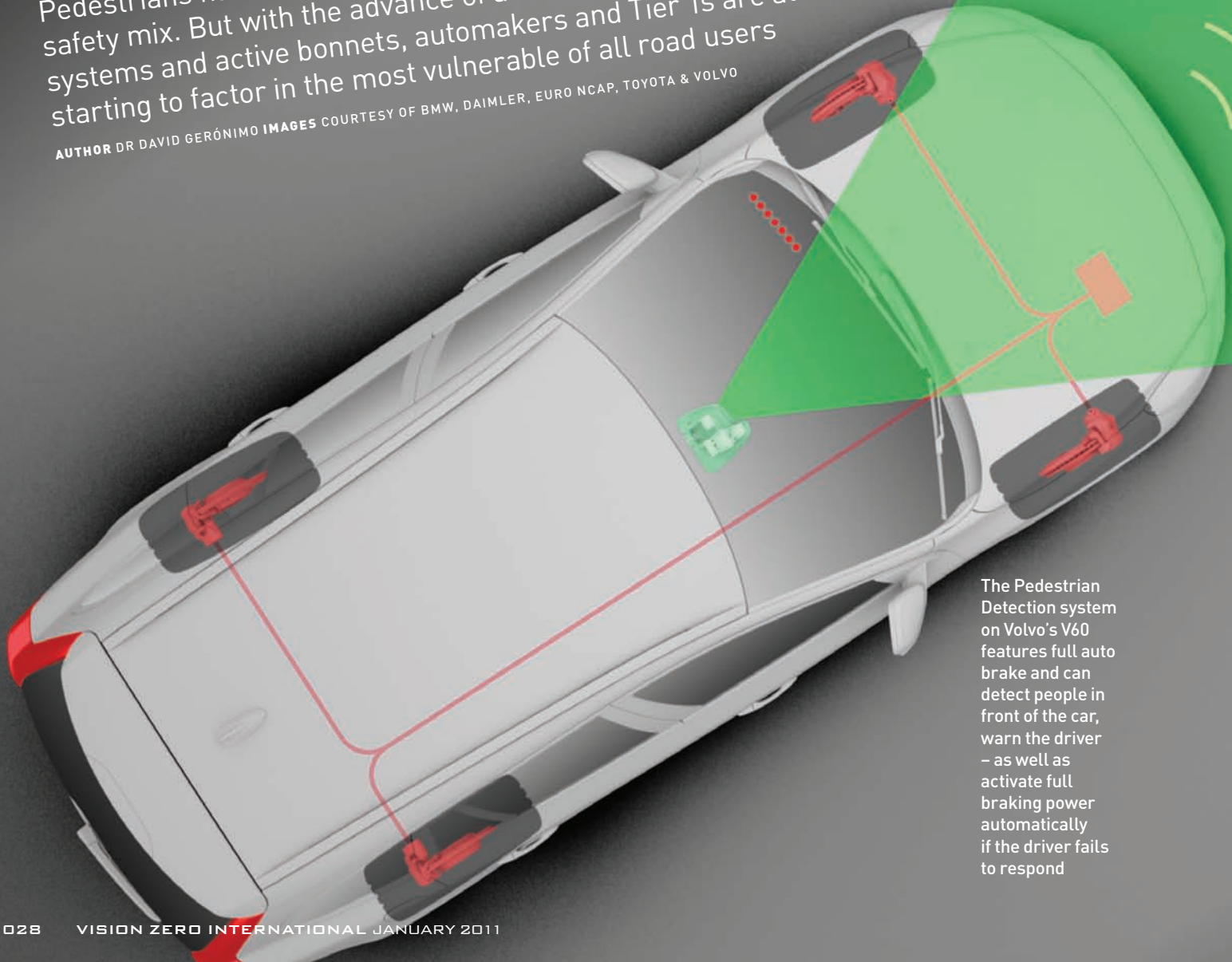


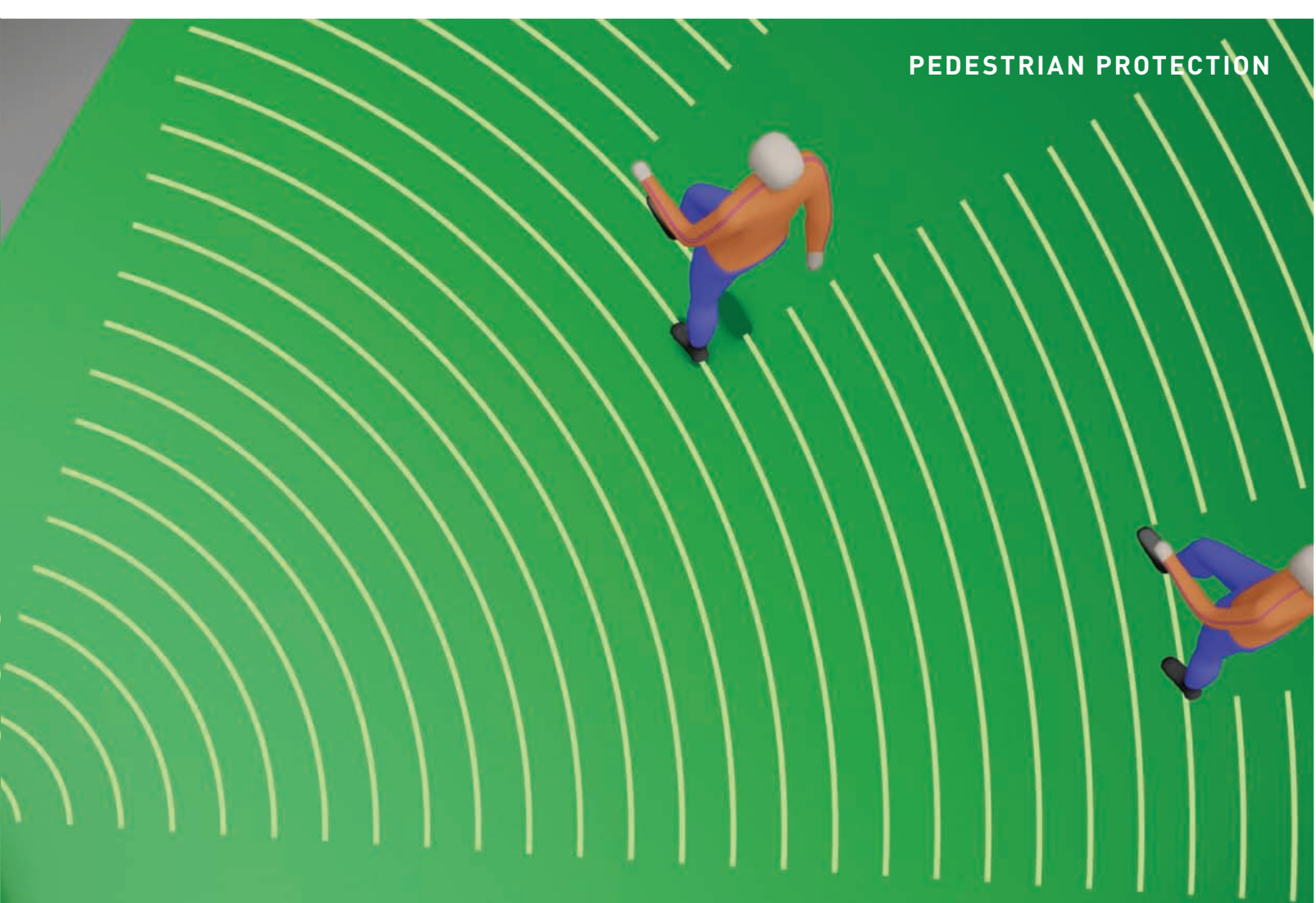
People power

Pedestrians have long been the forgotten component in the traffic safety mix. But with the advance of automatic emergency braking systems and active bonnets, automakers and Tier 1s are at last starting to factor in the most vulnerable of all road users

AUTHOR DR DAVID GERÓNIMO IMAGES COURTESY OF BMW, DAIMLER, EURO NCAP, TOYOTA & VOLVO



The Pedestrian Detection system on Volvo's V60 features full auto brake and can detect people in front of the car, warn the driver – as well as activate full braking power automatically if the driver fails to respond



Every year, more than 7,000 pedestrians are killed and around 150,000 injured on the roads of the European Union. The statistics from the USA are somewhat similar, with around 4,000 people killed and 70,000 injured. As the number of vehicles in the world continues to increase – especially in emerging countries such as India, Brazil and China – the number of accidents involving pedestrians is likely to worsen.

What's clear from these figures is that pedestrians are the most vulnerable of road users. Yet they haven't received a great deal of attention from the automobile OEMs over the years, especially when compared with other traffic participants such as the car passengers or the vehicles themselves. This can be explained by two factors. First, the research budget – which defines the security emphasis – has traditionally been addressed to the product buyer, i.e. the driver and the

other vehicle occupants. Passengers, for instance, are nowadays protected by a increasing number of security measures; counting just the immediate post-crash time lapse they are protected by pre-tensioning seatbelts, frontal, side, curtain and other airbag configurations, as well as forthcoming advanced seats, anti-whiplash headrests, etc. Second, technology limitations have until this decade delayed the opportunity to deal with such an external and unpredictable target that pedestrians pose. In fact, it was not until the emergence of modern sensors and the availability of high-computational resources at relatively low prices that the research community considered the problem. Moreover, even in the ADAS community, pedestrian protection stands as one of the most challenging applications given the appearance variability and movement unpredictability of human beings, in contrast to other typical ADAS targets such as lane markings

PEDESTRIAN PROTECTION

or vehicles. This is one of the reasons why lane departure warning (LDW) and adaptive cruise control (ACC) have already been commercialised successfully by several companies, which cannot be said for pedestrian protection systems.

Vulnerable road users

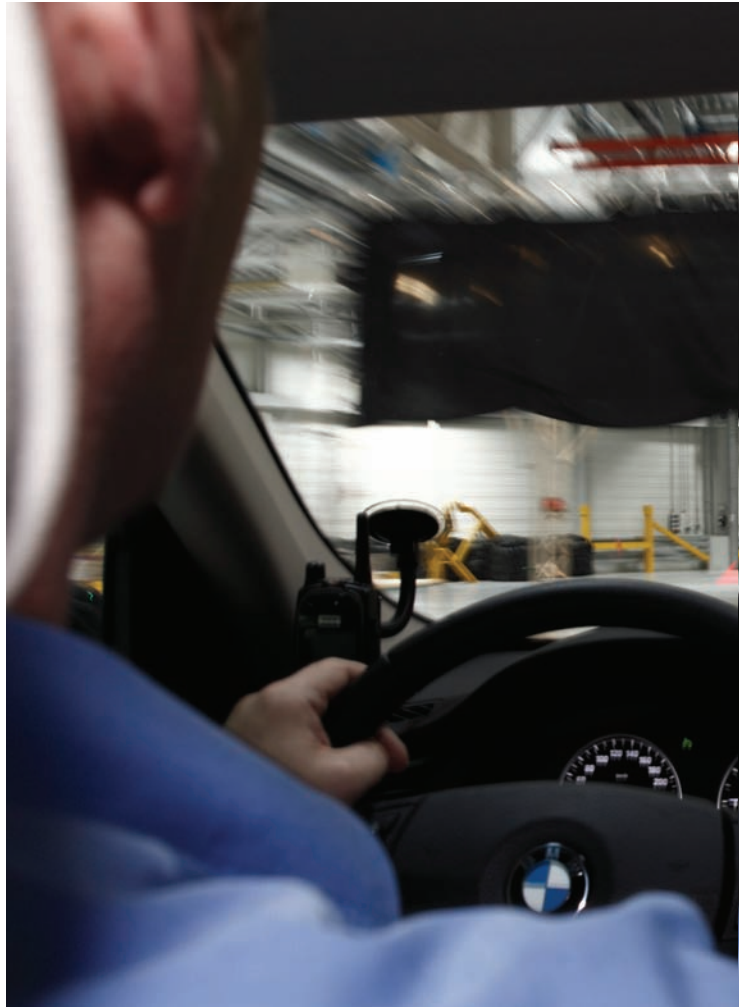
The first intuitive – and feasible given existing technology – step in the protection of pedestrians is the development of hardware measures. Similarly to the procedures to protect passengers, they tend to be focused on minimising the possible harms in the instant following a crash. These measures are sometimes referred to as ‘pedestrian safety through vehicle design’, and will be discussed later in this article. However, the principal aim of ADAS – to anticipate and avoid accidents – has taken the security of pedestrians to a new level. In fact, among all the actors in the traffic scene, pedestrians are probably the ones who would benefit most from the ‘anticipation’ concept.

In order to protect pedestrians, they must first be detected in the road or pavement in front of the vehicle, tracked through the scene, then finally the system must infer the real danger to take actions on the vehicle and provide the appropriate alerts to the driver. As mentioned, the nature of pedestrians makes the problem difficult to be solved with traditional sensors such as radar or infrared alone. The system needs an advanced understanding of

the scene in order to be reliable and useful. Researchers have presented enough evidence to prove this can be achieved through the use of cameras and computer vision. Vision technology offers the possibility to distinguish a traffic light pole from a pedestrian at 30m, and even reliably estimate the direction and speed of the target attending to its visual appearance, which has not previously been possible.

The process of detection

According to Gerónimo, López, Sappa and Graf, a pedestrian protection system can be divided into six different modules: preprocessing, foreground segmentation, object classification, verification-refinement, tracking and application (Gerónimo et al 2010). Such an architecture, although presented from the signal processing viewpoint, offers an idea of the requirements of such a system in terms of the analysis of the scene – the passive part of the process. The preprocessing can be seen as a bureaucratic step in any automatic process, regardless of the kind of sensor or algorithm used, so we won't enter in details. The foreground segmentation module (sometimes referred to as candidate generation) extracts candidates from the input signal – image acquired from a camera, lidar or radar map, etc – to be sent to the classification module, discarding as many background areas to inspect as possible. Binocular cameras, in spite of not being used in current commercial ADAS, offer the possibility of stereo



BMW's 'proactive pedestrian protection' is geared to preventing – or mitigating the consequences of – potential collisions with pedestrians

The need for new security standards

As security concepts in vehicle technology are introduced, new needs arise in the area of standards. The traditional requirements for the automotive industry are related to the physical properties of the vehicle, such as behaviour after impacts, or environmental aspects, such as carbon monoxide emissions.

In the case of pedestrian protection systems, *a priori* not directly related areas like psychology will also play their role in the new definitions. For instance, in order to fix a maximum number of false alerts or missed pedestrians per hour, many different psychological studies have to be performed. The active response of the driver to acoustic or visual warnings must be precisely balanced with respect to the real danger, otherwise the driver could be bothered by the system with unnecessary alerts or even mistrust it in case of missed alerts.

In this direction, the standard tests such as EuroNCAP will have to be updated in order to assure reliability and usability of pedestrian protection.



Euro NCAP testing of a Honda pop-up hood for improved protection of pedestrians in collisions



Mercedes-Benz's newly developed Active Bonnet, which enlarges the deformation area, reducing the risk of injury to pedestrians

starts. The first countermeasure is the driver warning, which gives the driver the possibility to avoid the danger as long as it is possible – a human-driven action tends to be preferred to a computer-driven one. Researchers from Honda R&D have proposed the use of a head-up video display containing infrared imagery for night-time pedestrian detection (Tsuji et al 2002). Likewise, Volkswagen presented two different HMIs also for night-time pedestrian detection – one based on a head-up display and another based on a segmented LED bar that highlights the position of the pedestrian. Another possibility is the use of acoustic warnings, such as those used in the EC-funded SAVE-U project (Marchal et al 2005).

If the driver hasn't been able to address the situation, the automatic countermeasures take place. In this case, the objective is to reduce the speed of the vehicle to safely stop the vehicle before hitting the pedestrian or in the worst case minimise the crash-speed. Research shows that the slower the speed of the vehicle at the moment of the crash, the lower the harms are for the pedestrian. According to researchers from the Chalmers University of Technology, for instance, as the impact speed decreases from 40 to 30km/h, the probability of severe head injury decreases from 50% to lower than 25% (Liu et al 2010).

Finally, in the case that the vehicle has been unable to avoid the pedestrian, the vehicle will still offer protection as a result of the aforementioned safety through design, such as safer bumpers or windscreens. The European Union has, for example, recently approved the directive on frontal protection systems – 2005/66/EC and others – which regulates the installation of so-called bull bars in the vehicle's front end. Moreover, additional technology such as pop-up hoods or external airbags can be

reconstruction, which is gaining popularity in the recently proposed systems (Gavrila and Munder 2007).

Object classification, verification-refinement and tracking are usually seen as a single module – the one that understands the scene. It is in this module where computer vision is more necessary due to its capabilities to make use of the rich information that cameras provide. The candidates are labelled as pedestrian or not using learning machine and image features, and then tracked through the different frames (Gerónimo et al 2010).

Depending on the type of sensor, the techniques will vary substantially, for instance daytime and night-time systems often make use of visible spectrum and thermal infrared spectrum images respectively. This obviously leads to additional problems

– temperature, glaring, camouflage effects, etc – that must be taken into account to meet the requirements of the system (Chan 2005).

Finally, the application step can be viewed as a risk-assessment process. Risk assessment is a novel research topic that not only takes account of the potential danger of a detected pedestrian but also whether the driver is already aware of the situation or not – known as driver in the loop (Pettersson et al 2005). Other measures are host vehicle data such as speed or direction – for instance via the CANbus – and the different possibilities in response to the possible accident (avoidance or mitigation).

Countermeasures

When a pedestrian in danger has been detected, the active part of the process

“MULTIMODAL ANALYSIS - THAT IS, COMBINING CUES FROM RADAR, LIDAR, VISIBLE OR INFRARED IMAGERY - IS EXPECTED TO BE THE HOT TOPIC IN THE YEARS TO COME”

The role of computer vision

» Although some driver assistance systems making use of just active or very task-specific sensors have already been successfully commercialised – radar-based adaptive cruise control from Toyota or the downward-looking infrared-based lane departure warning (LDW) from Citroën – cameras will be the sensors for the next generation of ADAS.

The information provided by cameras, working either in infrared or visible spectra, is in many aspects superior to that provided by other sensors – higher resolution, colour, relative temperature, accurate object size, etc. Through the use of computer vision, this information can be processed to compute high-level reasoning, such as discovering occluded pedestrians or estimating their behaviour in seconds.

Moreover, other applications such as LDW, adaptive light control or collision avoidance systems, are likely to increase their robustness and capabilities through the use of computer vision in the sense that it offers additional cues to the process.



Toyota has introduced a new Safety Pack for the third-generation Prius T Spirit – including radar-based ACC

deployed. Honda R&D has published research articles presenting experiments with pop-up hoods, the idea being to increase the distance from the pedestrian to the engine in case of impact, which is detected via a bumper sensor in their case (Nagatomi et al 2005). Other companies such as Nissan or Jaguar are also about to commercialise this technology. Alternatively, Volvo and Autoliv have recently published reports of prototypes using an external airbag that inflates just between the bottom of the windscreen and the hood to absorb the impact of a pedestrian's head. (Erlingfors and Östling 2009). Similar prototypes are being developed at a university level as well by auto manufacturers such as Volkswagen, Nissan and others.

The future to come

With the aim of moving forward from these research proposals and prototypes, the first attempt to commercialise a complete pedestrian protection system will be made by Volvo in 2011, with its 'Collision Warning with Full Auto Brake and Pedestrian Safety' installed in the S60. The system – developed in cooperation with Mobileye – consists of a fusion of radar and vision systems to provide automatic braking. First, a radar sensor detects objects and calculates their distance from the car – the foreground segmentation step. A monocular camera is subsequently used to

Video still showing the log sequence of the Pedestrian Detection system on the Volvo S60



distinguish pedestrians from other background objects using computer vision. The implemented driver warnings consist of both acoustic and flashing lights in the head-up display. Finally, if the driver is unable to stop the vehicle in time, the brakes are automatically applied. Currently, there is a big expectation to analyse the performance of this system under more challenging conditions, for instance at night or in crowded environments.

If such a system is successful, Volvo would have set an important milestone in the long path to what could be called a completely assisted driver environment, especially attending to the particular difficulty that pedestrians pose. But what can be expected for future pedestrian protection systems? In addition to the continuous developments regarding the understanding of the scene, in which computer vision has an important role

to play, sensor combination could be a potential future approach to the problem. Although many proposals combining sensors already exist, the multimodal analysis – that is, combining cues from radar, lidar, visible or infrared imagery – is expected to be the hot topic in the years to come. As soon as the performance of pedestrian detectors reaches satisfactory levels, more difficult weather conditions such as rain or fog will be the next hurdle to overcome as some sensors do not perform well under certain conditions.

The future is full of new possibilities that will lead to more robust and elegant solutions. The next generation of cameras will allow us to detect further pedestrians easily as a result of their higher resolution. Likewise, higher radar or lidar sensor resolution will help to discriminate humans from other objects easily, hence filtering out potential false positives more quickly. Of course, any computer vision development achieved in other areas such as surveillance or database retrieval – which may seem far removed from automobiles – will in fact represent a great jump in the protection systems, just as it happens to any aeronautics technology when applied to automobiles. ◀

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