Trends towards Automotive Electronic Vision Systems for Mitigation of Accidents in Safety Critical Situations

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1. Introduction

When discussing vehicular safety, there are two key concepts: The first is the concept of *Primary Safety*, which can be defined as 'the vehicle engineering aspects which as far as possible reduce the risk of an accident occurring' (DfT (UK), 2008a); in contrast, *Secondary Safety* can be defined as 'all structural and design features that reduce the consequences of accidents as far as possible' (DfT (UK), 2008b).

It is important to note that these two aspects of safety sometimes interact in conflicting ways. For example, to improve secondary safety in vehicles, manufacturers often strengthen and increase the size of a vehicle's A-pillar (the vertical or near vertical shaft of material that supports the vehicle roof on either side of the wind-shield). However, this can decrease the visibility of the vehicle's immediate environment to a driver (i.e. increase the vehicle's blind-zones[1]), which has a negative impact on the primary safety of the vehicle.

In this chapter, we will discuss the role of automotive vision systems in improving the primary safety of vehicles. The development of electronic vision systems for the automotive market is a strongly growing area of development, driven in particular by consumer demand for increased safety in vehicles, both for drivers and for other road users, including Vulnerable Road Users (VRUs), such as pedestrians, cyclists or motorcyclists. Consumer demand is matched by legislative developments in a number of key automotive markets; for example Europe, Japan and the US have either introduced or are in the process of introducing legislation with the intention of reducing the number of VRU fatalities, with some emphasis on the use of vision systems.

There are several areas in which electronic vision systems can be utilised. These can be broadly divided into two applications: visual display applications for passive human

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[1] A vehicles blind-zones are the areas around the vehicle that cannot be seen directly by the driver by looking forward or by using any of the vehicles standard rear-view mirrors (internal and external) from the normal sitting position. The term "blind-zone" is used in preference over the other commonly used term "blind-spot", as this is the term used in some of the jurisdictions described in this section, and more accurately describes the (often sizeable) areas that cannot be seen by a driver of a vehicle.

actualisation, and scene processing for active machine vision-based safety assessment. Visual display applications require the display of the vehicle's environment in such a manner that is both intuitive and useful to the driver of the vehicle. Scene processing applications require a video stream that is suitable for automated processing of the scene.

For display-based applications, typically, the aim is to display a vehicle's blind-zones to the driver. With this is mind, we discuss some of the factors that motivate the use of wide-angle and fish-eye camera technologies in vehicles. With scene processing applications, typically the aim is to process the scene captured by the cameras to intelligently provide or enhance information delivered to the vehicle driver. This information would then be used to provide active warning to the driver in safety critical situations such as detecting the presence of a VRU, a lane departure warning or lane-merge situation. Another application might be to prepare the vehicle for an imminent impact in pre-crash situations. Additionally, some non-safety critical situations (or driver assist situations) include vehicle detection and distancing for adaptive cruise control, auto headlamp dimming and road-sign recognition.

Low-light situations are of critical importance to the overall safety of all road users. Proportionally, there is a far higher accident-per-trip ratio during night-time compared to daytime. Due to advances in technology, the sensitivity of image sensor has improved in recent years, and continues to improve, which allows continually improved low-light performance of camera systems. However, in the absence of a minimum of environmental lighting, visual cameras will fail to return useful information. Therefore, we also discuss the use of passive far-infrared imaging devices for both display and scene-processing applications.

The remainder of this chapter is broken down as follows: in Section 2, we will discuss the general global trend towards the use of electronic vision systems on vehicles, including a detailed examination of statistics, legislation and standards, and with a particular emphasis on safety of pedestrians and other VRUs. In Section 3, we will describe some of the basic technologies that exist and some of the issues with particular applications. Finally, in Section 4, we draw some conclusions about the future roles of automotive camera devices.

2. Global trends

The World Health Organisation states that traffic accident are one of the leading causes of death glablly, accounting for 1.2 million fatalities and 50 million injuries annually (Peden et al., 2004), with pedestrians accounting for 65% of the fatalities; 35% of these being children. Therefore, safety both within and in the presence of vehicles is a growing concern globally. Traditionally, specific emphasis has been placed on the secondary safety of vehicles. For example, the European New Car Assessment Program (Euro-NCAP, 1997), which was established in 1997, provides objective information on the safety of drivers and passengers in cars in crash situations. In a study commissioned by the Euro-NCAP, 94% of respondents list safety in vehicles as a major concern (Hobbs, 1996). There are similar organisations in Japan (J-NCAP, 2010), the United States (US-NCAP, 2010), Australia and New Zealand (A-NCAP, 2010), China (C-NCAP, 2010) and Korea (K-NCAP, 2010). However, more recently, interest in the protection of VRUs, e.g. pedestrians and cyclists, has increased. The OECD define VRUs as "those unprotected by an outside shield, namely pedestrians and two-wheelers" (OECD, 1998). This section discusses the global trend towards increased VRU safety, with specific emphasis on how automotive vision systems can be utilised to meet these demands.

2.1 Statistics
2.1.1 European Union

In Europe, official statistics for VRU deaths due to the victims not being visible to the driver of a vehicle are not readily available, as there is no single repository for such information. However, the European Commission's CARE Road Accident Database claims that there were 3,961 VRU pedestrian fatalities within urban areas in 2005 (CARE, 2010). It is reasonable to assume that a significant number of these deaths were caused by the driver of the vehicle being unaware of the presence of a VRU. This assumption is supported by several statistics. The European Commission Directorate-General for Energy and Transport estimates that the lack of visibility in the blind-zone towards the rear of a vehicle directly causes 500 deaths a year in the EU (ECDGET, 2004). Furthermore, the Commission of the European Communities estimates that every year, approximately 400 European road users lose their lives in collisions with Large Goods Vehicles (LGVs)[2], because the driver did not see them when turning to the blind side of their vehicle (i.e., turning to the left in the UK and Ireland, to the right in other EU countries) (CEC, 2009).

2.1.2 North America

Statistics for the United States are equally disjointed, with no official statistics directly available for VRU injuries due to vehicle blind-zones. However, there are several sources that strongly suggest that blind-zones are a cause of injuries and fatalities: The Kids and Cars Organisation in the United States claims that 941 children were killed in non-traffic collisions[3] in the United States between 2002 and 2006. They further claim that 49.5% of the fatalities (or 466 children) were due to the vehicle reversing while children were present in a vehicle's rearward blind-zone (KCO, n.d.). The National Highway Traffic Safety Administration claims that 221 people were killed and 14,000 people were injured in 2007 by vehicles that were completing a reversing manoeuvre. 99 of the deaths and 2,000 of the injuries involved children under the age of 14 (NHTSA, 2007).

In a study between July 2000 and June 2001, the Centers for Disease Control and Prevention (CDC) (McLoughlin et al., 2002) reported that there were an estimated 9,160 non-fatal injuries to children in non-traffic automotive collisions, with approximately 20% (or 1,832 children) of these injuries caused by the vehicle moving backwards. Between 2001 and 2003, the CDC reported that an estimated 7,475 children (2,492 per year) were treated for moving vehicle backover injuries (Patel et al., 2005). In Canada, it has been shown that the age distribution for children struck by a vehicle reversing is lower than children struck by a vehicle moving forward (Nhan et al., 2009), with over 50% being below the age of five. Again, while the blind-zone is not directly implicated in these injuries, it is reasonable to assume that a significant proportion of these injuries were due to the children being present in the vehicle's rearward blind-zone. Wang & Knipling (1994) estimated that lane change/merge crashes in 1991 accounted for approximately 244,000 police-reported crashes with 224 associated fatalities. Furthermore, the authors reported that the principal causal factor in such crashes is that the driver "did not see other vehicle".

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[2] The term 'LGV' is used in this paper, instead of the term 'heavy goods vehicle (HGV)', as this is the terminology used in most European Union documentation because of the fact that the word "heavy" does not have a direct translation in all European languages.

[3] Non-traffic collisions are collisions involving vehicles while they are not in a traffic situation (for example, while on private residential property)

2.1.3 Asia

Gandhi & Trivedi (2007) give a good overview of statistics in developing countries in their introduction. During 2001, there were 80,000 fatalities on Indian roads, which grew in the last decade by 5% per year (Singh, 2005), with 60%–80% of the road fatalities being VRUs (Mohan, 2002). In China, in 1994 pedestrians and cyclists accounted for 27% and 23% of the fatalities respectively, compared to 13% and 2% in the United States (Mohan, 2002). In Japan, 25% of all fatal car accidents involve pedestrians (Takeuchi & Ikari, 2007).

2.1.4 Night-time

Vehicle collision statistics confirm that night conditions are an important area of focus for road safety and collision prevention. In the EU (EU-15) there were more than 43,000 fatal road accidents in 2006 (CARE, 2010). Almost one third of these road fatalities (32.3%) occurred during the hours of darkness (ERSO, 2008). In 2005, 45.5% of pedestrian fatalities in the EU were in darkness (ERSO, 2007). A similar pattern is prevalent in statistics from the USA, with 47.2% of fatal accidents occurring in darkness (FARS, 2010) and 70% of pedestrian fatalities occurring at night (6pm-6am) in 2008 (NHTSA, 2008). In Japan, 55% of all road fatalities occur during night-time (Oya et al., 2002). These statistics confirm that the hours of darkness account for a disproportionate amount of road collisions and fatalities, as there is a substantially reduced traffic volume during night hours. It has been estimated that per vehicle mile, the road fatality rate is 3-4 times higher in darkness than in daylight (Fors & Lundkvist, 2009).

A review by VTI, the Swedish National Road and Transport Research Institute (Fors & Lundkvist, 2009), provides an in-depth analysis of the numerous factors that contribute to the imbalance between day-time and night-time road accident rates. They determine that human vision is not well adapted to night conditions. Visual acuity, contrast sensitivity, spatial resolution, distance perception and reaction time all deteriorate as overall light levels decrease. VTI state that numerous factors contribute to driver performance at night including low luminance (Plainis et al., 2006), tiredness (Akerstedt et al., 2001), alcohol (Akerstedt et al., 2001), and glare from oncoming headlamps (Andre, 1996).

2.2 Legislation and standards

2.2.1 European Union

To match the consumer desire for increased safety in vehicles, the European Union has introduced legislation that requires LGVs to have large portions of their blind-zones made visible to the driver. Legislation in the form of Directive 2003/97/EC (EPC, 2003) was introduced in 2003. Although the initial requirements of this directive aimed to reduce collisions caused by the blind-zones of LGVs and improve road safety for new vehicles circulating from 2006/2007 onwards, the legislation does not cover the existing fleet of LGVs in the EU. However, since it has been estimated that existing fleets will not be fully replaced until 2023, Directive 2007/38/EC (EPC, 2007) was introduced in 2007. This legislation required the retrofitting of the required indirect vision systems to all existing fleets within 24 months of enactment of the bill (i.e. by July 2009). Directives 2003/97/EC and 2007/38/EC were introduced in response to the UNECE World Forum for Harmonization of Vehicle Regulations Agreement E/ECE/324 Regulation No. 46 (UNECE, 2009).

The shaded areas in Figure 1 show the areas of a left-hand drive LGV's environment that must be visible to the driver via the use of "Indirect Vision Systems" (IVS), as required by these directives. The United Kingdom have suggested increasing the size of the visible regions for objects 1m off the ground UNECE (2010). Examples of IVS's include additional

mirrors to the standard rear-view mirrors (internal and external), as well as camera-monitor devices. However, practical problems arise with the use of additional mirrors as the extra mirrors can themselves introduce additional blind-zones, by obstructing direct forward vision, as well as having additional cost and styling implications.
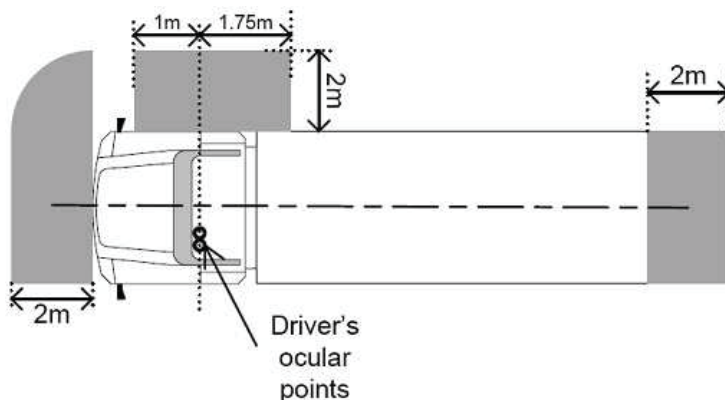

Fig. 1. Area required by Directive 2003/97/EC to be visible to drivers of (left-hand drive) LGVs via the use of IVSs (not including areas covered by the standard and wide-angle wing-mirrors).

As early as 1994, camera devices were identified as a means of reducing accident rates on roads in Europe: "A camera fitted at the rear of the vehicle with a screen on the dashboard to enable the driver to see directly what is happening behind the vehicle, particularly when backing up, is often claimed to be a facility that should be introduced more generally, but so far no country has made it compulsory" (ECMT, 1994). Now, there is a clear provision in Directive 2003/97/EC for the use of camera-monitor devices for the coverage of vehicle blind-zones in this directive. In fact, the use of camera-monitor devices over mirrors is often not only desirable, but necessary in certain situations. For example, it is practically impossible to cover the area at the rear of an LGV with mirrors alone, so camera-monitor systems are the only practical solution.

More recently, EU regulations place the onus on automotive manufacturers to protect VRUs by introducing new passive secondary standards (EC, 2009) on a staggered basis from 2011-2019. However, a vehicle will be granted immunity from a large section of the requirements if it is equipped with a collision avoidance system. This is based on a European Commission study (Lawrence et al., 2006) that found that VRU protection can be significantly improved by a combination of primary and secondary safety measures, particularly adoption of active brake assistance systems. While secondary safety systems aim to reduce injury on impact, primary safety measures aim to avoid an impact or mitigate the conditions under which it takes place.

2.2.2 United States

In the United States, legislation in the form of H.R.1216 (The Cameron Gulbransen Transportation Safety Act of 2007) (HR1216, 2007) is designed to protect against children being injured or killed in non-traffic vehicle related incidents, such as when a vehicle is reversing. Relating to the potential use of cameras, the H.R.1216 Act requires a "field-of-

view to enable the driver of a motor vehicle to detect areas behind the motor vehicle to reduce death and injury resulting from backing incidents, particularly incidents involving small children and disabled persons" and that the expanded field-of-view "may be met by the provision of additional mirrors, sensors, cameras, or other technology to expand the driver's field of view". H.R.1216 also requires the National Highway Traffic Safety Administration (NHTSA) to "maintain a database of injuries and deaths in non-traffic, non-crash events involving motor vehicles". (HR1216, 2007).

Additionally, H.R.1216 also requires the NHTSA to initiate rulemaking to amend the Federal Motor Vehicle Safety Standard (FMVSS) No. 111: Rearview Mirrors (FMVSS, 1971) to improve a driver's ability to see areas to the rear of a motor vehicle in order to mitigate fatalities and injuries associated with backover incidents (FMVSS, 2009). This rulemaking was initiated in March 2009, with final rulemaking due in February 2011. Several major automotive manufacturer's have made submissions on this review that explicitly propose camera-monitor devices for inclusion in the standard (GM, 2009; Nissan, 2009; Magna, 2009; Gentex, 2009; IIHS, 2009), with at least one stating that "it is clear that rearview video systems can provide the widest range of coverage" (Magna, 2009), and another "urges [the NHTSA] to establish a no-blind-spot requirement" and that they "expect that rearview video systems will be a popular means of meeting such a requirement" (IIHS, 2009).

In addition to vision based applications, the NHTSA have committed to continue to review technologies that provide object detection capabilities (FMVSS, 2009). Indeed, in their documentation, the NHTSA have explicitly acknowledged that, in future, video-based and infrared-based obstacle detection may be employed in meeting the requirements of the proposed standard.

2.2.3 Japan

In Japan, legislation has also been proposed (again in response to UNECE Regulation No. 46 (UNECE, 2009)) that would require medium and large vehicles to be equipped with devices that allow drivers to detect objects in the vehicles blind-zones, either directly or indirectly using mirrors or camera-monitor devices (see Figure 2) (UNECE, 2005). For the purpose of the proposed legislation, a cylinder one metre high with a diameter of 0.3 metres placed anywhere within the coverage areas must be at least partially visible to the driver of the
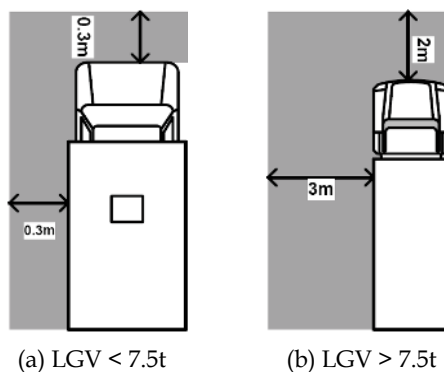
(a) LGV < 7.5t   (b) LGV > 7.5t

Fig. 2. Proposed Japanese legislation: area in which a cylinder (1m high, 0.3m diameter) must be at least partially visible to the driver of the (right-hand drive) LGV (UNECE, 2005).

LGV directly, by mirror or by camera. However, in this legislation, it is proposed that objects within blind-zones caused by A-pillars and external mirrors need not be visible to the driver of the vehicle (UNECE, 2002).

In both the EU and the Japanese requirements, the focus has been on LGVs, as these pose the greatest risk to other road users, including pedestrians (Desapriya et al., 2010).

3. Technologies

The general opinion of within the automotive industry is that camera-based technologies will provide the best means to prevent road fatalities. For example, the Insurance Institute for Highway Safety recently stated that "NHTSA has presented evidence suggesting that current non-visual technologies (e.g., radar and sonar sensors) do not represent an effective solution to the problem of backover crashes. Both the unreliability of current sensors to detect people and drivers slow responses to audible warnings suggest that requiring or even allowing such systems in lieu of vision-based systems is not advisable at this time" (IIHS, 2009). The NHTSA themselves have said that "camera based systems may have the greatest potential to provide drivers with reliable assistance in identifying people in the path of the vehicle when backing" (NHTSA, 2006).

The camera-monitor combination can be thought of as a passive device – it displays information to the user, but provides no active warning in the presence of, for example, pedestrians or other objects. While the visual display of information is perhaps the most important aspect for driver/VRU safety, the NHTSA have said that a "driver must look at the display and have the capability to identify an object or person in the path when backing up, and to react and brake quickly enough to prevent the incident" (NHTSA, 2006). This reaction time can potentially be reduced significantly if a warning can be issued to the driver of the vehicle. One automotive manufacturer has stated in a research paper that "sensing the surroundings of the vehicle is the key technology for such [driving assistance and warning systems]. Machine vision technology, especially, is expected to detect surrounding objects with high space resolution as well as lane markings painted on the road surface" (Takahashi et al., 2003).

Thus, in this section, we discuss some of the camera-based technologies that can be utilised to provide visual information and active warnings to drivers of vehicles.

3.1 Visual systems

The aim of a visual camera systems is typically to display a vehicle's blind-zones to the driver. The sizes of blind-zones are determined by the size and design of the vehicle and mirrors, and will vary significantly according to vehicle model and manufacturer.

Consumers' Union (2010) have examined the rearward blind-zone of many non-commercial light-duty passenger vehicles (from small passenger cars to large sports utility vehicles). The zone was measured by determining how far behind the vehicle a 28-inch (0.71 metre) traffic cone needed to be before a person, seated in the drivers seat, could see its top while looking directly through the rear window, i.e. not using mirrors. For a 5-foot 8-inch (1.73 metres) tall driver, the distance measured was up to 44 feet (13.4 metres) for a commercially available four-wheel drive vehicle registered in 2006. In the same vehicle, the blind-zone distance for a 5-foot 1-inch (1.55 metres) driver extends to 69 feet (21 metres).

The blind-zone for LGVs is naturally much larger than that of light-duty vehicles. Ehlgen & Paidla (2007) calculated the forward blind-zones of a given LGV as shown in Figure 3.

Furthermore, the rearward blind-zones of LGVs tend to be very large; it has been calculated that several LGVs have a rearward blind-zone that can extend up to 65 metres on the ground plane behind the vehicle.
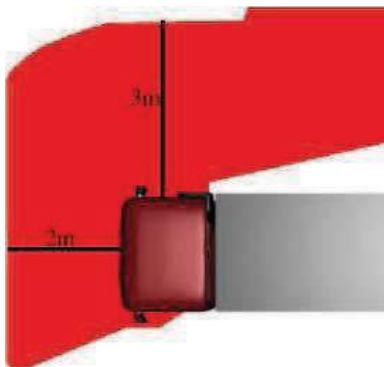

Fig. 3. Measured blind-zones around the front of a given (left-hand drive) LGV (Ehlgen & Paidla, 2007).

While rear-facing cameras can be used to cover some blind zones, the use of standard lenses has limitations. As shown in Figure 4(a), standard lens camera systems (e.g. 45° Field-Of-View (FOV) lenses) are unable to fully cover the blind-zone of some SUVs. A standard lens camera with FOV of 45° can only cover perhaps 1m of the SUV rearward blind-zone. Figure 4(b) illustrates how the use of a wide-angle lens camera system (e.g. > 100° FOV lenses) enables the entire SUV rearward blind-zone to be covered.

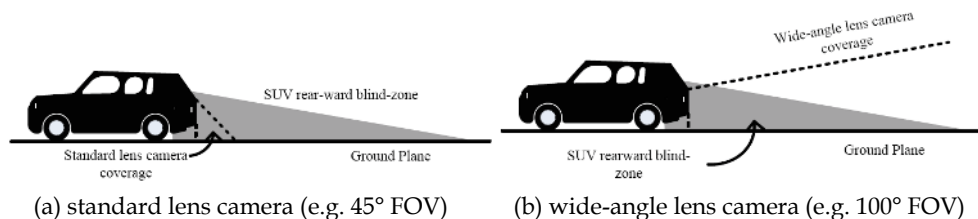(a) standard lens camera (e.g. 45° FOV)   (b) wide-angle lens camera (e.g. 100° FOV)

Fig. 4. Coverage for standard and wide-angle lens cameras mounted on the rear of a typical SUV.

Figure 5(a) shows a sample placement of two wide-angle cameras mounted on an LGV. Camera 1 is a 170° FOV fish-eye camera, located approximately half-way down the length of the LGV, and 3m off the ground plane. The optical axis of camera 1 is tilted at 15° from the side of the LGV trailer. Camera 2 is a 135° wide-angle camera, located in the middle of the front cabin at about 2m off the ground plane. The optical axis of camera 2 is tilted at 20° from the front face of the cabin. The angles and locations of the cameras are chosen to maximise the usable field-of-view of the cameras, and minimise the amount of the body of the vehicle captured by the cameras. With both cameras corrected for distortion, Figure 5(b) shows the areas in the vicinity of the vehicle that can be displayed to the driver. Such a camera system would cover all the blind zones of the LGV shown in Figure 3, and would meet the requirements of both the EU Directive 2003/97/EC (Figure 1), and the proposed Japanese legislation (Figure 2).

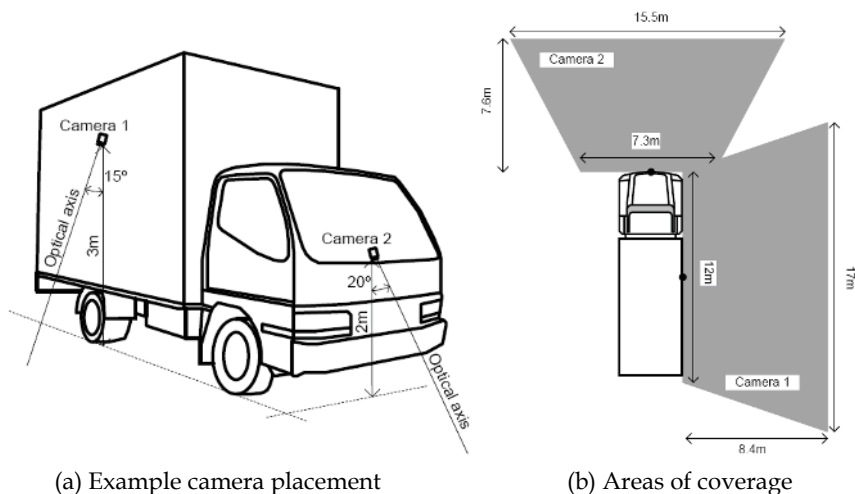(a) Example camera placement   (b) Areas of coverage

Fig. 5. Example of a potential wide-angle camera placement on an LGV that would meet the requirements of the EU Directive 2003/97/EC and the proposed Japanese legislation.

While wide-angle lenses greatly increase the area in blind zones that can be covered, problems arise due to the deviation of wide-angle lens cameras from the rectilinear pin-hole camera model, due to geometric distortion effects caused by lens elements. Fish-eye cameras deviate substantially from the pin-hole model, introducing high levels of geometric nonlinear distortion. Figure 6 shows an example of an image captured from an automotive fisheye camera. Because of this distorted representation of the real world scene on-screen, there is the potential for the driver to not recognise obstacles and VRUs. Additionally, the distortion may cause the driver to misjudge distance to objects, due to the nonlinearity of the view presented. Thus, camera calibration and fish-eye compensation are important tasks for automotive camera applications. Not only do they make images captured by the camera more visually intuitive to the human observer, they are often also necessary for computer vision tasks that require the extraction of geometric information from a given scene. Hughes et al. (2009) describe in detail how the geometric fish-eye effects of can be compensated, and Friel et al. (2010) describe a method demonstrating how calibration can be performed automatically using typical automotive video sequences.

Fig. 6. Automotive fish-eye example illustrating the effects of fisheye distortion.

3.2 Advanced Driver Assistance Systems (ADAS)

Driver inattention is one of the most common causes of traffic collisions (Ledesma et al., 2010), and as such, there is a desire for technologies that actively draw the attention of a driver in a danger situation. Thus, the demand for Advanced Driver Assistance Systems (ADAS) is expected to increase as consumers grow increasingly safety conscious, and insurance companies and regulators begin to recognise the positive impact such systems can have on accident rates. Concurrently, vision systems are becoming increasingly common in road vehicles due to advances in technology, as discussed in the previous section. Some vehicles currently come equipped with vision systems for displaying blind zone and as parking and reversing aids. However, supplemental functionality can be extracted from these cameras by using them to detect other road vehicles and VRUs. The detection of other road vehicles is a core component of many ADASs such as Automatic Cruise Control (ACC) (Hofmann et al., 2003), Advanced Collision Warning (ACW) (Dagan et al., 2004), overtaking vehicle monitoring (Hegeman et al., 2005), automatic headlamp dimming (Alcantarilla et al., 2008) and automatic blind zone monitoring (Kiefer & Hankey, 2008). It is beneficial to use standard colour cameras for these functions as they are low-cost, readily available, and may already be present on the vehicle. The colour video produced can be simultaneously used for other ADAS utilising colour data and for full colour display purposes. Additionally, standards exist that outline the performance of manoeuvering aids with distance ranging (BS ISO, 2004; 2009). Further information on vehicle detection techniques can be found in the comprehensive review by Sun et al. (2006).

Quite apart from vehicle detection algorithms, there are a several other topics of interest in the area of ADAS.

3.2.1 Lane Departure Warning (LDW)

The NHTSA has recognised that Single-Vehicle Road Departure (SVRD) crashes lead to more fatalities than any other crash type (Wang & Knipling, 1994), and as such, lane departure warning was a key technology identified by the NHTSA Intelligent Vehicle Highway System (IVHS) program that could potentially reduce the number of fatalities and injuries associated with SVRD (Mironer & Hendricks, 1994). However, at present, there are no EC directives, US directives, standards or regulations that cover LDW systems. The main forum for the creation of Standards for LDW systems is the International Organisation for Standardisation (ISO). However, while ISO standards are voluntary, there have been several instances where existing ISO standards have formed the basis for proposals to amend European Legislation (Visvikis et al., 2008).

Two standards documents are identified that are relevant for LDW systems. These are the ISO 17361:2007 Lane Departure Systems (ISO, 2007) and the American Federal Motor Carrier Safety Administration Concept of Operations and Voluntary Operational Requirements for Lane Departure Warning Systems (FMCSA-MCRR-05-005) (FMCSA, 2005). These define LDW systems as in-vehicle systems that warn the driver when an unintentional lane departure has occurred.

A previous study of the area can be found in (McCall & Trivedi, 2006). Typically, LDW algorithms segment the road markings, followed by localisation of the lane borders before lane departure can be determined. There have been several proposals for the segmentation of road markings from images, including, for example, tangent-vectors (Furusho et al., 2002), colour information in various colour spaces (Chiu & Lin, 2005; Tsung-Ying et al.,

2006)[4], or width and colour intensity using top-hat or Gaussian filters (Takahashi et al., 2003; Baldassano et al., 2009). The localisation of lane markings can also be achieved in several ways, for example, lane-deformable models (Park et al., 2003; Wang et al., 2004) or indeed simple linear models (e.g. Hough transform), which are within the technical specification of ISO 17361:2007 and FMCSA-MCRR-05-005.

Once the lane markings are localised, the time at which lane departure occurs needs to be predicted to provide warning to the driver. Reviews of the literature have revealed that there are two main methods for lane departure prediction (Gonzalez-Mendoza et al., 2004; Taylor et al., 1999). One is lateral offset (Taylor et al., 1999), which monitors the relative distance between the lane-boundary and the vehicle, and gives a warning when the vehicle approaches to or remains near the vicinity of the lane edge. In essence, this can be thought of as a "virtual rumble strip". The second is Time to Lane Crossing (TLC), which is the calculation of the time remaining until the vehicle crosses over the lane edge, assuming that the vehicle speed and steering angle do not change. Typically, both are reliable warning criteria (Sukhan et al., 1999). In general, TLC provides more warning time, because warnings are issued when the system predicts that the vehicle is likely to be in danger. However, as it does not take into account the drivers' reactions, the rate of false positives is generally higher than the lateral offset method (Gonzalez-Mendoza et al., 2004). Also, the lateral offset method is generally simpler to implement, as specialised hardware is not needed to measure the host vehicles steering angle or speed. Both ISO 17361:2007 and FMCSA-MCRR-05-005 describe the concept of lane departure warning in terms of lines across which a warning is issued by the system, which is similar to the lateral offset method. Figure 7 shows an example of lane boundary detection for an LDW system.

(a) Automotive image   (b) Segmented roadmarkings   (c) Detected lane boundaries

Fig. 7. Example of lane boundary detection for a lane departure warning system

3.3 Night-time
3.3.1 Infrared for pedestrian detection

Visible spectrum cameras are severely limited when it comes to the task of detecting pedestrians in low-light conditions, as they can only observe what is illuminated by vehicle lamps or street lamps. While removing the near-infrared blocking filter from a regular camera can extend its low-light pedestrian detection capabilities, it has been found that far-infrared thermal night vision technology yields substantially better range for detecting

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[4] Though an issue with this is the lack of international standards in the area: lane marking colours can vary from country to country

pedestrians than these near-infrared systems (Tsimhoni et al., 2004). Far-Infrared technology is greatly suited to the task of night-time automotive pedestrian detection as thermal radiation from humans peaks in the 8-14μm spectral band, and no illumination is required. As pedestrians are generally warmer than the background environment, especially at night, they appear with higher intensity in far-IR imagery, greatly aiding automatic segmentation. Figure 8 shows an example of the difference between a pedestrian viewed using a visible spectrum camera and an infrared camera at night.

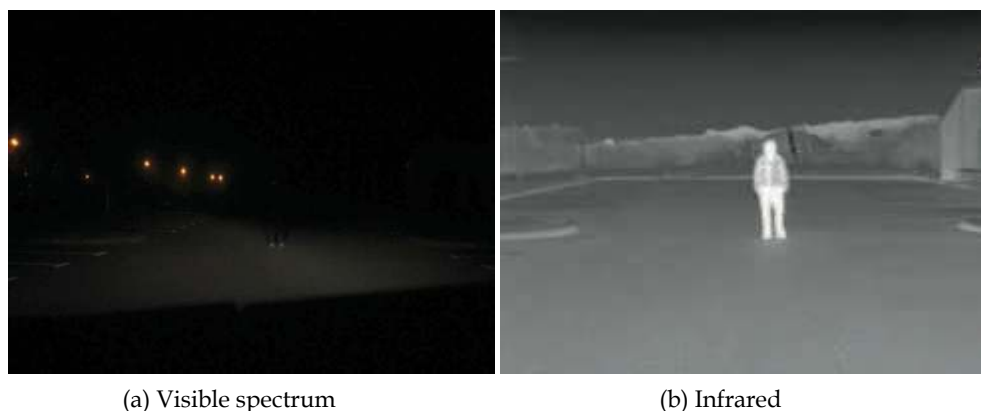(a) Visible spectrum   (b) Infrared

Fig. 8. Example automotive images of a pedestrian at 35m with dipped headlights

The structure of most pedestrian detection systems consists of a Region of Interest (ROI) generation stage, typically via thresholding of some form, for example, Bayes Classification (Nanda & Davis, 2002), region-growing (Bertozzi et al., 2005; Chen et al., 2008), or defining a threshold based on maximum/minimum intensity values in the infrared image (Fang et al., 2004; Xu et al., 2005). This is generally followed by a process that classifies these regions as pedestrian or non-pedestrian. Objects can be filtered according to, for example, aspect-ratio (since pedestrians are generally expected to be taller than they are wide) (Xu et al., 2005), inertial parameters (total rotational momen tum of a candidate with respect to its centre) (Fang et al., 2004), horizontal and vertical grey-level intensity profiles (Fang et al., 2004), or, as humans display bilateral symmetry, grey-level symmetry and edge symmetry of pedestrians can also be used to segment regions of interest (Bertozzi et al., 2004). Edge density can also be analysed as pedestrians in far-IR images are usually much brighter than the background, and there can be a sharp change in image intensity at their edges (Bertozzi et al., 2004). The gradient operator can also be used to aid detection (Meis et al., 2003; Suard et al., 2006).

3.3.2 Vehicle detection at night

As already noted, the techniques commonly employed for vehicle detection in daylight conditions have been comprehensively reviewed by Sun et al. (2006). However, most of the features employed for daylight vehicle detection have limited use in dark conditions and night-time. Vehicle shadows, horizontal and vertical edges and corners are difficult or impossible to detect in darkness, and the most significant preceding vehicle features in dark environments are rear-facing lamps. Vehicular rear lamps appear as some of the brightest

regions in a frame of night time automotive video, so it is common in image processing techniques for lamp detection to begin with some form of thresholding. Grayscale or brightness thresholding is a common starting point (Alt et al., 2008; Alcantarilla et al., 2008), though typically further filtering is required as there are many potential light sources that are not rear vehicle lamps, such as street lamps, headlamps of oncoming vehicles and reflections from signs. Employing a red color filter has been shown to be an effective way to remove non-vehicle light-sources, using a variety of colour spaces (Chen, 2009; Wang et al., 2005; Cabani et al., 2005; O'Malley et al., 2010a).

Current commercial systems use non-standard camera hardware with custom hardware filters – i.e. non-Bayer colour filter arrays with combinations of red and clear filters have proven effective in detection of red lamps and differentiating between tail lamps and other light sources (Stein et al., 2009; López et al., 2008). Another system utilises two coated lenses (one blocking red light, one allowing only red light to pass) to focus incoming light onto different parts of a single image sensor (Schadel & Falb, 2007; Beschtel et al., 2008). While custom hardware can have performance advantages, these cameras cannot produce color images so cannot be reused for other ADAS that use color image processing. Thus, they have very limited use in terms of displaying video to the driver, and can also adds cost and complexity to automotive systems.

In addition to tail lamp detection, headlamp detection (O'Malley et al., 2010b) is an important application for systems such as automatic headlamp dimming, or rearward vehicle detection for applications such as collision warning, blind-spot monitoring and overtaking vehicle detection. Headlamps have been detected by utilising, for example, top-hat filters (Alcantarilla et al., 2008) or optical flow (Ohta & Niijima, 2005).

Once tail lamp or headlamp candidates have been detected in a video frame, to improve robustness, a system can be put in place to pair the detected tail-lamps, to associate detected lamps with a target vehicle (Chen, 2009; O'Malley et al., 2010a;b). Figure 9 shows an example of the detection of tail lamps and headlamps.
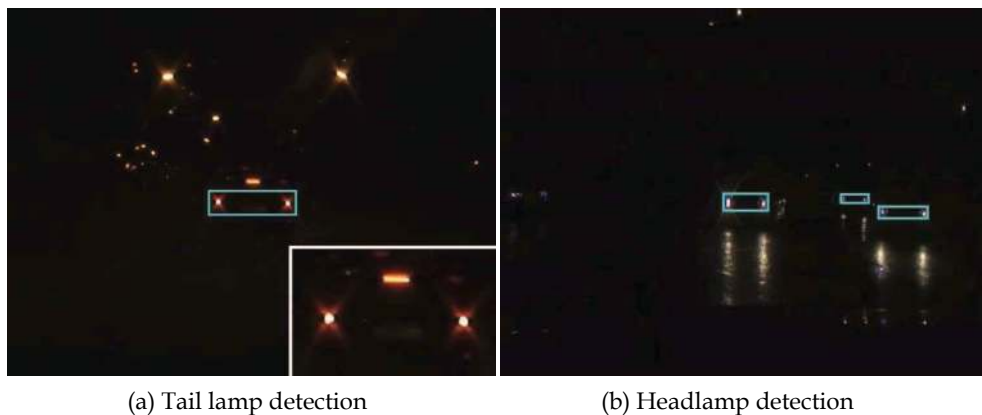

(a) Tail lamp detection   (b) Headlamp detection

Fig. 9. Examples of vehicle detection at night (O'Malley et al., 2010a;b).

3.4 Other

There are other applications of vehicular vision systems that are, perhaps, less safety critical than those discussed in previous sections. For example, road-sign recognition is becoming a

popular application (Lopez & Fuentes, 2007). Poor weather conditions can also be detected (Kurihata et al., 2005). Cameras that are already installed on vehicles could also be used for recording in accident situations, with benefits such as decreasing management and legal costs, be a tool for education and emphasis of safety to drivers and, in general, discourage poor driving practices (Sul & Cho, 2009).

4. Conclusions

In this chapter, the rationale for the on-vehicle use of camera systems has been discussed. With increasing numbers of vehicles on the world's roads, statistics show that a significant percentage of traffic fatalities are caused by drivers who are not aware of VRUs and other road users. While customer demand for products that give information about a vehicles blind-zones to the driver is already high, pending and existing legislation is, de facto, making the installation of such cameras on vehicles a necessity, particularly for large SUVs and LGVs. However, while small vehicles are exempt from current European and Japanese legislation, US legislation specifically targets the smaller private vehicles.

Ultimately, camera systems will be necessary equipment for improved visibility around vehicles, particularly SUVs and LGVs, where the blind-zones are substantial. Wide-angle/fish-eye camera systems are currently the best candidates, because of their ability to display even the largest blind-zones of a vehicle.

Given that camera systems will be used extensively in the future for visual systems, the versatility of vision systems means that it makes economic sense that these systems should be reused for autmotive machine vision tasks. Several safety-critical ADAS applications have been discussed in this chapter, though these are only the more popular applications. There are, undoubtedly, a multitude of other applications that can be applied to an automotive camera system, for safety or assistance situations.

Camera systems will soon be as commonplace on vehicles as climate control systems or antilock braking systems.

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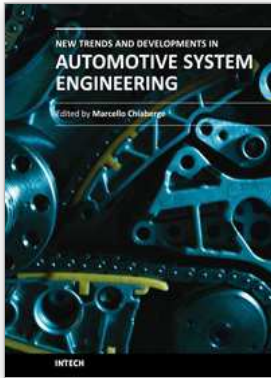
New Trends and Developments in Automotive System Engineering

Edited by Prof. Marcello Chiaberge

In the last few years the automobile design process is required to become more responsible and responsibly related to environmental needs. Basing the automotive design not only on the appearance, the visual appearance of the vehicle needs to be thought together and deeply integrated with the â€œpowerâ€ developed by the engine. The purpose of this book is to try to present the new technologies development scenario, and not to give any indication about the direction that should be given to the research in this complex and multi-disciplinary challenging field.

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