Doctoral Thesis Summary:

Systems to increase the safety of road traffic in weather conditions that alter visibility - research and solutions

Author: eng. Răzvan Cătălin MICLEA

The major progress in the field of IT&C effectively changes our lives from several points of view, among the reference ones being safety and comfort. If we analyze the field of passenger transport, public or private, we notice changes that only a decade ago would have seemed impossible: autonomous cars or buses that comes with the new concepts of interconnection "vehicle-to-vehicle (V2V)" or "vehicle-to-infrastructure (V2X)", the new concept of "hyperloop" train as the fifth mode of transport by car, classic train, ship and plane or the various electric transport "gadgets" (electric unicycle, electric skateboard, electric scooter, segway, etc.). All these ideas appeared as necessities to increase the comfort and safety of passengers, to shorten the travel time and to make it easier especially in the very crowded metropolises.

This paper entitled "Systems to increase the safety of road traffic in weather conditions that alter visibility - research and solutions" analyzes a current problem, but which will be of great interest in the future - especially if we talk about autonomous vehicles - and refers to the issue of visibility in different weather conditions. Besides the problem caused by the fog on visibility, was also analyzed the blinding glare caused by the sun's rays and the headlights of the other traffic participants, in night conditions. As mentioned above, these phenomena cause great difficulties for drivers today, but they will also impact autonomous vehicles that must identify traffic signs, road markings, pedestrians or other objects that appear on the road, in order to make the necessary decisions.
The thesis is structured in four parts with a total of seven chapters (fig. 1) distributed as follows:

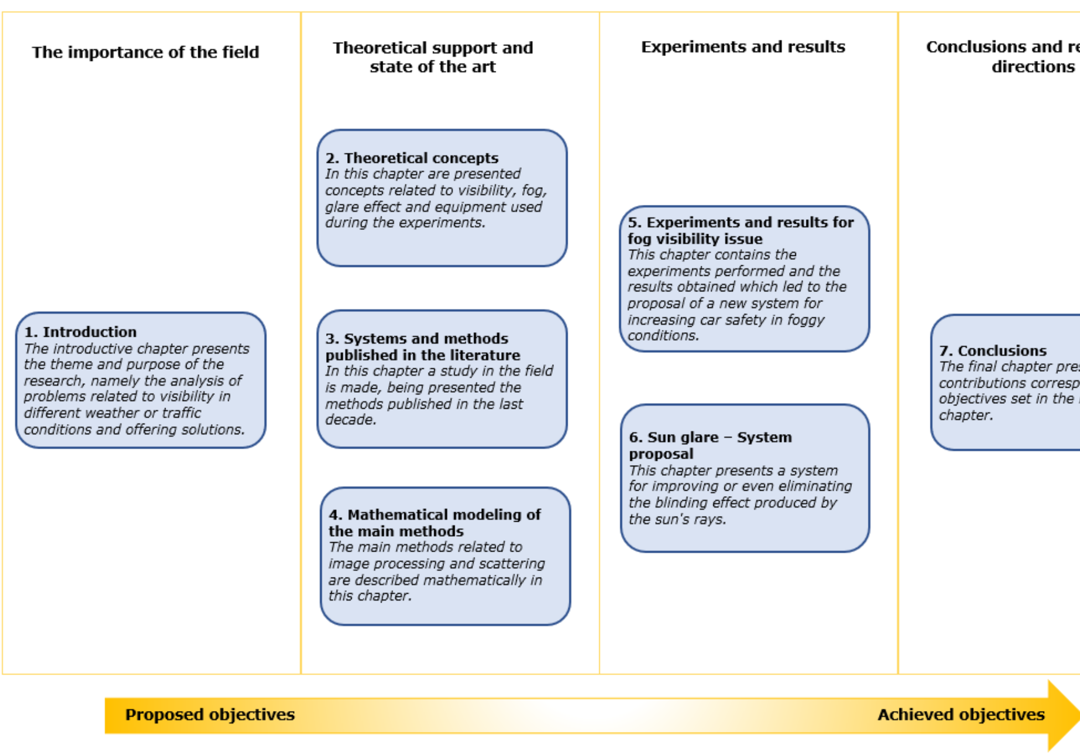


Fig. 1. Thesis structure

1) The first part contains Chapter 1 which presents the importance of the field, theme, purpose and objectives of the research;
2) The second part consists in the theoretical support, being presented introductive concepts and terminology that will be used in the rest of the paper (chapter 2), a study of the literature, with methods presented in the last decade (chapter 3) and a mathematical modeling / presentation of these methods (Chapter 5);
3) The third part includes Chapters 5 and 6, which present experiments, results and system proposals for the two addressed issues;
4) The final part presents the conclusions and personal contributions.

The main purpose of this thesis is to address two of the important issues - the distance of visibility in foggy conditions, respectively avoiding driver blindness due to sunlight - and offering new solutions, at the current level of technology, to increase safety on public roads.

The "visibility" problem is not only specific to drivers, being vital in the case of autonomous cars (identification of pedestrians, traffic signs, other traffic participants, etc.). The need to solve it will remain valid even after the implementation of the V2X concept.

The causes of approximately 25% of traffic accidents (a figure that remains constant in the last two decades) are the weather conditions / factors that influence (reduce) visibility. Among the phenomena in the atmosphere - rain, snow, fog and sunlight - in this paper (as mentioned above) the last two categories will be treated, with emphasis on the effects of fog - because its impact is greatest on visibility; the smaller the particle size and the higher the particle density, the lower the visibility and the greater the danger of accidents.
Next we will refer, very briefly, to the essential aspects presented in each of the seven chapters.

The first chapter presents the field of the thesis, the opportunity to develop the paper, the purpose and pursued objectives. The categories of "visibility" factors which can influence road safety are listed (fig. 2) and the reference will be mainly on the visibility side: factors related to the observer, factors related to atmospheric content, factors related to airlight, factors related to the observed target object.

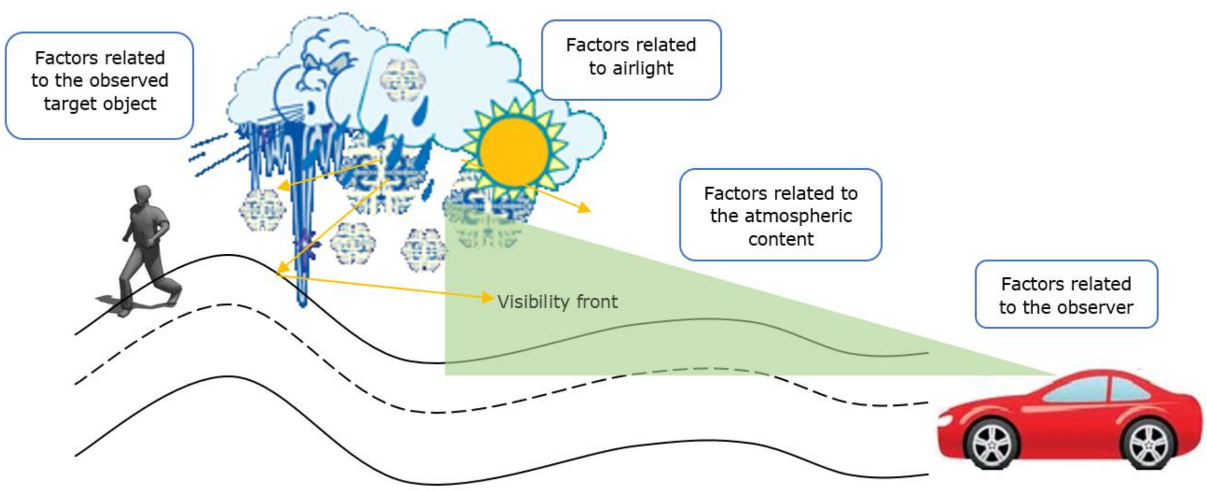


Fig. 2. Factors influencing visibility

The following are the main objectives of this research, to solve the problem of visibility, namely:
(i) the development of an experimental model, in the laboratory, which allows the study and experiments, under conditions of repeatability, of techniques and methods (existing and new proposed by the author) for estimating visibility in fog conditions;
(ii) developing a practical solution - whereby drivers or autonomous vehicles are informed of visibility conditions - leading to increased road traffic safety;

(iii) avoiding driver blindness, due to glare (sunlight), by introducing a dynamic, digital sun visor system – possible to be realized in the future, as an alternative to the solutions based on "smart glass" technology.

The second chapter presents concept related to visibility (terminology, fields and methods of measurement as well as instruments / equipment for performing these measurements), fog (types, composition and formation), blindness caused by the sun in daytime conditions or by other participants in night traffic; these elements will be used throughout the rest of the paper, drawing parallels between the experimental results and the theory. The last part of the chapter presents the main equipment used in the experiments in this research.

Chapter 3 presents an analysis of the methods and systems in the literature, published in the last ten years, regarding visibility in foggy conditions. The methods were divided into two main categories: improving visibility, respectively fog detection and estimating the visibility distance (fig.3).

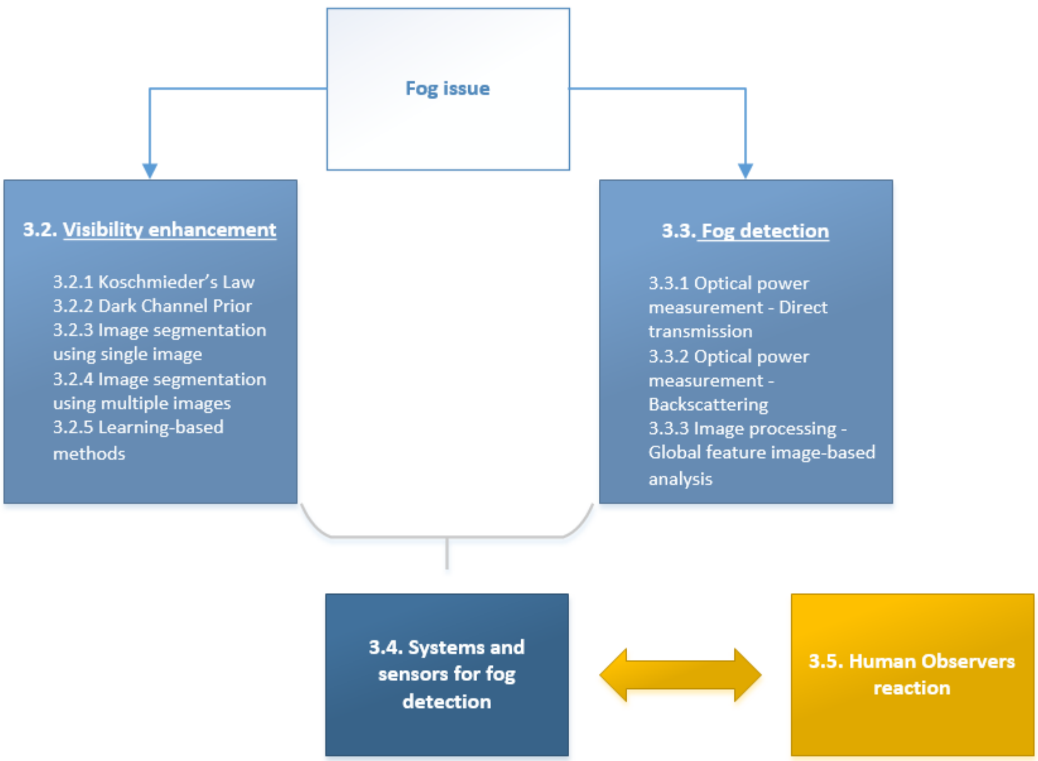


Fig. 3. Overview of current methods and systems related to the problem of lack of visibility caused by fog

If the first category (visibility enhancement) includes only image processing methods, in the second category (fog detection) were identified, in addition to image processing methods, methods related to optical power measurement - either by direct transmission, or by measuring the scattering of the reflected waves. The evaluation of these methods was made taking into account eight criteria, namely: computation complexity, data processing speed, real-time use, possibility to use them in day or night conditions, availability of necessary equipment / systems on current vehicles, possibility to distribute the results to other traffic participants, reliability, respectively the link with the visual acuity that would confirm that the results offered by the automatic systems are valid for a human being. This synthesis had the role of identifying the strengths but also the weaknesses of each method, in order to try to develop a reliable and robust system to be used on public roads. The conclusion of this analysis was that in order to create a system that provides reliable results, it is necessary to interconnect different methods / systems, for example a method based on image processing with an optical power measurement method, in the idea to validate each other's results and to have a back-up solution.

Chapter 4 presents the mathematical support needed to understand the models and modeling of the physical phenomena that underlie the occurrence of the identified problems, as well as the scientific means used to solve them.

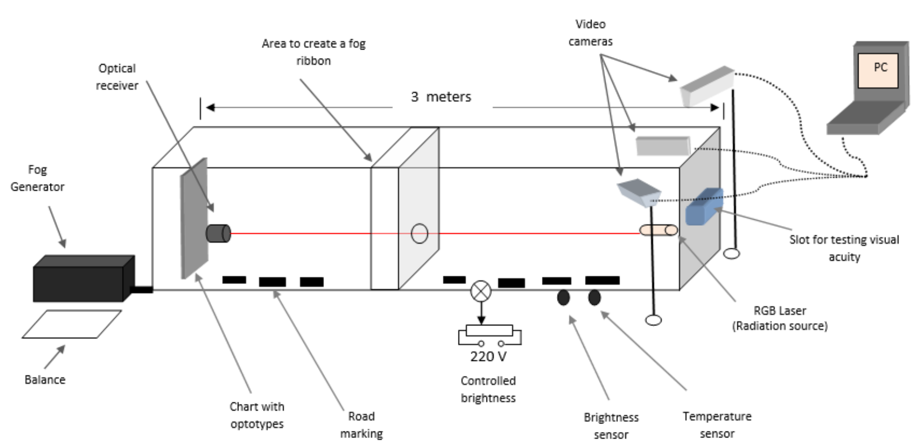
For the part of improving the visibility of images affected by fog is presented Koschmieder law [1], one of the most representative methods in the literature, which proposed a relationship between the apparent and inherent contrast of an object at a certain distance, against a sky background; this law is applicable for daytime conditions. To cover the case of night conditions, Allard's law is presented. The third method presented is the "Dark Channel Prior" method [2], a method that has been the basis of many works, recently published in the literature; it is a statistical method based on fog-free images captured in an external environment, which removes fog from a single image used as input. For the beam scattering part, caused by the fog particles, the laws of Rayleigh and Mie are presented, applicable for different particle sizes.

The purpose of presenting these methods is to apply and test them in practical experiments and highlight the convergent and divergent points of the two categories in order to try a combination of them in a functional, real system.

Chapter 5 presents experimental results realized in the laboratory; it starts with a stationary approach, through which the attenuation of the laser beam was monitored with the help of a video camera, in different fog conditions; based on this information, a visibility distance was estimated and a travel speed was recommended. Furthermore, using the same input images, but this time analyzing the scattering of the beam in the fog, an analogy with the field of view was tried [3].

Afterwards, the behavior of two light sources (LED and laser, these technologies being the future in the field of car headlights) was analyzed, first varying the power at their input, and then maintaining a constant power and introducing fog into the room (from conditions without fog, low fog, moderate fog, up to dense fog conditions). In this way, we realized a connection between the power injected in the light source and the change of visibility for the different categories / fog situations. Fog, having about the same effect on visibility as eye diseases, the next step was to analyze the visual acuity in the same fog conditions (mentioned above), thus making an analogy between different fog conditions and eye problems, by analysing the human observers' reaction. These measurements were performed in a small space, the distance between the chamber and the optotype table being only one meter, thus requiring a resizing of the optotypes [4].

In order to comply with the ophthalmologists' requirements for the visual acuity assessment, a three meters length experimental model was realized [5]. The main requirements which were met with the realization of this experimental model are:
- Offering the possibility to achieve different fog conditions;
- Flexibility and repeatability in testing methods from both categories described in Chapter 3, those for improving visibility and those for fog detection;
- Meeting the ophthalmological requirements for measuring visual acuity - the experimental model has a length of three meters and is represented schematically and realized in Fig. 4 (a), respectively (b).



(a) structural project

(b) physical performance in the laboratory

Fig. 4. Experimental model for testing and validating methods for determining visibility in fog

The validation of the experimental results (got from the automatic system) was performed with the help of human observers (over one hundred), and the differences between the results provided by them compared to those returned by the system were analyzed and discussed. Compared to the experimental model shown in Figure 4, a number of changes have occurred in the practical implementation, the most important being to realize two such models, one to analyze a layer of fog and the second for dense fog. Thus, in the first experiment the impact of the fog on the laser beam was analyzed by measuring its optical power after traversing a thin layer of fog, of 30 cm (fig. 5), but also an uniform fog, of 3 meters (fig. 6).

Fig. 5. Fog layer configuration: a) Dense fog conditions; b) Conditions with moderate fog

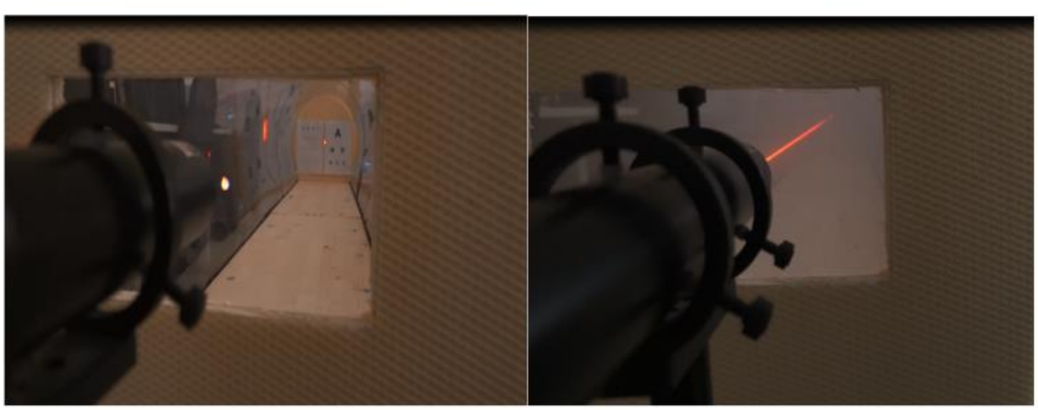


Fig. 6. Long-range configuration: a) Fog-free conditions; b) Fog conditions

It was concluded that the beam is impacted by the number of particles encountered on its path, but also by their size and density; the smaller their size and the higher the density, the greater the impact on the beam.

Going further with the experiments, in the same fog conditions (the fog level was monitored throughout the experiments) visual acuity was measured / established with the help of a camera, through an OCR algorithm, but also with the help of human observers. It turned out that the results provided by the system and by human observers are roughly in the same range. The exceptions being analyzed, it turned out that the deviations, for the most part, were caused by human observers with already known eye diseases. At the end of these two experiments, it was synthesized a link between the optical power measured after passing a fog layer and the visual acuity; this result allows, after a simple measurement of the optical power of a light beam to identify the visual acuity and then to be able to estimate the visibility distance and finally to recommend an safety travel speed.

Then the influence of fog on devices based on backscattering was analyzed - Telemeter and Lidar (fig. 7). The behavior of the two devices, in foggy conditions, differs extremely much. The telemeter provides correct results up to a certain fog density, at which point it is no longer able to provide any valid results (perceived by the device as a distance greater than 40m), returning in this case either an error or indicating the distance to the fog cloud. The measurements of the lidar, the second device tested during this experiment, are impacted by fog particles from the first moments when these appear inside the chamber, but it is still able to return results at very high fog densities - the distances indicated by the device decreasing as much as the density of the fog increases. One of the reasons for obtaining these results would be the wavelengths of the two devices, the lidar having a bigger wavelength (905nm) than the telemeter (632nm), which makes the waves transmitted less impacted by fog particles. As a conclusion of these measurements, the lidar seems suitable to be used in a more complex fog detection system, its waves being able to be reflected from the fog even at a higher density, while the telemeter proves completely useless in dense fog conditions.

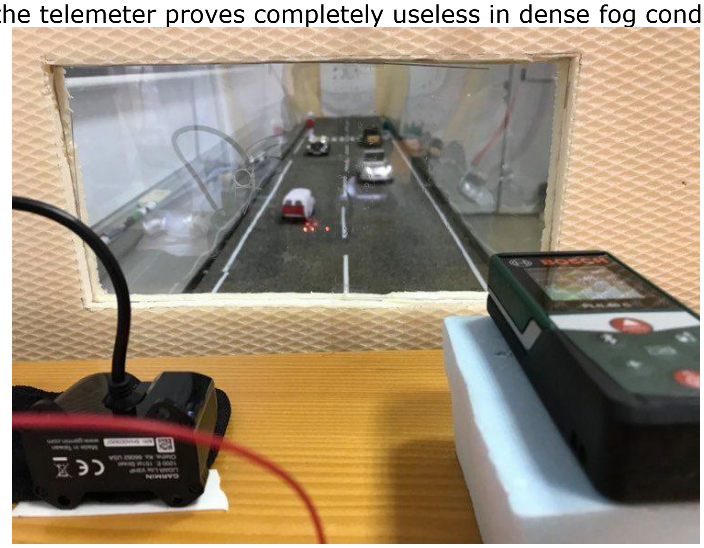


Fig. 7. Evaluation of lidar and rangefinder results in different fog conditions

As a next step, the structure and composition of the fog, generated with the fog generator, were analyzed, in deep details, to understand the fog particle size influence on light sources and visibility. We continued with the presentation of the physical-mathematical aspects of the phenomenon of laser beam scattering, caused by fog particles.

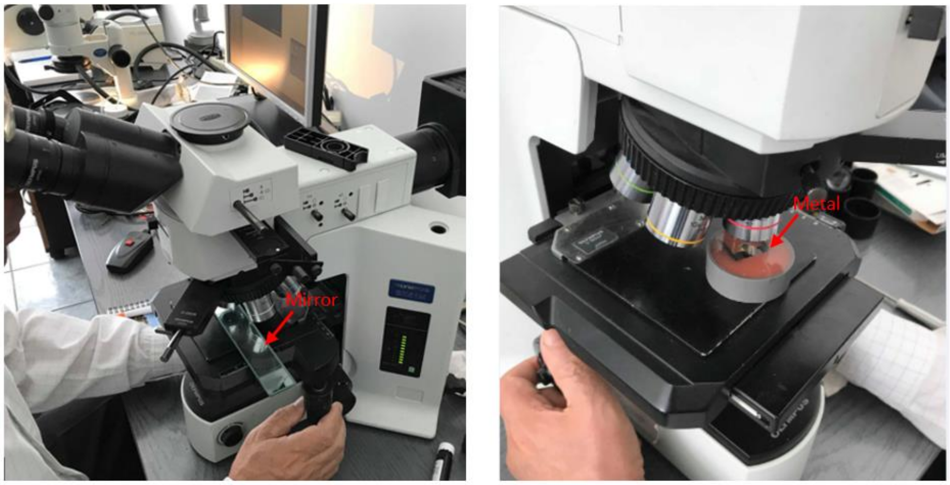


Fig. 8 Analysis of fog particles on a) mirror b) metal

Using a microscope, the generated fog particles were analyzed (Fig. 8) from several points of view, such as: the area of each particle, the shape factor, the aspect ratio, but also the classification of the particles in different classes, depending on the characteristics described above; the next step was to mathematically determine the influence of particle scattering and absorption on the laser beam, using the Mie scattering method. It was concluded that visibility is more strongly impacted when there is a higher density of smaller particles due to their motion in the environment. Due to Brownian motion, turbulence and gravity, the collision between particles takes place, which leads to an improvement in visibility and a reduction in the impact of fog on the light source.

This confirmed the theory that an environment composed of smaller particles and high density has a stronger impact on light beams, but also on visibility, compared to larger particles. As the particle size increases, the intensity of the dispersion decreases, and the decrease becomes even stronger as the dispersion angle increases. For all particle sizes analyzed, forward scattering was predominant (smaller angles); these results are in accordance with Mie's scattering theory, for particles much larger than the wavelength of incident light. A laser with a wavelength of ~ 650nm (red) was used in the experiments.

Based on all these data, a model is proposed to identify the attenuation of optical power at a specific distance, by extrapolating the values obtained in the laboratory for a distance of three meters, at much greater distances. The total attenuation coefficient at a specific distance x (μ_x) can be calculated by multiplying the average attenuation coefficient of a section of the beam by the number of sections relative to the desired observation distance. Going further, the visibility distance can be estimated, based on the theory of designing an eye diagram (table with optotypes) - the observation distance must be 68.75 times greater than the largest optotype in the diagram. This leads to the assertion that the observation distance is 13.75 times greater than the object to be observed in case the details of this object are distinguished (using the fifth row in the optotype table in this determination) , respectively 68.75 times higher for a less clear observation of such an object (reporting made primarily by optotypes).

Thus, a road sign of 70cm size, in foggy conditions leading to an attenuation of about 70% of the optical power measured after passing a fog cloud, is visible from a distance of about 50 meters, while from a distance of about 10 meters, even small details can be distinguished by a person with normal visual acuity. A second example could be a pedestrian of 1.7 meters high, in the same fog conditions described above, it is visible from a distance of about 115 meters, and details can be distinguished from about 23 meters.

The principles mentioned above and summarized in Table 12 are very useful for the design of a stationary system, installed near a highway or expressway, knowing the distance between equipment and aiming to identify adverse weather conditions, estimate a visibility distance and notify the driver (see fig. 5.53). Later these principles can even be used in the design of a mobile system for detecting fog and estimating the distance of visibility.

In the last part of chapter 5, experiments were performed related to improving the visibility in an input image (taken with a camera); the input images for this experiment were taken in experimental model number two (the one of 3 meters length), modified so as to allow the simulation of a real traffic scene, by resizing all objects in the scene (road markings, vehicles and pedestrians) on a scale of 1: 17.5; In this model, different fog conditions were created, monitored with the help of a video camera, and then an attempt was made to remove the fog from the images using several image processing algorithms. The final comparison, presented in the paper, was made between the histogram equalization method ("Histogram Equalization") and the "Dark Channel Prior" method (DCP); the best results, among the tested methods, were recorded by the later one (see fig. 9).

Fig. 9 Image with dense fog: a) original; b) fog removed; c) refined by applying DCP

The proposed system for improving visibility and estimating the visibility distance, resulting from the study of the literature and analysis of experimental results, led us to a combination of systems (a collaborative system): a stationary system, installed near the public roads, to estimate visibility by optical power measurements and a mobile one (being installed on vehicles) consisting of a video camera together with a lidar (fig. 10). The synchronization of these systems and the interpretation of the results offered by them, will increase safety on the public roads in unfavorable weather conditions.

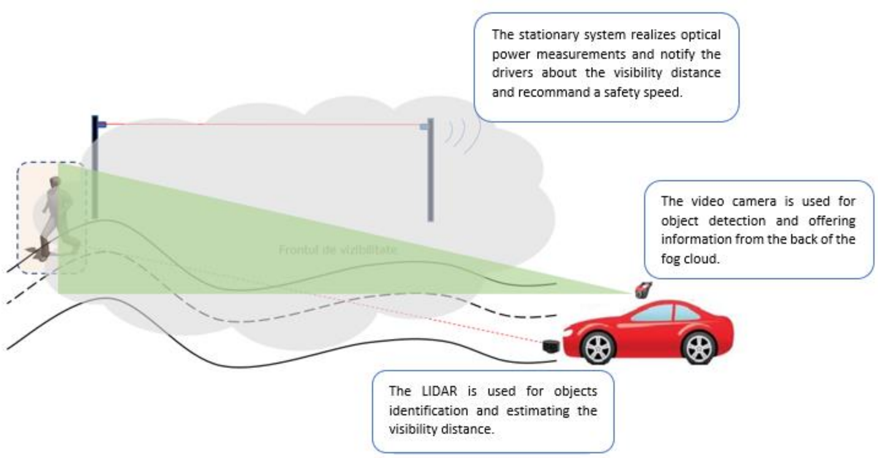


Fig. 10 Proposal for a collaborative system to increase traffic safety in foggy conditions

The stationary system will measure the fog density by taking into account the level of optical power reduction, and based on this information will be able to estimate the visibility distance, transmitting this result to vehicles. The video camera on board, with the speed adapted to the visibility conditions, will detect traffic signs, road markings, pedestrians or other traffic participants, while the lidar will come in addition by detecting possible obstacles in front of the vehicle, but it will also provide a visibility estimation - in the specific case of the foggy areas through which it moves. By accumulating information from all these "sources", the vehicle's central system can prevent and notify drivers of potential dangers, but can also take autonomous measures such as deceleration or braking, in case of danger.

In the thesis is presented a real traffic situation on the highway, highlighting the system elements that ensure safety in low visibility conditions: laser transmitters and receivers for stationary systems respectively lidar and camera for mobile ones. In the near future, there will be more and more frequent cases in which autonomous cars will appear on public roads alongside the classic ones driven by the drivers. As drivers' actions are unpredictable, these systems will have to have an extremely short evaluation and response time in order to be able to avoid possible accidents.

In **Chapter 6** was studied the glare phenomenon caused by sunlight, which proved to be one of the main factors leading to accidents on public roads. If until five years ago the classic sunshade was the only method used against glare caused by the Sun (which is outdated compared to other components of a modern vehicle and does not contribute to driver safety), in recent years automotive companies have presented at international showrooms different solutions, all still in the prototype phase. Most of these solutions are based on changing, with a certain level, the transparency of the vehicles' windows (windshield, rear window, side windows).

In the thesis is proposed a system based mainly on equipment already available on the vehicles - the idea being just to give them other functionalities [6]. Thus, with the help of a sensor that indicates the direction of the Sun's rays and a light level sensor, the light intensity and the place where the sun's rays will intersect on their way to the driver's eyes are detected. In order to analyze if the sun's rays impact / disturb the driver's visibility (based on the driver's internal detection, face brightness, but also the direction of his gaze while driving), video cameras are used. Based on the interpretation of this information, the coordinates of the intersection point between the rays and the driver's gaze on the windshield surface must be determined; at that point, a spot must be created / projected to protect the driver from the blinding light (fig. 11). The coordinates are sent to an ECU that creates an image / spot of a certain size (default) and will transmit it to the HuD to project it on the windshield.

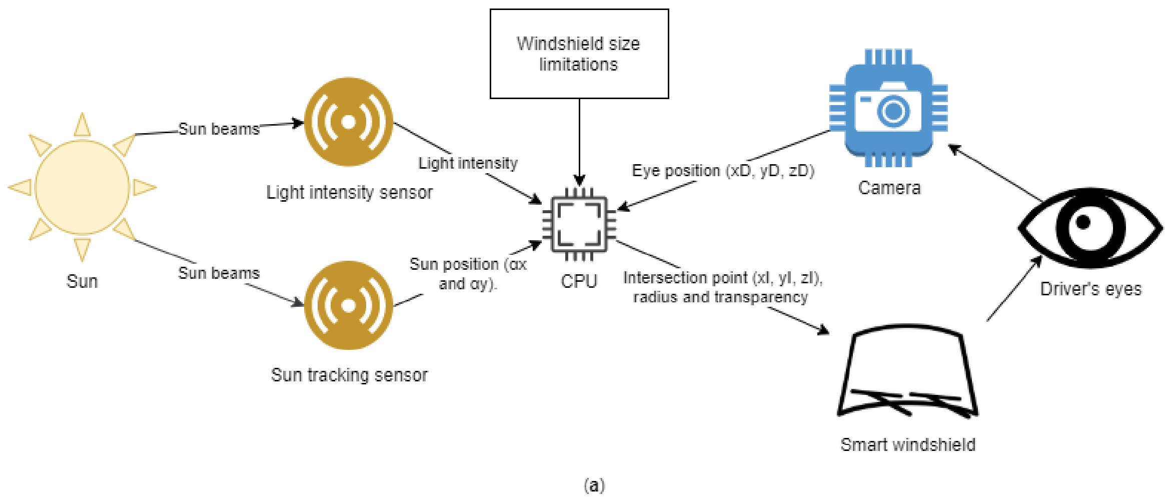


Fig. 11 Graphic overview of digital sunshade

Considering the progress made in the field of HuD in recent years, it seems only a matter of time (a few years) until such a system will be available with a sufficiently low production cost to benefit both the driver and producer.

Afterwards, a study on the applicability and benefits of installing an anti-glare system on vehicles was presented. In order to test and highlight the principles described in this part of the research, different scenarios that can be encountered in real life were simulated in MATLAB [7]: the one in which both the position of the Sun and that of the driver are fixed, then the one in which one of the points is fixed (Sun / driver) and the other mobile, and the last case both points are mobile.

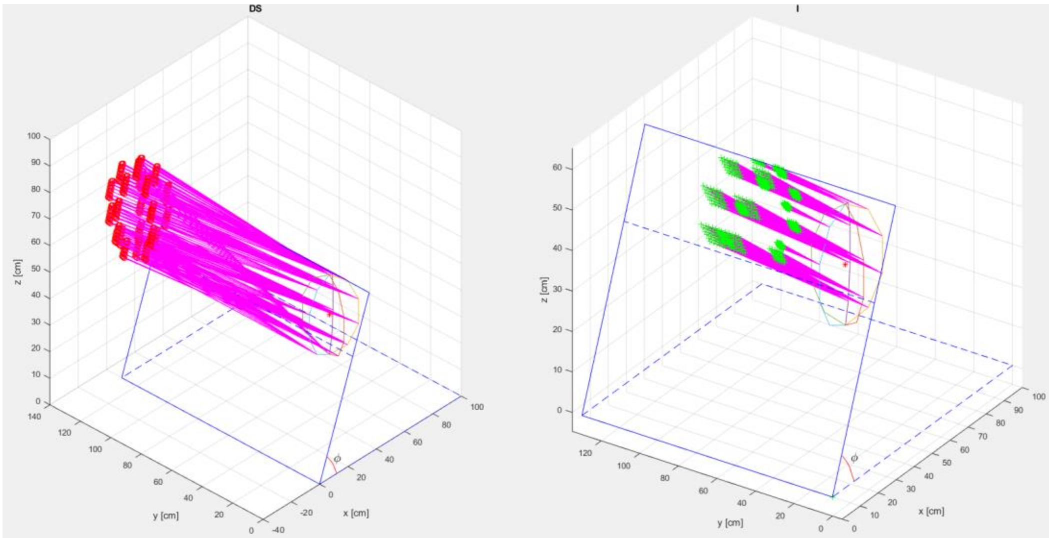


Fig. 12 The fourth test scenario - S and D are moving points

As it is known, there are also scenarios in which the sun's rays are reflected from the road, being also extremely harmful to the visibility. In this case, we consider that the same approach will be applied, using a HuD and projecting a dark spot (spot) in which the area where the reflected sunlight produces discomfort. The analysis of this specific case and the calculation of the position of the dark spot on the windshield are not presented in this paper. In the future, the simulation environment will be replaced with a real prototype that can be tested in a laboratory, and then the prototype will be installed on a vehicle to address real scenarios.

Chapter 7 presents the conclusions, the personal contributions, regarding the three objectives initially set, namely:

(i) the development of an experimental model, in the laboratory, which allows the study and experiments, under conditions of repeatability, of techniques and methods (existing and new proposed by the author) for estimating visibility in fog conditions;

To achieve this goal, two experimental models were presented:

- The first one, measuring 100cm x 30cm x 60cm (LxWxH), in which to perform experiments that do not require a large measuring distance but also to achieve a narrow fog curtain, only 30cm;
- the second, measuring 300cm x 48cm x 47cm (LxWxH), in which the analogy between the results provided by the automated system and the visual acuity of human observers can be achieved and the ophthalmological requirements fulfilled.

(ii) developing a practical solution - whereby drivers or autonomous vehicles are informed of visibility conditions - leading to increased road safety;

The solution reached is a collaborative system, presented in Chapter 5 of the thesis.

Related to this objective, the following methods were tested and analyzed in an original way:

- Absorption of the laser beam in fog, monitored with a video camera (experimental model of 100 cm);
- Dispersion of the laser beam in fog monitored with a video camera (experimental model of 100 cm);
- Analysis of the fog influence on the optical power of different light sources (LED, Laser) and correlation with visual acuity;
- Analysis of the fog influence on a laser beam (direct transmission) and correlation with visual acuity (experimental model of 300 cm);
- Analysis of the fog influence on devices based on backscattering - Telemeter and Lidar (experimental model of 300 cm);
- The influence of fog particle size on light sources and visibility;
- Remove fog from images (visibility enhancement) by applying different image processing algorithms.

- Presentation of the principles which can lead to the design of a stationary system (which can later become even mobile) which based on optical power measurements calculates an attenuation coefficient which then leads to the visibility distance estimation.

(iii) avoiding glare effect on drivers visibility, due to sunlight, by introducing a dynamic sun visor system;
A system capable of protecting drivers against the glare effect caused by the sun rays is proposed, which is very advantageous in terms of implementation costs, using existing technologies which can already be found in a high-performance car:
- sun tracking sensor to detect the point where the light has the maximum intensity on the windshield surface;
- an eye tracking system to find out the driver's position;
- a head-up display (HuD), to project a black "spot" on the windscreen and thus minimizing the power of the external light that disturbs the driver;

The results were verified and highlighted using MATLAB environment, in which were simulated various scenarios that can be encountered in real life.

The research results were validated by publishing 10 scientific papers, of which 7 in the field of thesis, presented at prestigious international conferences and journals, 6 papers being indexed in Web of Science. Two of the publications [8] and [9] precede the subject of the thesis.
The topic of the publications is very well structured, covering almost all the contributions of the thesis.
The author holds a European patent in the automotive field (https://worldwide.espacenet.com/publicationDetails/biblio?DB=EPODOC&II=7&ND=3&adjacent=true&locale=en_EP&FT=D&date=20180411&CC=EP&NR=3305580A) currently being published in journals, all this proving its value as a trained researcher.
The works published as author / co-author, related to the research topic, are referred to during the thesis and indicated in the Bibliography section.

Selective Bibliography

[1] H. Koschmieder, Theorie der horizontalen sichtweite, Beitrage zur Physik der freien Atmosphare, 1924.
[2] K. He, J. Sun și X. Tang, „Single Image Haze Removal Using Dark Channel Prior," în *IEEE Transactions on Pattern Analysis and Machine Intelligence (Volume: 33, Issue: 12, Dec. 2011)*, 2011.
[3] **R. Miclea** și I. Silea, „Visibility Detection in Foggy Environment," în *Control Systems and Computer Science 2015 20th International Conference, Bucharest 27-29 May 2015, pp 959-964*, 2015.
[4] I. Silea, **R. Miclea** și F. Alexa, „System for Visibility Distance Estimation in Fog Conditions based on Light Sources and Visual Acuity," în *EEE International Conference on Automation, Quality and Testing, Robotics (AQTR)*, 2016.
[5] **R. Miclea**, I. Silea și C. Dughir, „Experimental Model for validation of anti-fog technologies," în *Second International Scientific Conference on IT, Tourism, Economics, Management and Agriculture (ITEMA), pages 914-922*, 2017.
[6] **R. Miclea**, I. Silea și F. Sandru, „Digital Sunshade Using Head-up Display," în *Soft Computing Applications (SOFA 2016) - Advances in Intelligent Systems and Computing, vol 633. Springer, Cham*, 2016.
[7] V.-I. Ungureanu, **R. Miclea**, A. Korodi și I. Silea, „A Novel Approach against Sun Glare to Enhance Driver Safety," *Applied Science,* vol. 10, nr. 9, 2020.
[8] Florin-Daniel Sandru, Sorin Nanu, Ioan Silea, **Razvan-Catalin Miclea**, "Kalman and Butterworth filtering for GNSS/INS data", Published in: 12th IEEE International Symposium on Electronics and Telecommunications (ISETC), pages 256-260 Publisher: IEEE, Date and Location of Conference: 27-28 Oct. 2016, Timisoara, Romania; INSPEC Accession Number: 16540790, DOI: 10.1109/ISETC.2016.7781106, Published in: 2016

[9] Florin-Daniel Sandru, Ioan Silea, **Razvan-Catalin Miclea**, “LoRa® based multi-sensor system for heavy-duty vehicle detection in restricted areas”, Published in: 1st International Conference on Computational Methods and Applications in Engineering ICCMAE 2018, Date and Location of Conference: 23-26 mai 2018, Timisoara, Romania; INSPEC Accession Number:
DOI: 10.1051/itmconf/20192903005, Published in: 2019
[10] Răzvan-Cătălin Miclea, Ioan Silea, Florin Alexa, Ciprian Dughir “Visibility Enhancement and Fog detection – solutions presented in recent scientific papers”, *Accepted*, 5th ICICT 2020 (Proceedings by Springer), February 2020, London, United Kingdom

TIMIȘOARA
October, 2020