Use and development of the PAVIN fog and rain platform in the framework of the H2020 AWARD project

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Abstract: Cerema is a member of the European All Weather Autonomous Real logistics operations and Demonstrations (AWARD) project which aims to bring major innovations to the transport industry, fleet operators and the entire logistics sector. The project contributes to the accelerated deployment of innovative, connected, and automated freight transport solutions in Europe and worldwide.

The Cerema ITS research team plays an important role in this project. Among other things, it is involved in setting up the protocols and carrying out tests in degraded weather conditions. For this, the PAVIN Fog and Rain platform, located in Clermont-Ferrand, is used for the development of the sensor suite and associated algorithms. It is also an opportunity for the research team to develop this physical simulation platform, particularly concerning the production of maritime fogs, by extending the size range of the reproduced fog droplets.

The results of the tests carried out and the innovations obtained are presented in this communication.

Keywords

independence, confidentiality and neutrality. The platform is 30 m long, 5.5 m wide and 2.20 m high. This volume allows for the reproduction of realistic road scenarios, including vehicles, pedestrians and road equipment, in day or night conditions. It is also possible to set up reference tests with targets calibrated in reflectance and thermal black bodies. The platform is mainly dedicated to the automotive (ADAS, AVs, lighting) and road (marking, traffic signs, monitoring) domains but also to other advanced domains such as rail, aeronautics, maritime, construction or military.

Into the chamber, fog and rain of varying intensities may be produced on demand. Fog density may be replicated in the Meterological Optical Range (MOR) range of 10m to 1000m. The Droplet Size Distribution (DSD) is representative of continental or maritime fogs. Rain conditions may be produced with rainfall rate ranging from 10 to 180mm/h.

The MOR [1] is defined as the maximum distance (in meters) at which a calibrated object is visibly distinct from its background. The lower the MOR, the denser the fog. Fog with a MOR of 10m is considered extremely dense and is occasionally encountered on roads.

Rain intensity [1] is characterized by the rainfall rate in mm/h, corresponding to the height of water in mm that falls on a surface area of 1m² over a 60-minutes period. The greater the rainfall rate, the heavier the rain. A rainfall rate of 120mm/h represents violent storm peaks in Europe.

2.2. Main activities

While the platform was first used to analyse the impact of fog on human vision, it is now mainly used to evaluate computer vision systems that are installed in vehicles, whether for ADAS or AV, but also to make roadside surveillance cameras smarter. Research on computer vision has become predominant since 2010, with the rise of ITS and the AV development. Concerning the use of the PAVIN platform, it can be classified into three main areas:

- measurement of weather conditions by camera (artificial intelligence)
- numerical simulation of meteorological phenomena
- measurement of the impact of adverse weather conditions on vehicle perception systems

Concerning the measurement of weather conditions by camera, camera-based weather measurement initially derived from work on the impact of rain on cameras. Indeed, it was shown that rain has a quantifiable impact which is proportional to the rainfall intensity on common image features of the literature [2]. The impact on the image features was then used to detect the actual weather conditions, including fog and rain conditions. Then, the use of image features was left aside, and Deep Convolutional Neural Networks (DCNN) were successfully used in the WeatherEye solution (up to 90% of good detection) [3] [4]. For the artificial intelligence optimisation, a first learning step can be done from images recorded in the PAVIN platform, before being transferred and fine-tuned on images that are acquired on a real site.

Concerning the numerical simulation of adverse weather conditions, the first numerical simulation tools developed with the PAVIN platform were about fog. The work started in 2000 and continued until 2010. Authors first used visible light cameras only in night conditions. These researches were resumed by the Cerema team in charge of the platform in 2020 and are currently in progress. First, some experiments were conducted to check the impact of the wavelength and the fog droplet size distribution on the transmission of electromagnetic radiation [5]. According to the literature, they show that the light transmission is not the same for all wavelengths. The objective is now to use these first results to develop and validate a new fog numerical simulator based on radiative transfer equation and Monte-Carlo method (Figure 2) [6].

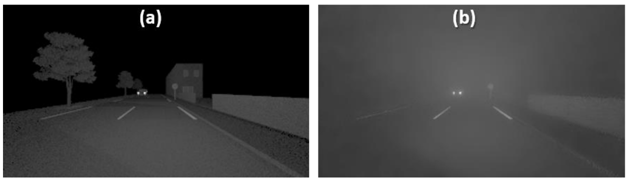


Figure 2: Simulated road scene in the visible: (a) without fog, (b) with 3D fog with MOR = 21 m [6].

Concerning the measurement of the impact of adverse weather conditions on vehicle perception systems, the first public work was conducted in the context of the AWARE project, from 2014 to 2017 [7]. The objective of this project was to analyse which wavelength bands are least penalized by fog. Several cameras in the visible light (VIS), Short-Wave Infrared (SWIR), Mid-Wave Infrared (MWIR) and Long-Wave Infrared (LWIR) ranges were thus compared in the platform [8] [9]. This topic was then continued in the DENSE project, from 2016 to 2019 [10] [11]. The DENSE project aimed to develop a series of all-weather sensors, allowing the automation of a particular vehicle. The conditions targeted included fog, rain and snow. The sensors set was composed of stereoscopic cameras in VIS, (Near-Infrared) NIR and SWIR domains, LiDARs (Light Detection And Ranging), radars and time-of-flight cameras. The research studies characterized the boundary weather conditions for each of the sensors [12] [13] [14] [15] [16] [17] (Figure 3) and used data fusion to extend the admissible conditions. This work was then continued in the AWARD project, which is the subject of a focus in the next Section.

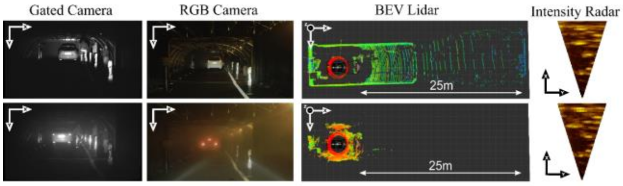


Figure 3: Multimodal sensor response of camera, LiDAR, gated camera, and radar in fog. Clear conditions in the first row, fog (MOR=23m) in the second row [18].

3. AWARD project results: a case study

3.1. Scope

Within the AWARD project, some partners, like Easymile [19], Navtech, Foresight Automotive [20] or Adasky have carried out tests within the PAVIN platform. In this paper, we will give a focus on works done with Foresight Automotiv vision system.

This proprietary technology (Figure 4) is based on the utilization of 3D video analysis and advanced image processing algorithms to achieving accurate obstacle detection in adverse environmental conditions. This technology can be customized to address the numerous challenges facing ADAS and AVs.

The QuadSight vision system consists of 2 pairs of stereoscopic vision channels: a visible light stereo channel in conjunction with a thermal stereo channel, providing depth perception to obtain a clear 3D view of the environment. Stereoscopic vision technology uses two synchronized cameras to generate a depth map, allowing for the detection of an object, either classified or non-classified, and its accurate size, location, and distance. Monocular vision object detection technologies are usually based upon inferencing and rely on Deep Neural Networks (DNN) object recognition. Using DNN for object recognition will always encounter corner cases where there is an unknown object to the trained n
stereoscopic technology provides a hybrid 3D detection solution for both classified and non-classified objects.


Figure 4: QuadSight vision system by Foresight[2]

According to the latest published literature, most of the 3D object detection studies address only favourable climatic conditions. This is the case of most of the datasets in the field [21] [22] [23] [24]. Some recent datasets deal with adverse weather conditions, but only address visible light cameras and contain only few images [25] [26]. Other datasets that include many images exist for traffic surveillance applications [4] [3], fog removal [27] [28] [29] [30] [31] [32] or weather classification [25] [26]. These do not concern 3D object detection for automotive purposes and they do not contain thermal images. Concerning automotive sensors for autonomous driving, some recently published studies propose algorithms to deal with fog conditions by incorporating data fusion from LiDAR and stereoscopic visible light cameras [33] [18] [34]. Other studies analyse the impact of fog, rain and snow on LiDARs [35] [36] [17]. These studies do not use thermal cameras for detection, such as the QuadSight vision system. Some other studies use data fusion with the use of thermal cameras [37] [38]

The QuadSight vision system was tested under a range of artificially reproduced weather conditions. The novelty of the work done with Foresight Autmotive is to present results of 3D object detection: (a) on a commercialized system, (b) using visible light and thermal wavelengths, (c) in controlled fog and rain conditions. This work allows for a demonstration of the characterization of the Operational Design Domain (ODD) under harsh weather, and a scientific analysis on a commercialized system.

3.2. Protocol

A specific scenario was designed to characterize the quality of object detection of the QuadSight vision system in poor weather conditions. The system software allows 3D detection of various objects, in this case, vehicles and pedestrians. As seen in Figure 5, a human pedestrian producing a true-to-life thermal signature, and an electric Renault Kangoo vehicle was used as test subjects. Various target-sensor distances, weather and illumination conditions combinations are tested. These include day/night, fog of varying densities (MOR = 10m, 20m and 50m), and rain of varying intensities (rainfall rate = 11mm/h, 70mm/h and 120mm/h).

In daylight conditions, only the ambient light is present. In nightlight conditions, the headlights of the vehicle on which the QuadSight vision system is placed are turned on. In total, we have 84 experiments (2 targets [car + pedestrian] x 2 illumination conditions [day + night] x 7 weather conditions [1 clear + 3 rains + 3 fogs] x 3 target-sensor distances [10, 17 and 25m]).

For the analysis, the measures of precision and recall were used. First, the position of the pedestrian

[2] https://www.foresightauto.com/solutions/quadsight/

and the vehicle over the entire dataset was manually annotated. The 3D object detection algorithm was then applied to the images. To determine whether a detection is valid, the Intersection of Union (IOU) metric was utilized. These are common state of the art metrics.

3.3. Results

The results of precision and recall scores are recorded in Table 1. The results confirmed the expected system performance for both visible light and thermal channels based on past experimental data (Figure 5). The visible light cameras are highly dependent on the environmental lighting conditions and subsequently, show reduced performance at low lighting (night) levels. This is not the case for thermal cameras; however, as they are dependent entirely on object heat and emissivity. On this basis, the results of different lighting conditions do not show any change in performance.

The rain at all levels had minimal effect on the performance of both visible light and thermal channels. The results show improved detection of pedestrian target compared to the electric car target at fog levels 10 and 20m. This can be explained by the difference in heat emissivity of pedestrian and car. As opposed to combustion engine vehicles which expel a large amount of heat, an electric vehicle is more similar in temperature to the surrounding environment. The improved detections of both pedestrian and car by the thermal channel compared to the visible light channel at fog 10 and 20m is explained by the reliance on object emissivity as opposed to lighting conditions (Figure 6). All fog scenes tests were performed immediately following the rain scenarios, while all objects were still wet, reducing contrast between the object and the surrounding environment. Sometimes the results drop slightly, but this can be explained by local variations in the test conditions, such as the exposure time setting or the position of the pedestrian.

Despite technical complications during the testing

results for both stereo vision light and thermal imaging. Combining the advantages of stereo systems using visible light and thermal cameras will help to increase road safety for all road users and will pave the way for better ADAS and autonomous vehicles. The thermal cameras enhance ADAS systems, allowing improved performance under many weather and lighting conditions. The concurrent use of these camera-based sensors provides a complete image of the surrounding environment, under

performance may be compromised.

Table 1: QuadSight system detection results (Precision / Recall)

		Pedestrian - IOU 0.5						Car - IOU 0.7					
		VIS			IR			VIS			IR		
	Target dist. →	**10m**	**17m**	**25m**	**10m**	**17m**	**25m**	**10m**	**17m**	**25m**	**10m**	**17m**	**25m**
Day	**Clear**	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100
	Fog 10m	100/100	NaN	NaN	100/100	100/100	100/100	100/100	NaN	NaN	97/100	NaN	NaN
	Fog 20m	96/100	99/100	99/100	100/100	100/100	100/100	100/100	100/100	NaN	100/100	100/100	100/100
	Fog 50m	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100
	Rain 11mm/h	100/100	100/100	100/100	100/100	95/100	96/100	100/100	100/100	100/100	100/100	100/100	100/100
	Rain 72mm/h	100/100	98/100	99/69	100/100	100/100	100/100	100/99	100/100	100/100	99/100	98/100	100/100
	Rain 120mm/h	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100
Night	**Clear**	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100
	Fog 10m	NaN	NaN	NaN	98/100	100/100	NaN	NaN	NaN	NaN	97/100	NaN	NaN
	Fog 20m	100/92	NaN	NaN	98/100	98/100	98/100	100/100	NaN	NaN	98/100	96/100	78/93
	Fog 50m	100/100	100/99	100/56	100/100	98/100	100/100	100/100	100/100	97/100	100/100	100/100	100/100
	Rain 11mm/h	100/100	100/100	99/100	100/100	100/100	95/100	100/100	100/100	100/100	100/100	100/100	100/100
	Rain 72mm/h	100/100	100/100	100/97	100/100	100/100	81/57	100/100	98/100	98/99	100/100	96/100	100/100
	Rain 120mm/h	100/100	100/100	94/74	100/100	100/100	93/100	100/100	100/100	100/100	100/100	100/100	100/100

**NaN values - There was no visible detection of the objects at the listed ground truth distances.*

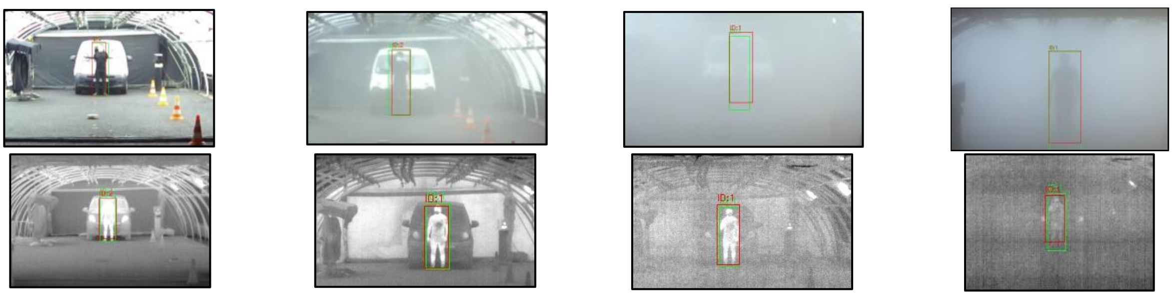
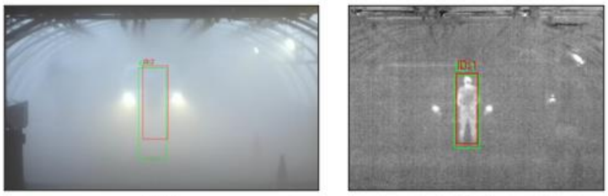


Figure 5: Example of detection results, in fog conditions at the maximum distance of detection. From left to right : Clear, Fog 50m, Fog 20m, Fog 10m. Up: visible light camera, down: thermal camera.



(a) (b)

Figure 6: Example of the pedestrian who is totally invisible on the visible light camera (a), while he is perfectly visible on the thermal camera (b).

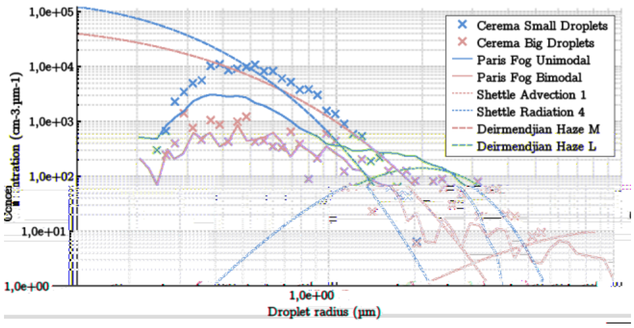


Figure 7: Particle size distribution of the PAVIN platform fogs compared to different models found in the literature [39]

4. The future PAVIN platform

4.1. The near future: research works to better address maritime fogs

Into the current platform, the two types of fog reproduced are similar to natural fogs. Indeed, as shown in the Figure 7, they have the same DSD as natural fog recorded in an outdoor measurement campaign [39]. However, it can be noticed that the fog models in the literature sometimes present droplets of even larger diameter (ex: Shettle Advection 1). For this reason, Cerema has proposed to study new ways of artificially producing fog in the framework of the AWARD project. Thus, measurements are underway and the exploitation of the results will allow to better address the large droplet fog.

4.2. A brand-new platform in 2024

From its construction in 1984
fog & rain platform has always evolved in order to stay correlated with actual stakes, renewing, improving and evolving its technical capacities and offer [40]. However, the building has achieved its maximum transformation and evolution possibilities and a complete redesign of the whole installation is inevitable. Then, Cerema initiated a new platform project in 2018 and its construction is planned for 2023 thanks to co-financing from the Auvergne-Rhône-Alpes region (France). One of the main objectives was to increase the dimensions of the building. The new building is 50 meters length, 7 meters width and 6 meters height (Figure 8). These new dimensions will enable to consider new realistic scenarios and also to include other types of vehicles such as trucks, shuttles or even not urban vehicle (agricultural, etc.). Moreover, the positioning of the whole building in the continuity of its access road will enable to consider dynamic tests with vehicle entering or exiting of the tunnel, at realistic speed.

Beyond the strong evolution of the dimensions of the tunnel, this new platform is also improving thermal and lighting properties of the climatic chamber. The main purpose is to provide particularly optimized stable conditions over time, especially among a testing campaign for example. It consists then in a strong optimization of thermal isolation and sun exposition of the whole building, which will make possible to produce an even much better-quality fog. For lighting purposes, both natural and artificial sources will be used with adapted goals. The main idea is to obtain a good homogeneity on ground irradiance and a minimal average value. The natural light will allow to make daytime tests with the real spectrum of the sun. This will be useful for the dimensioning of the sensors of the future which use more and more varied ranges of wavelengths (SWIR, MWIR).

The rain production quality will also be strongly improved thanks to the height of the test chamber; indeed, the nozzles will be at about 5.50 m and then the rain will be very realistic from 3.5 m height (better falling velocity). In addition, the platform will be built with the possibility to recover all the rain generated and then be able to reuse it, thus working with very low water consumption, and much longer rain production time.

This new platform will offer the Cerema a great evolution at a larger scale to address adverse weather stakes with AVs, and for other applications. The building of this new adverse weather platform will be correlated with the development of fog modelling with the objective to get a numerical twin of the facility. Then, the Cerema will propose both physical and numerical simulations of fog and rain visibility conditions. One of the final purposes will be to propose a full standardized testing platform for ITS within adverse weather conditions.

Figure 8:

5. Conclusion

After presenting the actual PAVIN Fog and Rain platform main features, we showed the main applications of this platform. These ones may be classified into three main areas: measurement of weather conditions by camera (artificial intelligence) ; numerical simulation of meteorological phenomena ; and measurement of the impact of adverse weather conditions on vehicle perception systems.

Regarding the last area, we have shown an example of use case realized within the AWARD project: we presented a method to characterize an ODD under controlled weather conditions. The QuadSight vision
PAVIN platform under harsh weather conditions: fog and rain at day and night lighting conditions.
sults for both stereo vision light and thermal imaging.

Finally, we presented the future developments of the platform. First of all, and still within the framework of the AWARD project, we will propose new production methods in order to obtain fogs containing larger droplets. Then in 2024, a brand-new platform will be created, in order to better respond to the future challenges of ADAS and AVs development.

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The research team currently in charge of the PAVIN platform (F. Bernardin, S. Liandrat, J-L. Bicard, D. Bicard, A. Ben-Daoued, M. Ferreira Fernandes and P. Duthon) will be delighted to welcome you and discuss with you to carry out your own tests, or set up new collaborative projects. Do not hesitate to contact us via the email address adweather@cerema.fr.

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