ImagingThe road ahead for car night-vision

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IMAGING

The road ahead for car night-vision

Car night-vision is fast becoming practical and cost effective thanks to improvements in moulded infrared optics and thermal image sensors.

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Figure 1 Avoiding accidents. BMW's new FIR night-vision system in action. An FIR image of the road ahead is presented to the driver by an internal display integrated into the dashboard. Warm objects such as people and animals show up as bright white features on the image. The system offers a range of 300 m and a refresh rate of 30 Hz.

Figure 2 Forward looking. **a**, The passive thermal image sensor is mounted on the car bumper just below and to one side of the front number plate. **b**, The sensor consists of a microbolometer featuring a 320 × 240 array of detector elements (pixels) that sense very small temperature differences in the environment of less than 0.1 °C.

Road accidents involving pedestrians are far more frequent at night than during the day. Analysis of US traffic fatalities by the University of Michigan Transport Research Institute (UMTRI) has shown that the risk of a pedestrian fatality is around four times higher at night than during daylight hours, after all the contributing factors are taken into account. Although higher alcohol consumption, increased fatigue and greater exposure to animals on the road are partly to blame, an important factor is the driver's dramatically reduced range of vision.

One reason that driving at night is so difficult is that high-beam headlights can rarely be used owing to the frequent presence of oncoming traffic. The experience is especially challenging for older drivers, who typically have shorter detection distances of just 30–50 m for dark objects when driving with low-beams and facing oncoming vehicles.

The main safety benefit of night-vision systems is to increase the driver's range of vision when using low-beam headlights and emphasize the presence of animals, pedestrians, cyclists and other vulnerable road users.

FAR- AND NEAR-INFRARED NIGHT-VISION

There are two types of night-vision technologies on the market: far-infrared (FIR) and near-infrared (NIR) systems. An FIR system is passive, detecting the thermal radiation (wavelength of around 8–12 μm). Warm objects emit more radiation in this region and thus have high visibility in the image. NIR systems use a near-infrared source to shine light with a wavelength of around 800 nm at the object and then detect the reflected illumination. The main advantage of NIR systems is that the cost is lower, because the sensor technology at these wavelengths is already well developed for other imaging applications such as video cameras. NIR hardware can also potentially be combined with other useful functions such as lane departure warning.

In contrast, FIR systems offer a superior range and pedestrian-detection capability, but their sensors cannot be mounted behind the windscreen or other glass surfaces. UMTRI studies comparing the ability of drivers to

Table 1 Comparison of NIR and FIR night-vision systems

NIR		FIR	
+	Lower sensor cost	+	Superior detection range
+	Higher image resolution	+	Emphasizes objects of particular risk for example, pedestrians and animals
+	Potential for integrating into other systems		
+	Favourable mounting location	+	Images with less visual clutter (unwanted features that may distract driver)
–	Sensitive to glare from oncoming headlights and other NIR systems	+	Better performance in inclement weather
–	Detection range depends on reflectivity of object	–	Lower contrast for objects of ambient temperature

spot pedestrians using both the NIR and FIR devices showed that under identical conditions, the range of an FIR system was over three times further than that obtained with NIR — 119 m compared with 35 m.

If the driver was also given an automatic warning of the approaching object from the system, the detection distance and accuracy of detection improved for both systems, but the FIR approach still offered a better range (Table 1). Moreover, drivers who tested the NIR system said that using it involved more effort.

THE MARKETPLACE

Night-vision systems were first introduced into the 2000 model of the Cadillac Deville (FIR) and thereafter by Lexus/Toyota in 2002 (NIR). In spite of initial consumer interest and optimistic forecasts, night vision did not establish a foothold in the market. Now, however, renewed interest in the technology is expected after the recent release of night-vision systems in the Honda Legend (FIR), the BMW 5–7 series (FIR) and the Mercedes S-class (NIR). The potential market is nevertheless restricted as these systems are currently only available, with a price-tag of about US$2,000, as features for luxury cars. Any widespread take-up in the car market will require an intense cost-reduction effort.

In September 2005, BMW introduced the Autoliv Night Vision System as an optional feature (Figs 1 and 2). At the heart of the system lies a custom-designed microbolometer — a thermal image sensor featuring a 320 × 240 array of detector elements (pixels) that sense very small temperature differences in the environment (less than a tenth of a degree). The sensor, 57 × 58 × 72 mm in size excluding the connector, is mounted on the car's front bumper just below and to one side of the number plate. By sampling its pixels and performing digital signal processing on the data stream, a video signal is created, which gives a thermal representation of the driving scene.

In terms of performance, the system offers a range of 300 m, a 36° field of view in the horizontal and a 30 Hz refresh rate. The key to making it cost effective is the use of high-yield vanadium oxide microbolometers with batch-processed vacuum packaging and moulded infrared optics, all of which were designed with low-cost, high-volume manufacturing in mind.

By using a highly sensitive FIR camera, the driver is given a clear view of the road ahead and can easily discern warm (living) objects that have a temperature different from that of the ambient air. The driving scene appears on a central instrument display, located in the central dashboard of the car as shown in Fig. 1.

For ease of use, the image is automatically optimized to preserve image quality over a range of driving conditions. For driving speeds in excess of 70 km per hour, the image is automatically magnified 1.5 times using an electronic zoom function. An electronic panning function, which is controlled by the angle of the steering wheel, ensures that the image matches the car direction and follows the curve of the road.

OPTICAL CHALLENGES

Aside from the microbolometer, the optical elements represent the main cost of night-vision technology. When designing the FIR system for BMW, Autoliv investigated both germanium and the chalcogenide glass GASIR from Umicore as potential lens materials. Germanium is a high-performance material for long-wavelength infrared lenses, with a high mechanical resistance and a refractive index of 4.0. It is, however, expensive and requires a costly process, known as single-point diamond turning, to machine it into an aspherical surface.

GASIR is a new type of infrared-transmitting glass with a refractive index of 2.5. It is an attractive candidate for high-volume infrared lenses as it can be moulded into a finished lens. In addition, the highly variable germanium market price affects GASIR to a lesser extent because it contains only about one quarter germanium. GASIR, unlike germanium, also possesses a refractive index that does not vary much with temperature, allowing for a simple opto-mechanical design that does not require temperature compensation.

One drawback of chalcogenide glasses like GASIR is their higher chromatic dispersion as compared with germanium. To overcome such dispersion, optics with diffractive or binary compensation must be fabricated. Fortunately, these specially shaped surfaces can be incorporated during the moulding process at no additional cost.

OUTLOOK

The primary focus of a car night-vision system is to help reduce the number of night-time fatalities by enhancing the visibility of pedestrians, other vulnerable road users and animals to drivers. The latest FIR-based systems are able to image pedestrians from longer distances than their NIR-based counterparts, but they are more expensive to manufacture. NIR detectors offer superior image resolution, but the images suffer from the glare of headlights from oncoming vehicles.

As for the technology of choice in the future, the answer will be dictated by which is able to deliver sufficient performance for the function in mind, for example pedestrian detection. Until NIR systems are able to meet this goal, FIR systems will remain the preferred choice, despite being the more costly approach.

The main focus of FIR system development should now lie in reducing the cost of their components, and this will involve optimizing all aspects of the system. Decreased pixel size and improved manufacturing yields will reduce detector prices. Improvements in the signal-processing capability will become affordable through continued gains in microprocessor functionality and power. Driving down the cost of night-vision systems could also help manufacturers to fulfil the proposed new EU directive on pedestrian protection.

Given that the capabilities of NIR and FIR partly complement one another, the optimal system may ultimately involve a fusion of both technologies; for example, using an NIR system for generating an image, with a lower-resolution FIR sensor for purposes such as pedestrian detection.

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