschirm im Kombiinstrument zu besten Ergebnissen für eine schnelle und ablenkungsarme Ablesung führt. Eine Voraussetzung für die schnelle Erkennbarkeit und Interpretation relevanter Objekte im Kamerabild ist eine Bilddarstellung mit hohem Kontrast und einer brillanten Bildqualität. Mittlerweile ist die nächste Generation in 2009 in den Markt eingeführt worden. Bedingt durch den technischen Fortschritt im Bereich der Bildverarbeitung führt diese 2. Systemgeneration eine Objektklassifizierung für Fußgänger und Radfahrer durch und warnt den Fahrer in gefährlichen Situationen. Die dritte Generation wird voraussichtlich ein kontaktanaloges

Head-up Display verwenden, bei dem der Fahrer durch Symbole gewarnt wird, die in die Windschutzscheibe eingespiegelt werden.

Introduction

The probability for an accident at night is by the factor 4 to 5 higher than at daytime. Accident statistics show, that night vision driver assistance systems have a high potential for reducing accidents and fatalities by collision avoidance and collision mitigation means. Night Vision Systems based on Near-Infrared Radiation (NIR) or Far-Infrared Radiation (FIR) can be used to enhance driver's perception at night. The system must be an optimal vision aid allowing him to drive like cruising with high beam on without blinding oncoming traffic.

Special emphasis has to be put on a careful design of the Human Machine Interface (HMI) to avoid distraction by the system. For a quick and distraction-free reading of the image presented to the driver the picture must allow a quick interpretation of the presented information by the driver. The display must be positioned in an ergonomically favorable position in the vicinity of the primary field of vision of the driver without distracting him longer than necessary from the traffic.

Types of night vision systems

The use cases for the Night Vision function are mostly non-illuminated country roads and situations with approaching vehicles which might hide pedestrians, cyclists or any obstacles on one's own lane due to dazzling. Independent of their basic technologies (FIR or NIR), the principle of this function is to present an enhanced live image in real time in the vicinity of the primary field of the driver's view.

There are two technical variants of night-vision enhancement systems on the market:

- The **Far-Infrared-based system (FIR)**. It has been used in military devices since many years and was first launched in 2000 in a Cadillac car. A second generation was introduced in Japan in 2004 by Honda and in 2005 by BMW.

- The **Near-Infrared-based system (NIR)**. Having been launched in a Toyota Landcruiser in 2003 with a HUD atop of the center console, it found its way into the Mercedes S-Class in 2005. Significant new Camera and HMI development has been made for the launch of this new system.

Far-Infrared system (FIR)

FIR night-vision enhancement systems receive thermal radiation emitted by objects in the far infrared wavelength range between 7 and 12 µm. These so-called passive systems do not require any additional source of radiation to illuminate the objects. The picture of the camera can be processed by an ECU for picture quality improvement and is then presented by a graphic display to the driver. Fig. 1 shows the basic setup of the FIR system [2].

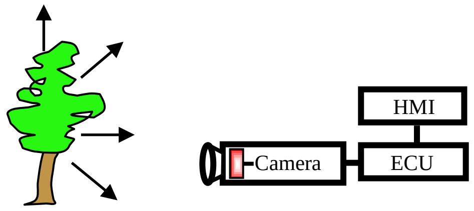


Fig. 1: Far-Infrared system (FIR)

The pyro-electrical thermal-image camera or micro-bolometer camera is able to take heat images only in the wavelength range mentioned above and, therefore, cannot be used for day-applications like lane recognition. The camera requires a temperature control.

As these wavelengths cannot pass through the windscreen glass, the camera must be mounted to the outside of the vehicle's compartment. Most thermal-image cameras use Germanium optics. Currently available cameras have a resolution of 320 x 240 pixels (QVGA). Fig. 2 shows the FIR-camera with washer unit and the vehicle integration in the front bumper of a BMW.

Fig. 2: FIR-camera (left), vehicle integration (right) [3]

In the image of a thermal camera warm objects appear as bright contours against the dark (colder) background while cold objects are displayed dark. Only objects having a higher temperature than the ambient are detected by the camera. The most striking feature of the FIR image is the wide reach of the system. Pedestrians and other objects can be detected at ranges of 300m and more. Lane markings and traffic signs, however, can be seen only vaguely if they have adapted their temperature to the ambient air [4]. Fig. 3 shows an image of a FIR camera.

Fig. 3: Image of a FIR camera. [5]

This way of presenting the image appears rather unusual to most of the drivers because it does not correspond to a normal reflected echo-return picture. Another drawback is the fact that objects are displayed rich in contrast at low outside temperatures but only vaguely in a warm environment.

Near-Infrared system (NIR)

Near-infrared systems use radiation in the spectral range between 800 nm and 1,000 nm. As objects do not emit any radiation in this range of wavelengths, objects in front of the vehicle must be illuminated. The reflections are collected by an infrared-sensitive video camera. Fig. 4 shows the block diagram of the NIR system. It consists of two Halogen illumination modules, the camera, an ECU for picture quality improvement and a HMI.

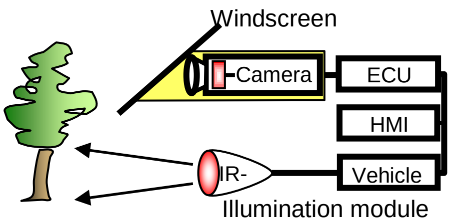


Fig. 4: Near-Infrared system (NIR)

Silicon image sensors are sensitive in the mentioned wavelength range. As the upper limit of the sensitivity of these sensors is 1,100 nm, they can hence be implemented in day-time applications as well. The camera module is mounted on the windscreen, usually in the region behind the interior mirror (from drivers view).

Halogen headlights, being commonly used for the automobiles high and low beam, possess a high infrared share with the maximum in the range between 900 and 1,000 nm. In practical applications light modules consisting of a halogen headlamp with an externally mounted optical filter for the visible spectrum, are integrated into the front headlights. Fig. 5 shows the image of the NIR system.

Fig. 5: Image produced by an NIR system [5]

The image clearly shows that only those objects being illuminated by the IR headlamps are visible. As the NIR spectrum is close to the visible spectrum, natural objects reflect NIR similarly to visible light. Hence the image appears as familiar to the driver as a black-and-white TV picture bearing a high resemblance to the normal viewing impression at high beam. Furthermore, lane markings are clearly visible. One drawback may result in the poor visibility of pedestrians with dark clothing.

In order to obtain a high-contrast, brilliant image and ensure good recognition of objects, high-quality systems use an electronic control unit to post-process the video image. This facilitates reliable detection of pedestrians at a distance of 150m and more. Currently available video sensors feature a resolution of 640 x 480 pixels and more. Fig. 6 shows the CMOS-camera and the vehicle integration in the rearview-mirror area. [6]

Fig. 6: CMOS-camera (left), vehicle integration on windscreen (right)

The requirements to a NV-camera are high. Typical situations are darkness and bright light sources at a time. Only CMOS technology shows the preconditions for this application. The picture must be free of disturbing light effects, such as ghosts or halos. The keys for the achievement of these high quality criteria are an imager with high dynamic range (typically >120 dB) and a perfect glass lens. The imager chip delivers a high resolution digital gray level image in VGA format which is preprocessed by a camera electronic circuitry, and then transmitted to the ECU.

For a familiar and high quality picture an intelligent picture processing is necessary. Making use of an edge filter, structures within the picture are pointed out and, thus, the recognition of objects is improved and the sharpness of the picture is enhanced. Secondly, to adapt the picture to the dynamic range of the display, a strongly nonlinear output characteristic was implemented improving significantly the recognition of objects and structures [7].

HMI for Night Vision systems

The human machine interface (HMI) plays a major role with this kind of system, because it directly shows the benefit of the system to the driver. In principle, there are three different display zones characterized by differing requirements as regards the performance of the relevant display medium. These three communication centers in the vehicle are:

- The windshield. The information can be seen without the driver having to take his eyes off the road and without the need for visual accommodation. At a first glance this location seems to be ideal for night vision information.
- The instrument cluster for information being relevant to the driver. It is located outside the driver’s primary field of view.
- The center console for lesser important information for driver and passengers.

Where should be shown what kind of information?

- Information, to which the driver must respond, should be displayed within or close to the primary field of view (HUD or Instrument cluster).
- Status information or operator dialog in the form of prompts, may be displayed in the operator-control unit in the center console. These multifunctional displays must be structured taking into consideration the regularities of human perception [8].
- Information aimed at entertaining should be kept away from the primary field of view.

The best compromise between a quick and precise perception of the Night Vision information and a possible distraction must be found. The distraction must be minimal.

Head-up Display

The first systems on the market in US- and Japanese cars made use of Head-up Displays. At that time the optical performance of HUD technology was rather poor and therefore the acceptance was rather low. Furthermore it was reported [8] that some drivers tried to drive the car by night by using the HUD without looking out of the window. This was very dangerous as the HUD-picture was displayed atop of the center console. During own unpublished investigations test persons reported that they disliked the HUD-picture in front of the driver because the human eye is intuitively attracted by the moving picture and the distraction by the system was higher that the benefit.

Head-down Display in the center console

In the region of the center console, sophisticated integrated information systems are introduced, combining all additional information in one compact display and operator-control unit. Systems of that kind have a high degree of acceptance

Using the Head-down display (HDD) in the center console for Night vision information has the charm of a low system cost if the vehicle is already equipped with a graphic display. However, with increasing amount of information there is the problem to find the right balance between night vision and other information being also important during night rides.

An additional aspect is that the human has a long eye-off-the-road-time when reading information from a display in the center console. The driver has now three observation zones: The road, the speedometer and other gauges in the instrument cluster and the night vision display in the center console. This puts more stress on him. Fig. 8 shows this solution in a BMW 2005 car model.

Fig. 8: Night vision on the multipurpose display in the center console, BMW, 2005 [3]

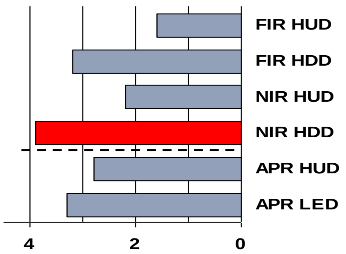
Head-down Display in the Instrument Cluster

The HDD in the Instrument Cluster fulfills both postulations of low distraction and quick readability. The graphic display is located far enough away from the primary field of vision without attracting the human eye. The display is readable at a quick glance together with the speedometer information and with a short eyes-off-the-road-time.

The idea of a reconfigurable instrument came first true in a luxury class vehicle, the Mercedes S-class 2005, see Fig. 9.

Fig. 9: Instrument cluster of the Mercedes S-class MJ 2005. Left: Conventional mode, Right: Night vision mode

A major objection against the reconfigurable instrument is the question of acceptance. Therefore, acceptance studies have been carried out by the Universities of Berlin and Chemnitz, Germany. They made an acceptance investigation with six different types of night vision systems with end users [9]. The result is shown in Fig. 10.



Far Infrared & Head-up display
Far Infrared & Head-down display
Near Infrared & Head-up display
Near Infrared & Head-down display
Warning symbol & Head-up display
Warning symbol & LED-chain

Fig. 5: Results of acceptance tests

The criteria for the evaluation by the test persons were:

- Recognition time and recognition distance.
- Evaluation of a NIR- System vs. a FIR-system,
- HUD vs. HDD
- Two kinds of warning systems, one with a HUD (APR HUD), the other with an LED chain (APR LED) in the lower region of the windscreen.

The figure shows that the NIR-system with a display in the instrument cluster (NIR HDD) ranked as best. The main arguments heard from the test persons were:

- High resolution display with excellent optical appearance and brilliant picture quality,
- Self explanatory system, and
- Little additional workload while reading the display.

The study also shows a high potential for systems with Collision warning system, but significant improvement of the HUD quality is necessary.

Recent and Future Developments

Meanwhile, the second generation of night vision systems has been developed and is being introduced in the market during the year 2009. These systems do not only show a picture to the driver but they have the feature to detect, and to classify objects (to a certain extent) and to warn him in hazardous situations [10]. After tracking a detected object a contour matching step is performed. The head and shoulder part of a human is very characteristic, allowing a reliable classification of pedestrians and bikers.

In a first step a warning symbol is shown on the display. This makes it easier for the driver to detect relevant information within the picture. Fig. 11 shows the display of the new Mercedes 2009 E-Class [11]. The warning symbol is in the upper right corner of the picture close to the detected pedestrian. The multifunction graphic display of the E-Class is located in the center console region.

Fig. 11: Night vision warning system

The third generation will allow the realization of systems without graphic screen, but warning the driver according to the prevalent situation only in those cases where a relevant object is detected. Insofar a secure detection of lane markings and a reliable course prediction is essential to correlate the position of an object with the course of the own lane.

This feature requires a contact-analogue HUD with Laser projection, being able to project warning symbols anywhere on the windscreen where objects can appear within the field of view of the driver. Systems of the kind are under development. Fig. 12, left picture, shows how a warning symbol could appear for the driver.

Another, simpler solution could be a LED-chain located at the basement of the windscreen. The direction to the detected obstacle in the horizontal is indicated with a single LED from the chain. Fig. 12, right picture, shows an example. This technical solution is significantly cheaper than the contact-analogue HUD.

Fig. 12: Warning symbol on a contact analogue HUD (left) and with a LED-chain (right)

Further development focuses on warning systems which alert the driver from any object on or near the road, if required.

Summary and future aspects

A comparison of the technology and of the aspects of image representation and image processing shows that the NIR-system is superior to the FIR-system on some criteria. The NIR technology will enjoy at a long term basis a massive cost benefit due to the meanwhile low price of the video camera and due to its usage by several applications at a time. Furthermore, research has shown that although the wider reach of the FIR system represents an increase in comfort, this does not automatically translate into any considerable plus in term of safety and acceptance.

Current first generation night vision systems presenting live images in the primary field of the driver's view can be realized with Head-up- and Head-down displays. Investigations have shown that the latter produce less distraction to the driver while reading the display than HUDs. On a longer term basis these systems will be substituted by systems based on object detection. These second generation systems provide warnings instead of images to the driver, and will also be used e.g. for lane departure warning or obstacle collision warning, which will require new ideas for human machine interfaces. Further on, object detection will be the basis for controlling actuators for lane keeping functions and collision mitigation and collision avoidance functions at night.

With the increase of embedded micro-controller performance and the ongoing development of software algorithms, functions based on object classification will be able to control special safety features.

The evolution of night vision functions is a process which depends on one hand on the development of hardware and software technologies, on the other hand on the acceptance of each driver and the overall contribution to the communities in reducing fatalities.

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