Lecture Notes in Mobility

Jörg Dubbert · Beate Müller
Gereon Meyer *Editors*

Advanced Microsystems for Automotive Applications 2018

Smart Systems for Clean, Safe and Shared Road Vehicles

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Gereon Meyer, Berlin, Germany

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Editors
Jörg Dubbert
VDI/VDE Innovation + Technik GmbH
Berlin, Germany

Gereon Meyer
VDI/VDE Innovation + Technik GmbH
Berlin, Germany

Beate Müller
VDI/VDE Innovation + Technik GmbH
Berlin, Germany

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Preface

Self-driving and electric on-demand taxis and shuttle buses are widely considered as the optimal means of future urban transport. They seem to provide solutions for the most pressing current issues in the mobility sector, such as road fatalities, climate change, and pollution, as well as land use for transport. While those vehicles are first being tested in controlled environments around the world today, they may rapidly reach maturity due to the disruptive character of the underlying innovations: According to the roadmaps of the European Technology Platforms in the automotive domain, advancements in smart sensors, control and communication systems will enable the implementation of high-degree connected and automated driving (i.e., SAE levels 3 and above) on the motorway and in urban environments in the 2020-25 time frame. This coincides with the projected begin of a broad market introduction of electric vehicles: Due to fast progress in battery and powertrain systems' performance in combination with economies of scale, an up to ten percent market share of such vehicles has been predicted for 2020, quickly rising to 40 percent by 2025.

The two technical fields of automation and electrification are highly interlinked due to similarities in (a) the electronics and data architecture of control, (b) the cooperation in energy matters, and (c) the systemic character of the operating environment. In an ideal world, a self-driving car, e.g., would no longer require any passive safety systems, as it would be safe per se. Consequently, such vehicle would be much lighter and, if electrified, could be much more energy efficient, thus providing a longer driving range. It should be noted, however, that due to its higher level of convenience, a self-driving car may be used more intensively. This and the increase in computing power and sensor equipment could lead to the reverse effect of using more energy, counteracting the advantages of electric vehicles in terms of energy savings and climate protection. A joint study by a number of National Laboratories in the USA recently found that these two opposite effects counterbalance each other: While the energy consumption per km may decline by a factor of 1/3, the overall energy consumption may increase by a factor of three.

True synergies of electric, connected, and automated driving may be unlocked in combination with shared mobility, though. Car sharing as a systemic mobility service offer would reduce the total cost of ownership of automated and electric vehicles, facilitate the management of battery charging, and reduce the number of parked cars. And ride-sharing, provided, e.g., by self-driving and electric on-demand shuttles, would in addition be highly cost-efficient and customer-oriented, and it could potentially reduce the overall number of cars on the streets. The exploitation of such synergies may accelerate innovation at both enabling technologies and applications levels, which would be essential for fully realizing the benefits of connected, automated, and electrified vehicles.

The International Forum on Advanced Microsystems for Automotive Applications (AMAA) has been covering the progress in connected, automated, and electrified vehicles and the enabling technologies for many years. In view of the above-mentioned considerations, the topic of the 22nd edition of AMAA, held at Berlin on September 11–12, 2018, was “Smart Systems for Clean, Safe and Shared Road Vehicles.” The 2018 AMAA conference also marked the transition from a previous to a new Coordination and Support Action for its support, namely from “Safe and Connected Automation in Road Transport” (SCOUT) of the connectedautomateddriving.eu initiative to “Coherent Support for Mobility.E Strategy” (COSMOS) of the ECSEL Joint Undertaking. The AMAA organizers, VDI/VDE Innovation + Technik GmbH together with the European Technology Platform on Smart Systems Integration (EPoSS), greatly acknowledge this continuous funding of their efforts by the European Union.

The chapters of this volume of the Lecture Notes in Mobility book series by Springer have been authored by engineers and researchers who attended the AMAA 2018 conference to report on their recent research and innovation activities. The papers presented had been selected by the members of the AMAA Steering Committee and are also available through academic libraries worldwide. In our roles as the organizers and the chairman of the AMAA 2018, we would like to express our great acknowledgment to all the authors for their excellent contributions to the conference and also to this book. We would also like to appreciate the tremendous support that we have received from our colleagues at VDI/VDE-IT, particularly from Ms. Monika Curto Fuentes of the AMAA office.

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Jörg Dubbert
Beate Müller
Gereon Meyer

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Contents

Smart Sensors

All-Weather Vision for Automotive Safety: Which Spectral Band?

Nicolas Pinchon[1], Olivier Cassignol[2], Adrien Nicolas[2], Frédéric Bernardin[3], Patrick Leduc[4], Jean-Philippe Tarel[5], Roland Brémond[5], Emmanuel Bercier[6](✉), and Johann Brunet[7]

[1] VALEO Comfort and Driving Assistance, 34 rue Saint André, 93012 Bobigny Cedex, France
nicolas.pinchon@valeo.com

[2] SAFRAN Electronics & Defense, 21 Avenue du Gros chêne, 95610 Éragny Sur Oise, France
{olivier.cassignol,adrien.nicolas}@safrangroup.com

[3] CEREMA, 8-10 rue Bernard Palissy, 63017 Clermont-Ferrand Cedex 2, France
frederic.bernardin@cerema.fr

[4] CEA/Léti, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France
patrick.leduc@cea.fr

[5] University Paris-Est, IFSTTAR, Cosys/Lepsis, 14-20 Boulevard Newton, 77420 Champs-sur-Marne, France
{Jean-Philippe.Tarel,Roland.Bremond}@ifsttar.fr

[6] ULIS, 364 Route de Valence, Actipole – CS 10027, 38113 Veurey-Voroize, France
e.bercier@ulis-ir.com

[7] NEXYAD, 95 Rue Pereire, 78100 Saint-Germain-en-Laye, France
jbrunet@nexyad.net

Abstract. The AWARE (All Weather All Roads Enhanced vision) French public funded project is aiming at the development of a low cost sensor fitting to automotive and aviation requirements, and enabling a vision in all poor visibility conditions, such as night, fog, rain and snow.

In order to identify the technologies providing the best all-weather vision, we evaluated the relevance of four different spectral bands: Visible RGB, Near-Infrared (NIR), Short-Wave Infrared (SWIR) and Long-Wave Infrared (LWIR). Two test campaigns have been realized in outdoor natural conditions and in artificial fog tunnel, with four cameras recording simultaneously.

This paper presents the detailed results of this comparative study, focusing on pedestrians, vehicles, traffic signs and lanes detection.

Keywords: Vision · ADAS · Visibility · Adverse weather · Fog Infrared · Thermal

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1 Introduction

In the automotive industry, New Car Assessment Programs (NCAP) are increasingly pushing car manufacturers to improve performances of Advanced Driver Assistance Systems (ADAS), and especially autonomous emergency braking on vulnerable road users (VRU). For instance the 2018 Euro NCAP roadmap is moving towards pedestrians and pedal cyclists detection in day and night conditions.

This trend matches accidentology figures, like those provided by French Road Safety Observatory (Table 1).

Table 1. 2014 French accidentology data in adverse conditions [1]

	Injury casualties	Fatalities
Night	32%	41%
Wet road	20%	20%
Adverse weather	21%	23%

In the longer term, after automated parking and highway driving, all weather and city driving will be the main technical challenge in the automated driving roadmap.

Current ADAS sensors as visible cameras or Lidars are fitting functional requirements of VRU and obstacle detection in normal conditions (day or night). However, these technologies show limited performances in adverse weather conditions such as fog or rain.

Automotive industry is thus facing this new challenge of detecting vehicle environment in all conditions, and especially in poor visibility conditions, such as night, fog, rain and snow.

This topic has been addressed in the framework of the AWARE French public funded project, aiming at the development of a sensor enabling a vision in all poor visibility conditions. This paper presents an experimental comparative study of four different spectral bands: Visible RGB, Near-Infrared (NIR), Short-Wave Infrared (SWIR) and Long-Wave Infrared (LWIR). Sensors and field tests are described in Sects. 2 and 3. Experimental results are detailed in Sect. 4, focusing on pedestrians, vehicles, traffic signs and lanes detection.

2 Sensors

In this project, we only focus on cameras technologies, and not on distance measurement systems like LIDARs or RADARs. But it is well-known that both technologies are complementary and necessary to bring redundancy for improving the detection system's reliability and accuracy [2].

Four cameras were tested during the project. The Table 2 shows their characteristics.

Table 2. Cameras characteristics

Camera	Sensor	Spectral band	Optics
Visible RGB	CMOS – SXGA (1280 × 966) 3 × 8 bits, pitch 4.2 μm	0.4–0.65 μm	HFOV = 54° VFOV = 40° F-number = 2
Extended NIR	CMOS – SXGA (1280 × 1024) 10 bits, pitch 5.3 μm	0.4–1 μm	HFOV = 39° VFOV = 31° F-number = 2.9
Extended SWIR	InGaAs—VGA (640 × 512) 14 bits, pitch 15 μm	0.6–1.7 μm	HFOV = 39° VFOV = 31° F-number = 1.8
LWIR	Microbolometer—VGA (640 × 482) 14 bits, pitch 17 μm	8–12 μm	HFOV = 44° VFOV = 33° F-number = 1.2

The visible RGB CMOS camera is used here as a reference for the test.

Extended NIR camera uses monochrome CMOS photodiodes with a cut-off wavelength close to 1 μm. It detects the reflective visible and NIR light from the scene. It thus requires an illumination by sun, moon or night glow or an illuminator positioned on the vehicle.

Extended SWIR camera is based on InGaAs III-V material and extends from a wavelength of 0.6 μm, red to human eye, to 1.7 μm in the SWIR infrared band. SWIR spectral band is typically used for active (reflective) vision in very dark condition with a good contrast as SWIR light is generally more reflective than visible light.

LWIR sensor is an array of microbolometers. It detects the thermal radiation in the spectral band extending from 8 μm to 14 μm. Any object emits radiations which depend on its temperature. For a human or an animal at ambient temperature, the maximum of emission corresponds to a wavelength close to 10 μm. LWIR is used for the detection of a temperature contrast and do not require an illuminator.

Mid-Wave Infrared (MWIR) has not been added in the study for reasons of cost and capacity, due to the cooling system required for the detectors.

3 Field Tests

3.1 Outdoor Test Campaign

The four cameras were installed during one month in 2015 along the French motorway A75/E11 at the site named La Fageole. A weather station located near the cameras was equipped with a diffusiometer (meteorological visibility), a rain gauge, a luxmeter (ambient light) and a temperature and humidity sensor (ambient air) (Fig. 1).

More than 33 different scenarios have been set depending on weather conditions (rain type and intensity, ambient temperature), ambient light, and human eye visibility distance. Table 3 shows the most interesting recorded scenarios, with a class 3 fog (visibility distance < 100 m):

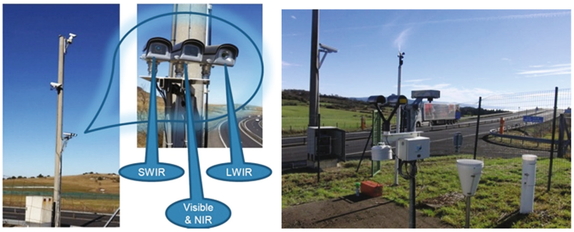

Fig. 1. Outdoor test campaign

Table 3. Most interesting recorded outdoor scenarios

Scenario	Weather	Visibility distance	Ambient light	Temperature
7	Day, heavy fog, light snow	75 m	5032 lx	−1 °C
11	Day, heavy fog and snow	69 m	1096 lx	−1 °C
22	Day low light, heavy fog and snow	75 m	104 lx	−0.8 °C
26	Night, heavy fog	99 m	0 lx	+1.5 °C

3.2 Tunnel Test Campaign

The tests were carried in the CEREMA fog tunnel in Clermont-Ferrand (30 m length, 5.5 m width and 2.5 m height). Artificial fog and rain are reproduced and controlled: fog and rain drop size, meteorological visibility of fog and rain intensity. Two fog classes are available: unimodal drop size distribution (DSP) centred around 1 µ and bimodal DSP centred around 1.5 and 10 µ. 74 scenarios were performed by varying the type of adverse weather conditions (fog and rain), scene illumination (night, day, automotive lighting, aircraft lighting) and glare (front vehicle). The scene in front of the cameras contained road pavement, road marking, pedestrians and lights (see Fig. 2).

Fig. 2. CEREMA fog tunnel

4 Field Tests

In this section, we describe the detection and recognition range performances that were measured in this study. It is important to keep in mind that these results reflect not only the intrinsic characteristics of the spectral bands but also the capability of the chosen cameras. The cameras were selected to be representative of the typical current state-of-the-art.

In order to prevent any detection algorithm artefact, a visual analysis has been performed by two different human observers. As expected, exact detection range values differed from one observer to the other, but the relative values were consistent. In all cases, brightness and contrast were carefully tuned in order to optimize ranges.

With respect of each camera's channels created by the four spectral bands, a video database has been created to remotely record videos of relevant scenes for each listed scenario. The Fig. 3 provides a sample of the video database (outdoor campaign):

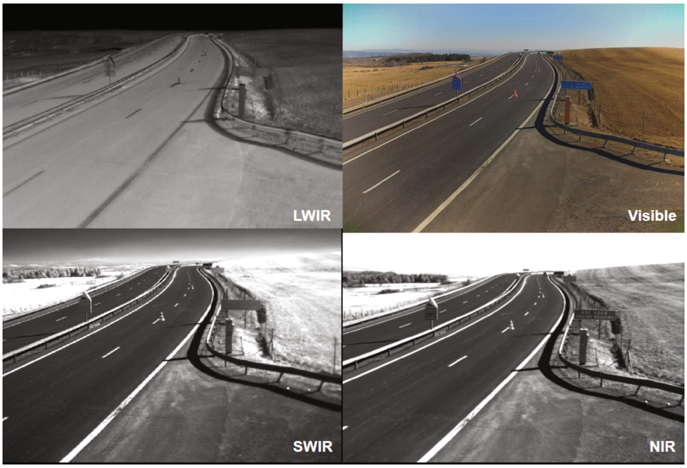

Fig. 3. Example of snapshots recorded by LWIR (top left), Visible (top right), SWIR (bottom left) and NIR (bottom right) cameras

4.1 Pedestrian Detection

Pedestrian detection tests have been performed into Cerema fog tunnel using real human bodies, as illustrated in the Fig. 4.

Objects moving in the fog generate important transmission inhomogeneities. In order to avoid errors due to this effect, we recorded films of human test subjects standing still at the end of the tunnel while the fog cleared over time. Detection was declared successful when the outline of the chest of the test subject became visible against the background. This way, detection ranges were measured at the height at which the transmission meter was set. The test subjects were $\sim$25 m away from the cameras. One of the test subjects wore a high visibility jacket and another one wore

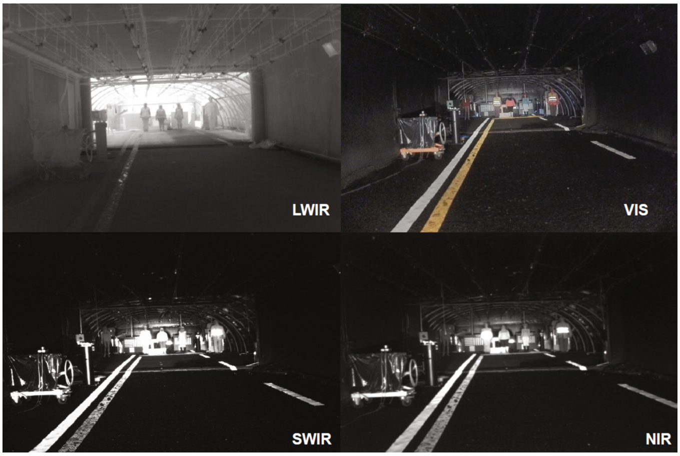

Fig. 4. Pedestrian detection test setup into Cerema fog tunnel, LWIR (top left), Visible (top right), SWIR (bottom left) and NIR (bottom right) cameras

dark clothes. As expected, Visible, NIR and SWIR detection performances were better for the subject wearing the high visibility jacket (even though this improvement is less pronounced for thicker fog). For this study, the case of the subject in dark clothes was deemed more relevant.

The following table gives the fog density, expressed as standard visibility ranges, at which the pedestrian becomes visible. A reduced visibility range indicates a successful pedestrian detection in a thicker fog, and hence a better capability to see through fog. Cases with glare are not included (Table 4).

Table 4. Fog thickness for pedestrian detection at 25 m with the different cameras

Camera	Fog density for pedestrian detection
Visible RGB	Moderate (visibility range = 47 ± 10 m)
Extended NIR	High (visibility range = 28 ± 7 m)
Extended SWIR	High (visibility range = 25 ± 3 m)
LWIR	Extreme (visibility range = 15 ± 4 m)

Error ranges mostly reflect the dispersion between the different scenarios used in the study.

Conclusions are the following:

- The LWIR camera has a better capability to see through fog than the NIR and SWIR ones. The visible camera has the lowest fog piercing capability.
- The LWIR camera is the only one that allows pedestrian detection in full darkness.

- The LWIR camera also proved more resilient to glare caused by facing headlamps in the fog. Other cameras sometimes missed a pedestrian because she or he was hidden by the glare (Fig. 5).

Fig. 5. Example of images recorded in the fog tunnel with the four different cameras

4.2 Vehicle Detection and Recognition

Vehicle detection ranges were measured in the outdoor test campaign.

Similarly to military range performance tests, we define two tasks of interest: detection and recognition. Detection means the presence of an object on the road can been acknowledged, even if the type of object cannot be assessed. Recognition means that the detected object can be classified into a category such as: truck, car, motorcycle, bicycle, pedestrian, animal, static obstacle… In particular, VRU can be distinguished from other vehicles. The Fig. 6 illustrates detection and recognition in two different spectral bands (images are from different scenarios).

Distances were calibrated within the cameras' field of view using the road markings (which are clearly visible for all cameras in images recorded on a sunny day) and an aerial map of the area. That method gives a distance measurement precision on the order of a few meters simply by noting the vehicle position within an image. The maximal distance that could be reliably assessed by this method was on the order of 150 m (Fig. 7).

Average detection and recognition ranges are given in the Figs. 8 and 9 for the different spectral bands and for each of the four scenarios of interest. A total of 22 vehicles were observed. Error bars give the dispersion between the different vehicles observed within a given scenario.

In VIS, NIR or SWIR, detection was performed using the vehicle headlamps. The case of a vehicle driving with headlamps off while in adverse conditions was not encountered in this study. Should it happen, however, detection ranges in VIS, NIR and

Detection		
Recognition		
Task	**VIS**	**LWIR**

Fig. 6. Examples of detection and recognition

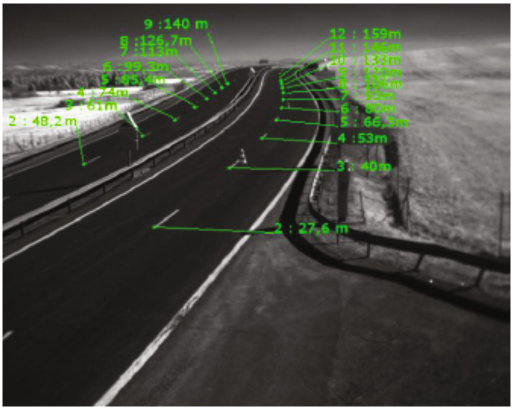

Fig. 7. Reference of range based on site map analysis and T1 lanes type of road marking

SWIR would be on the order of the recognition ranges. In LWIR, detection relied on the observation of hot vehicle parts: the wheels, the motor or the exhaust system.

In some foggy instances, recognition proved difficult or even impossible in VIS, NIR or SWIR because the vehicle remained entirely hidden by the glare of its own headlamps. When this happened, the vehicles were not taken into account in the average ranges given in Fig. 9. Images illustrating this phenomenon are given in the Fig. 10. SWIR here presents more glare than the other bands but it is only due to the camera settings, it is not an intrinsic characteristic of the spectral band.

The visual observation of the videos also confirmed the well-known fact that the exploitation of movement by the human visual system greatly increases detection capabilities: the success of the detection task is much higher when performed while