**IOSUD - Universitatea Politehnica Timişoara**
**Şcoala Doctorală de Studii Inginereşti**

# RESEARCH AND SOLUTIONS APPLICABLE TO THE REDUCTION OF SOME HARMFUL EFFECTS OF DRIVING MOTOR VEHICLES IN CERTAIN WEATHER CONDITIONS

**Doctoral Thesis – Summary**
for obtaining the scientific title of doctor at
University Politehnica Timisoara
in the doctoral field of Systems Engineering

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# 1. Introduction

## 1. Theme, purpose, and objectives of the thesis

The theme of the research presented in this paper aims to diminish or even combat the negative effects caused by certain meteorological phenomena on road traffic, focusing on the phenomenon of sunlight and fog. The two phenomena contribute considerably to reducing the visibility of road users. Thus, efforts have focused on understanding and analyzing the impact of sunlight and fog on humans, namely the driver, but also on perception sensors (including information processing methods) with which a modern or autonomous vehicle is equipped to achieve prevention mechanisms. These systems may be present in vehicles and/or on the side of the road, collecting and processing data to provide information to drivers or autonomous systems responsible for the vehicle's meter. The trends are for these autonomous systems to be directly mounted, deployed, and integrated into the car, acting automatically to facilitate the maintenance of traffic safety.

Starting from the analysis of statistics highlighting meteorological phenomena that can be considered as a cause for road incidents, but also studying the specialized literature in the automotive safety area, the phenomena that, although causing numerous incidents, are somewhat neglected by specialists, were selected. Thus, the main purpose of the thesis is to develop modern methods of prevention to counteract the negative impact of solar glare and fog phenomena on visibility, thus implicitly, on traffic safety. Thus, it aims to develop equipment with which a car can be equipped, capable of protecting the driver, but also certain sensors (or video cameras) from strong light coming from the sun. Through the expected results, not only better visibility is ensured, but also the comfort of the occupants of the car is improved. The effect of fog on visibility can be extremely little improved by various technologies, so for this case we aim to achieve a system located near the road, capable of providing both the driver and the systems with which a car is equipped, information on the density of fog in a certain area that the vehicle is going to travel. In the context of efficient vehicle-to-infrastructure communication, the system can request information from the car, based on which it can even provide an estimate of the recommended travel speed – which ensures that safe conditions are maintained. For situations where the driver or vision-based control systems fail to act promptly enough to mitigate the risks posed by temporary loss of visibility, safety systems based on measuring the distance between road users (obstacles on the road, pedestrians, other cars or various static objects such as pillars or walls) were analyzed,  In particular, the capabilities of a new type of sensor and its feasibility for use in the automotive industry were studied.

Thus, starting from these aspects, the following objectives were established and developed:

- (1) Elaboration of principles and solutions for implementation/realization for a new model of mobile digital sunshade, capable of counteracting the effects of solar glare on the driver, increasing both comfort and safety of road users. Specifically, it aims to test the validity of the proposed solution in a simulated environment, as well as to analyze the feasibility of integrating such a system on a modern car, wishing to reuse existing elements to keep manufacturing costs low;
- (2) Performance analysis of existing distance sensors intended for driving autonomous vehicles or performing maneuvers assisted by machine algorithms such as: environmental disclosure, obstacle detection, detection of cars traveling in the wrong lane or parking operation. Research is focused on introducing new distance measurement technologies in the automotive field and combating their possible shortcomings;
- (3) Study of existing literature methods designed to improve the visibility of the human user, but also that of the perception systems of an autonomous vehicle in a foggy

environment. At this objective, attention will be focused on the operation of a prototype made in the laboratory, capable of providing an estimate of the distance of visibility in fog, through image analysis. Methods to improve image storage and transmission will also be explored to streamline the process of determining visibility in fog.

Fig. 1 illustrates the meteorological elements covered in this paper, while also providing an indicative picture of possible prevention solutions that can be applied.

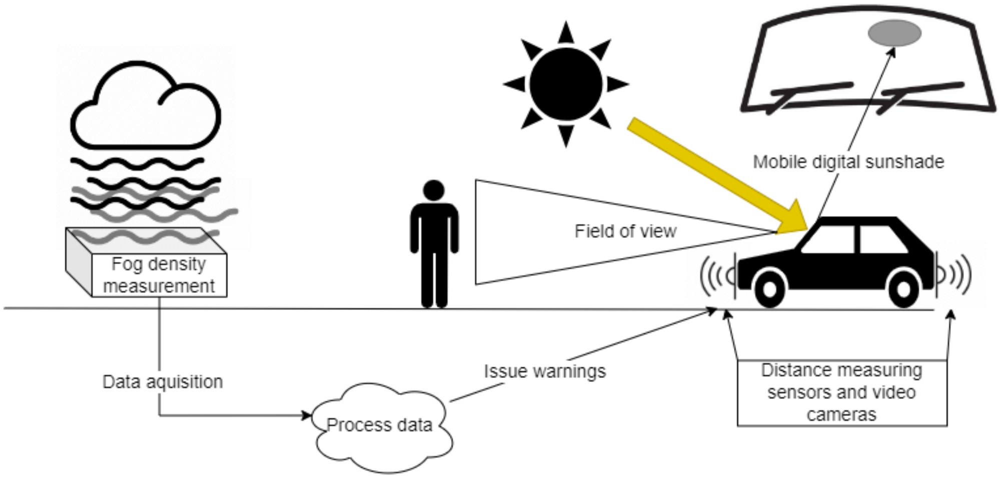


Fig. 1 Presentation of meteorological factors affecting visibility, as well as methods of incident prevention.

According to the figure, the thesis addresses systems and solutions present on a car or on the side of the road (each with a well-defined purpose and influence on different elements causing incidents), which work together and serve a common goal: increasing the safety of road users. Thus, by integrating illustrated systems, information is processed by issuing warnings that can trigger mechanisms to prevent incidents caused by deterioration of visibility.

### 1.1. The importance of the proposed theme in the context of the automotive field

Over time, road transport has proven to be the most affordable way people have resorted to when they had the need to move or transport goods. Thus, the number of cars has increased, be they private cars, motorcycles, buses, or trucks. Since, in most cases, the development of road infrastructure cannot keep pace with the large number of road users and can certainly not make up for the characteristic human inattention, the risk of accidents is increasing. Thus, one of the main goals of vehicle manufacturers worldwide has become the creation of systems that help mitigate the risks of collision between road users. When it comes to car safety systems, all cars on the road must meet certain safety standards designed to protect drivers, passengers, pedestrians and, more recently, the environment. In addition, car safety also refers to the study of the design and construction of equipment as well as the study of applicable regulations aimed at minimizing the occurrence and consequences of car accidents. If certain accident-causing elements can be controlled and limited, such as increased speed or tread quality, weather phenomena are beyond human control capabilities. Thus, a modern vehicle must be equipped with various active or passive solutions that contribute to reducing the negative effects produced by phenomena such as: rain, snow, fog, solar glare, etc. One of the key factors when it comes to avoiding collisions is visibility. Thus, the protection and prevention systems with which the car is equipped must ensure that the driver has sufficient visibility to drive safely and to be prepared to act appropriately to avoid any type of incident.

Systems that provide or estimate visibility can be either on board the car or on the side of the road. Tools in the first category can act directly on the driver or car to achieve their purpose (e.g., through automatic braking), while systems in the second category can mainly be used as a method of prevention. In this way, the user can be informed about visibility conditions through an infrastructure-vehicle communication. Of course, when visibility methods are not sufficient, other active safety features, often based on measuring the distance to a specific obstacle, will intervene to avoid possible damage. Many technologies used in the automotive sector, especially those aimed at improving passenger safety and comfort, rely on distance measurement operations. Technologies such as adaptive navigation systems, automatic braking systems, obstacle detection systems and parking assistance systems rely on distance measurement processes. As advanced driver assistance systems become more prevalent in regular vehicles, automakers have begun to combine cameras with other types of sensors, such as ultrasound, radar and, more recently, LIDAR (LIght Detection And Ranging). But the market is not limited to these sensors, there is always room for unexplored technologies in the automotive field such as VCSEL (Vertical-Cavity Surface-Emitting Laser) technology.

# 2. Fundamental aspects of road safety

Automotive safety is a key aspect of industry research and innovation. In the current chapter, notions, principles, some theories, and equations underlying the research in the topic of the paper are presented, these being highlighted, synthesized, and explained.

## 2.1. Automotive safety

Referring only to automotive safety systems, any car on public roads must meet certain safety rules designed to protect the driver, passengers and pedestrians. In fact, safety in automotive refers to the study of the design, construction, equipment, and regulations in force, aiming to minimize the occurrence and consequences of collisions involving vehicles. Traffic safety also includes road infrastructure facilities. Given the current context in the automotive industry, where a trend towards autonomous vehicles can be observed, traffic safety is an extremely important point for the entire industry in this field. In the context of achieving automotive safety, two categories of systems can be distinguished: those for active safety and those for passive safety.

Active safety systems refer to complex means that assist the driver to prevent accidents. Among such systems, which intervene directly to avoid a collision, giving the driver greater control over the vehicle, are: brake assist systems, adaptive navigation systems, obstacle detection systems, etc.

Passive safety systems implement those technical solutions that have the role of protecting the driver, passengers, but also pedestrians in the event of a collision. Such systems intervene when the incident could not be avoided using the active elements present in the vehicle and represent an increased protection mechanism in case of an accident. Some passive safety systems are: seat belts, airbags, head restraints, etc.

## 2.2. Visibility

According to DEX [1], visibility is "the distance up to which an object can be seen with the naked eye under given atmospheric conditions; state of clarity of the atmosphere, which determines this distance". Therefore, visibility is expressed as a distance, at which an object can be clearly discerned, being dependent on the conditions of the environment. In meteorology, visibility depends on the transparency of ambient air but is affected by many other external factors, being expressed in meters or miles (depending on the country). Certainly, visibility affects all existing forms of traffic: aviation (air), navigation (water) or land (roads). The curvature of the earth, eye level, the altitude of the viewed object, various obstacles as well as weather conditions limit the geometric range of visibility.

According to [2], the main factors affecting visibility are: environmental conditions (air pollution, high humidity, fog, smoke, heavy rainfall, windblown sand, blizzard, drizzle, snow, or strong sunlight or headlights), the object being observed (its dimensions, shape and color, movements it performs), the observer's condition (diopter or degree of adaptation of the eye to the environment in which it is), but also the background of the observed object (contrast between the observed object and its background).

## 2.3. Sun glare phenomenon

The phenomenon of glare can be expressed as difficulty seeing in the presence of bright light, such as direct or reflected sunlight (especially if the road is wet), or artificial light, such as car headlights at night. For this reason, some cars are equipped with mirrors with automatic anti-glare functions, and in buildings, blinds are often used to protect occupants. Glow is caused by a significant luminance ratio between the lens and the glare source. Factors such as the angle between the lens and the source of glare, as well as eye adaptation, have a significant impact on temporary blindness caused by glare. Glare can be divided into two categories [3]: discomfort-causing glare (defined as a psychological sensation caused by high light intensity in the observer's field of vision and does not necessarily affect vision) and disability-causing glare (temporarily impairs vision without necessarily causing discomfort).

## 2.4. Fog phenomenon

According to [4], fog is a visible aerosol consisting of small particles of water or ice crystals suspended in the air at a short distance from the earth's surface. Fog can be considered a type of low-altitude cloud, being strongly influenced by nearby water bodies (lakes, seas, oceans, swamps, or wetlands) or wind speed and direction. Simplified, fog is formed, when water vapor condenses. During condensation, water vapor molecules combine to form tiny droplets of liquid water suspended in the air. Fog influences human activity, mainly by reducing visibility, thus all methods of transport as well as their safety is adversely affected. Fog reduces visibility to less than a kilometer. The thickness of a fog layer is largely determined by altitude and atmospheric pressure.

## 2.5. Solar trajectory

According to Schombert Mueller's Notes on Astronomy specified in [5]: "The horizontal coordinate system (commonly referred to as the alt-az system) is the simplest coordinate system because it is based on the observer's horizon". The solar azimuth angle is a way to identify the position of the sun in the sky, it defines the horizontal position of the sun on the local horizon. When the solar position is targeted, the reference direction is north. Thus, the azimuth angle is the angle between north and the sun on the local horizon with the observer. Azimuth indicates horizontal coordinates of the sun, while elevation indicates vertical coordinates. Therefore, the elevation angle provides information about the altitude of the sun in the sky. The altitude-azimuth coordinate system is shown in Fig. 2.

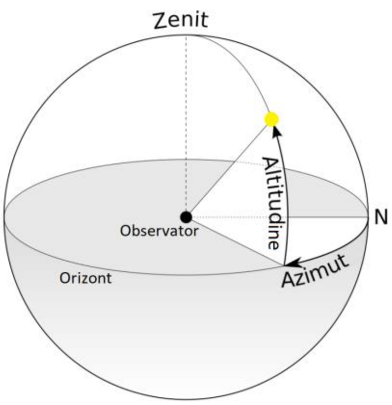


Fig. 2 Solar azimuth angle and solar elevation angle for a north-facing observer.

### 2.6. Automotive distance measuring devices

Distance measurement in the automotive field is essential. Collision detection and avoidance systems, adaptive navigation systems, automatic braking systems, obstacle detection systems as well as maneuvering assistance systems (e.g., assisted parking systems) are based on distance measurements. Thus, a wide range of technologies that increase traffic safety are dependent on certain sensors capable of obtaining distance to a point of interest. Regarding the sensors used to measure distance we can mention: ultrasonic sensor, IR sensor (InfraRed), LIDAR sensor, VCSEL sensor, LED TOF ( Light-Emitting Diode Time Of Flight) sensor or radar. These sensors work mainly by emitting a signal (the type of signal differs from one technology to another) and measuring it when it returns. Depending on changes in the initial signal, the distance is determined. The measured change can be in the form of: the time it takes for a signal to return, the strength of a modified signal, or the phase change of the returned signal from the original.

### 2.7. Filters and physico-mathematical aspects

In statistics, making measurements, processing images and signals, smoothing a data set means creating an approximation function that tries to capture important patterns coming from the data while filtering noise, other fine-scale structures, or rapid phenomena. When smoothing, the data points of a signal are modified so that individual points higher than adjacent points (probably due to noise) are reduced, and points that are lower than adjacent points are increased, resulting in a smoother signal. Smoothing can be used in two important ways that can help analyze data: by being able to extract more information from the data if the smoothing assumption is reasonable, or by being able to provide analytics that are both flexible and robust [6]. Many different algorithms are used in smoothing depending on available resources, maximum permissible complexity, etc. Smoothing methods often have an associated adjustment parameter that is used to control the degree of smoothness. During the work, the following filters were used: Moving Average, Savitzky–Golay or Kalman.

The mean absolute percentage error (MAPE) was used to evaluate the results of this paper. It has been used to provide an overview of errors between measured and predicted distances, providing a good measure to analyze the quality of the results obtained.

## 3. System to prevent glare caused by sunlight

Chapter three focuses on analyzing and combating glare caused by solar glare by creating a mobile digital sunshade [7].

### 3.1. Importance and novelty

Over time, various systems have emerged that increase safety and reduce the risk of accidents. Many of these solutions focus on combating and minimizing the negative effects caused by adverse weather events. Although it is a phenomenon that, according to statistics [8], causes more road collisions than rain, fog and snow combined, glare caused by sunlight has not received much attention in literature and industry. Because of this, existing solutions are outdated, poor, and unreliable.

This chapter presents extensively the theoretical aspects, architecture, design, possible methods of implementation and testing of a solar glare safety system presented as a mobile digital sunshade (a graphic example being shown in Fig. 3). Therefore, the aim was to replace the classic sun visor with a digital one, using as many of the systems and components already inside a vehicle as possible. Thus, the proposed system can acquire information on the position of the sun, light intensity and the position of the driver's eyes to determine where exactly on the windshield of the car the digital sunshade should be made. Once the central point of the sunshade has been established, decisions can be made about its shape, transparency, etc. Also, the profitability of such a system was not overlooked. For this reason, various hardware and software solutions were analyzed to minimize implementation costs. Throughout the chapter, the mathematical calculation process used to determine the position of the proposed sunshade on the windshield is presented, as well as the results of simulations carried out to test the correctness of the solution. The entire mathematical calculation process was implemented using the MATLAB environment, in which various test scenarios were also realized. Various system subcomponents necessary to simulate the digital sun visor, such as determining the position of the sun, light intensity, or driver position, were developed, and tested modularly, using the hardware and software components available.

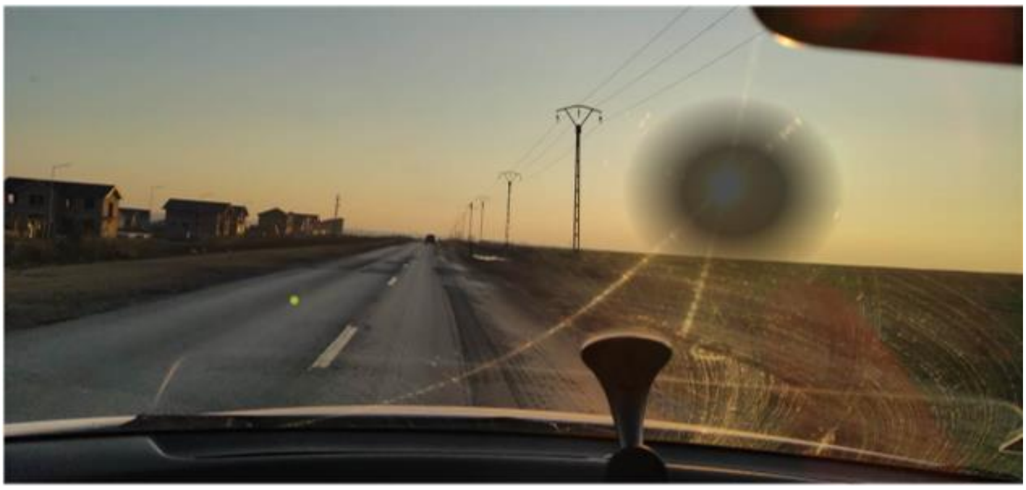

Fig. 3 Application of the sun visor in a case where the driver is affected by sunlight.

## 3.2. Current context

A neglected weather phenomenon is glare, which can be caused by multiple sources, depending on the time of day. At night, glare can be caused by headlights of oncoming vehicles. This problem can be solved by improving the technologies used to manufacture headlights. Therefore, using LED and laser technologies, combined with auto-dimming or self-adjusting technologies and the corresponding color temperature of the light, glare caused by headlights can be reduced. During the day, glare is caused by the sun that can temporarily blind the driver, thus increasing the risk of accidents. To date, there are not many solutions to the problem of glare. Manual sunshade is still widely used, but it has major drawbacks. First, it must be operated manually by the driver. The fact that the driver must position the sun visor combined with the glare caused by the sun can lead to loss of attention and therefore to an accident. Alternatively, a sun visor driven by an actuator [9] can be used9, which, based on a light sensor, decides whether to open or close the flap. Of course, such an approach may seem somewhat outdated considering the rest of the technologies used in the vehicle. Secondly, the entire windshield is not covered by classic sun visors. Thirdly, the classic sun visor is completely opaque, obscuring the driver's visibility.

Many companies such as Bosch or Continental Automotive have begun developing prototypes of sun visors or smart glass [10] that can change their transparency. Their deficiency is that they still cover only a limited area of the windscreen.

## 3.3. Digital sunshade

The digital movable sun visor has the potential to protect the driver of the vehicle against three types of glare sources: glare from the headlights of other oncoming cars (at night) (Fig. 4 a), glare from direct sunlight (Fig. 4 b) and glare from reflection from sunlight (e.g., when the road is wet) (Fig. 4 c).

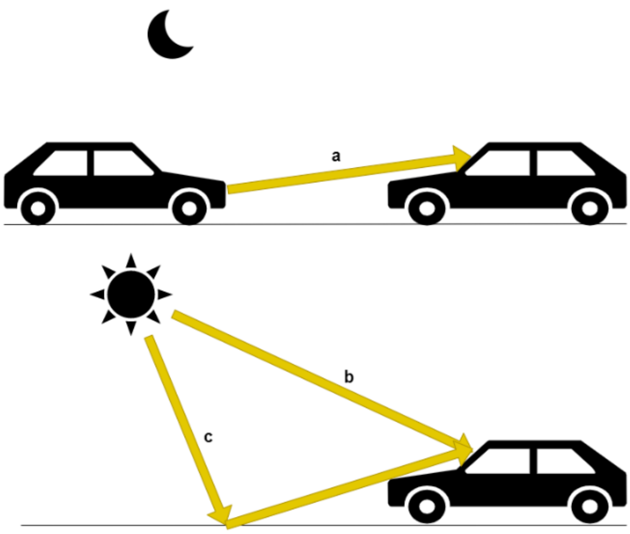


Fig. 4 Types of sources of glare: a - headlights of other cars coming from the opposite direction at night; b - direct sunlight; c - reflection of sunlight.

Since case (a) already has various solutions available on the market (self-adjustment of the light beam, dimming it, automatic switching of the driving or dipped-beam light when an oncoming car is detected) and case (c) is a very specific situation, attention has been focused on case (b). However, the two situations were not completely neglected, scenarios being analyzed in which the digital sunshade could have benefits and increase traffic safety.

For direct sunlight as a source of glare, the components of the entire proposed digital sunshade system are briefly (graphically) shown in Fig. 5.

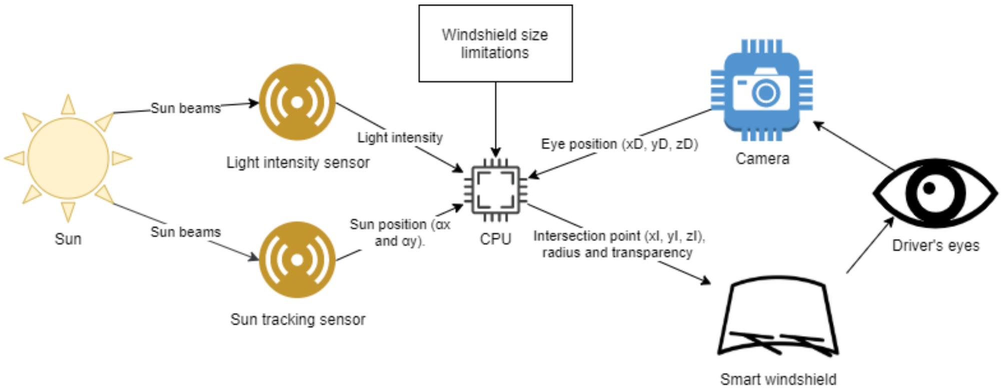


Fig. 5 Overview of the components needed to make the digital sunshade.

A block diagram describing the closed feedback loop system, along with its main components, is shown in Fig. 6. This also highlights input and output variables, functional correlations, and how the new position of the dark spot center is created. The proposed cyclicity of the system is one second, therefore, every second, sensors will measure the position of the sun and the intensity of light. The information provided, along with the predefined limitations, will serve as input variables for the phase in which the center of the dark point is calculated. After locating the new point, a decision is made to move the entire darker area to the windshield if a threshold of one centimeter is exceeded. That is, if the distance between the previous and new center exceeds the defined threshold, new instructions will be generated and provided to the driver, considering the predefined shape and size of the dark area. From this moment on, the instructions will be transmitted to the smart glass and the digital sunshade will be created. Most likely, the center of the area will be the darkest point and transparency will increase towards the limits. The previously calculated coordinates will serve as feedback, and the whole process will be repeated if the digital sunshade is needed.

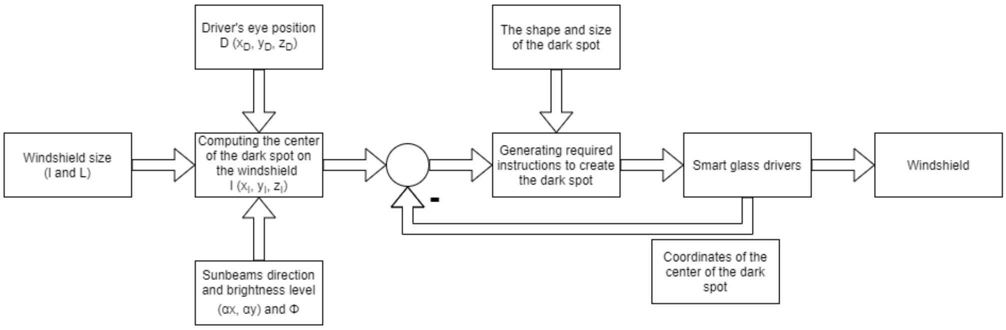

Fig. 6 Block diagram of the proposed mobile digital sunshade.

## 3.4. Tracking systems for the position of the sun and driver's eyes

A sun position sensor is a device that detects the direction of the sun relative to its position. A variety of sun position sensors have been designed and improved in recent years. It is obvious that the models, materials, and dimensions used depend on the solar applications in which the sensors will be used. The most general classification of sun position sensors is based on sensor type, signal type, data transmission, and solar tracking direction. Sun position tracking sensors are used in applications and technologies that refer to photovoltaic modules, satellites, solar collectors, etc. When choosing a sensor, the advantages offered, as well as design limitations, are considered. This considers: accuracy, solar tracking errors, desired properties, field of view (FOV – Field Of View), product marketing as well as evaluation of external parameters (climatic factors) that affect sensor performance. The type of sensors refers to all physical and operational aspects of the sun position sensors, i.e., geometric design, principle of operation (how the sensor measures the position of the sun), their performance and efficiency.

The position of the sun can be obtained by using a dedicated hardware component (e.g., ISS-DX sensor [11] Fig. 7 a) or specialized software (Fig. 7 b).

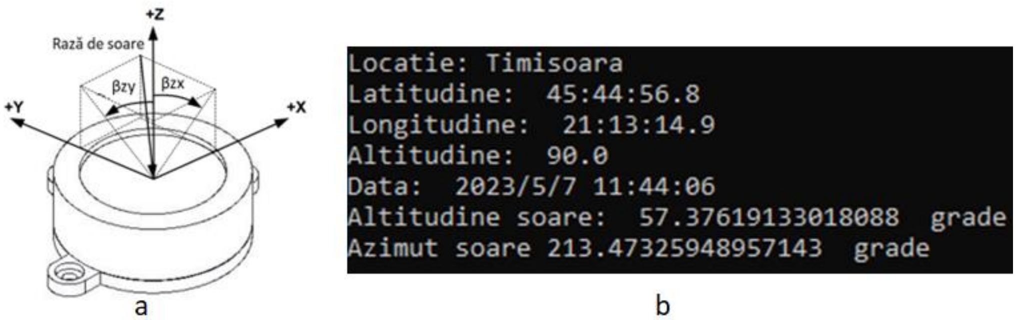

Fig. 7 Finding out the position of the sun: a - hardware; B - software.

To find out the position of the driver's eyes, a bibliographic study of existing research and the market was carried out, the problem being already solved by systems based on video cameras such as Smart Eye [12] or various python libraries.

## 3.5. Digital sun visor solutions and achieved results

Data from the sun-tracking sensor and camera is used to determine the location of the point on the windshield where the dark spot should be created. The opacity of the spot can be determined from the information provided by the luminous intensity sensor (ambient light sensor). The light source is represented by the sun, so it is necessary to determine the position of the source relative to a known point inside the car. The direction of sunlight can be achieved using dedicated sensors, cameras, or specialized software. To determine the position of the driver's eyes, the camera is used. Having the spatial coordinates of the light source (sun) and eyes, related to the same reference, it can be decided where exactly on the windshield to make the sun visor using built-in screens or smart glass [10]. Even though Head-up Display (HUD) technology can be considered as still in the initial development phase, it is proving to be of interest to large manufacturers, with prototypes of transparent displays already being presented.

With all the necessary components that provide information on the driver's position and the position of the sun relative to a reference point, the problem of finding out the center of the sun visor comes down to solving a geometric system in space. The chapter describes in detail the mathematical modeling of the digital sun visor, presenting the equations based on which the location of the sunshade on the windshield can be determined. The obtained system of equations was validated by performing simulations in MATLAB.

As the first step of the implementation process, a simulation was preferred to test and confirm the theoretical part, as well as the equations stated. Several scripts have been created to cover use cases when the driver's position is fixed and the position of the sun is movable, and vice versa. The most complex scenario, where both driver and sun have a variable position, is highlighted in Fig.8. The rays from the sun, which dazzle the driver, are drawn in purple, on the right side of the image being highlighted in green the points of intersection of the sunbeam with the windshield, i.e., the center of the digital movable sunshade. The driver's eyes are represented by a small circle. Also depicted in the figure was the windshield plane. With the coordinates of the center of the sunshade, it can be drawn, its shape, size and transparency being fully configurable by software.

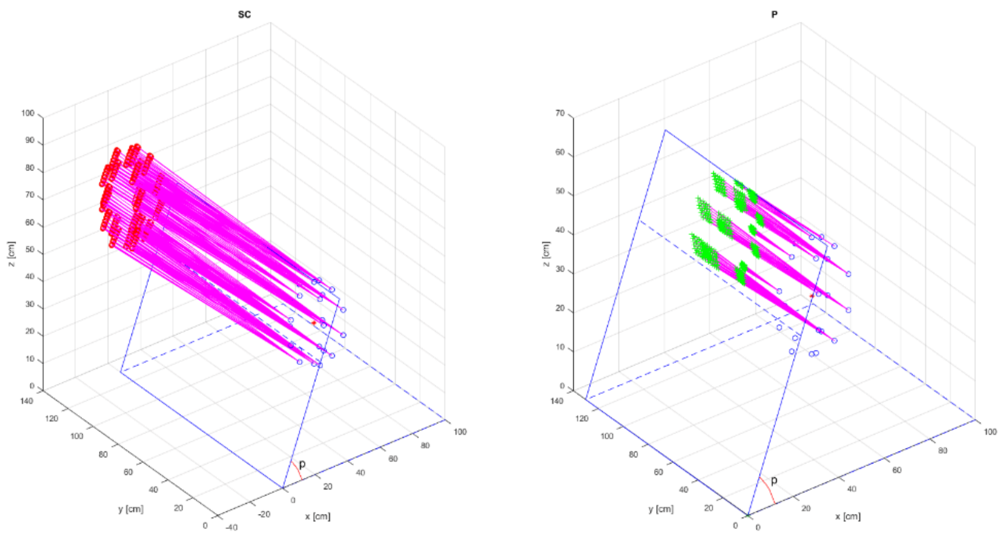


Fig. 8 Test scenario of the model of the digital sun visor.

Thus, in this chapter, a system of prevention of glare caused by the sun was laid, based on the use of as many elements as possible existing in a modern car.

# 4. Increasing traffic safety based on distance determination

Chapter 4 addresses solutions to increase traffic safety based on determining the distance between the vehicle and the elements of the environment (obstacles on the road, pedestrians, other cars, or various static objects such as poles or walls).

## 4.1. Relevance of distance determination in automotive

Many technologies used in the automotive field, especially to increase passenger safety and comfort, are based on distance measurement. Such technologies as adaptive navigation systems, automatic braking systems, obstacle detection systems or assistance systems during parking maneuvers [13], [14] are dependent on a distance measurement method. As Advanced Driver Assist Systems (ADAS) became ubiquitous on regular vehicles, automakers began using cameras in combination with other types of sensors, including ultrasound, radar and most recently, LIDAR. Radar, LIDAR and ultrasonic sensors are all active sensors that send out a signal and look for a reflection from other objects to determine how far away they are. By analyzing the phenomena and duration of signal propagation, be it a laser pulse, radio wave or sound, it is possible to accurately measure the distance to the reflecting object. The cameras' passive sensors only capture ambient light reflected from objects, without knowing where the source is. That light is captured by a two-dimensional image sensor. Most vehicles have either a single forward-facing camera or multiple clustered cameras with different focal lengths.

### 4.2. Using the LIDAR sensor in traffic safety applications

LIDAR technology is a method of determining ranges by aiming an object or surface with a laser beam and measuring the time for the reflected wave to return to the receiver. LIDAR has land, air, sea, both stationary and mobile applications. LIDAR technology is commonly used to produce high-resolution maps with applications in surveying, geodesy, geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, atmospheric physics, laser guidance, airborne laser mapping and laser altimetry. It is used to make 3D digital representations of areas on the surface of the earth and on the ocean floor near the coastal area or in the area where the ocean meets the land between ebb and flow. It has also been increasingly used in control and navigation systems for autonomous cars [15] and for helicopters or guided drones. A sensor, depending on the principle of operation on which it is built, can determine the distance by two methods. The first method is based on measuring the signal propagation time from transmitter to receiver. The second method is based on determining the phase shift between the emitted and reflected signal.

### 4.3. Environmental survey system for an autonomous vehicle based on LIDAR technology

In the first phase, the aim is to achieve a complex and fully automatic system for revealing the environment (warehouses, rooms of a building, various closed spaces), meant to assist in the navigation of automatic robots or autonomous means of transport in factories or parking lots. The need for this research is motivated by the emergence and intense growth of the intelligent car market that has led to the commissioning of autonomous vehicles for internal transport, in warehouses or companies, for goods or people. In this context, there has been an increased demand for low-cost solutions for navigating and mapping the vehicle environment. For any type of autonomous transport, including robots transporting goods to warehouses or hospitals, perception of the environment is essential, this being achieved using distance sensors and video cameras. Traffic safety for autonomous vehicles transporting people on a predetermined route can be improved if pre-built maps are available. Thus, through measurements and comparisons with map indications, the correct functioning of "autonomous driving" can be highlighted and possible new obstacles can be detected. This system [16] was achieved using LIDAR technology. To test the mapping algorithms with the help of the autonomous robotic platform, different contours were made, highlighted in Fig. 9, where the route that the robot decided to follow was also presented.

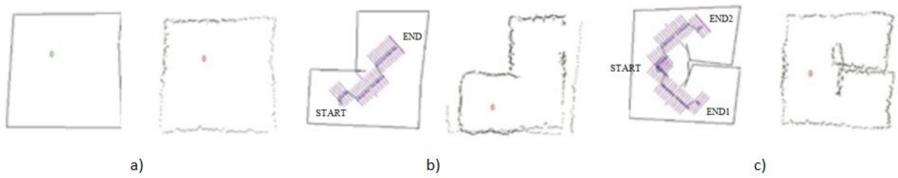


Fig. 9 Test scenarios of the mapping system based on the LIDAR sensor.

## 4.4. Use of ultrasonic sensor in traffic safety applications

An ultrasonic sensor is an electronic device that measures the distance of a target object by emitting ultrasonic sound waves and then converts the reflected sound into an electrical signal. Ultrasonic waves travel faster than the speed of audible sound (i.e., sound that humans can hear), with frequencies used being over 20 kHz. Ultrasonic sensors have two main components: the transmitter (which emits sound using piezoelectric crystals) and the receiver (which encounters sound after it has traveled to and from the target). The main disadvantage of using these sensors is given by the speed of sound used in the measurement process and its variation with temperature and humidity. Without compensation, at least for temperature, the measurement will be incorrect. Therefore, a standalone ultrasonic-only measurement solution may not be able to produce the desired performance for certain applications.

## 4.5. Using VCSEL sensor in traffic safety applications

Because LIDAR sensors are expensive, cheap alternatives were sought to make distance measurements between two elements. Thus, it is further aimed at determining the viability of TOF (Time Of Flight) sensors based on VCSEL technology to provide distance measurements that can be used for automotive applications, mainly for the purpose of guiding a driver or vehicle during the parking process. Two VCSEL-based sensors (one for reduced range, the other for increased range) were tested to determine the accuracy of measurements under similar real-world conditions [17]. The applied filtering and smoothing solutions (Moving Average Filter - MAF [18], Savitzky–Golay filter [19], Kalman filter [20]) are also presented and compared together with an integration proposal for this type of technology in the automotive sector. The measurement results and performance of VCSEL sensors are validated by comparison with other already established and widely used sensors in the automotive field.

The main disadvantage of VCSEL technology is the strong influence that light has on the results obtained, which is highlighted in Fig. 10.

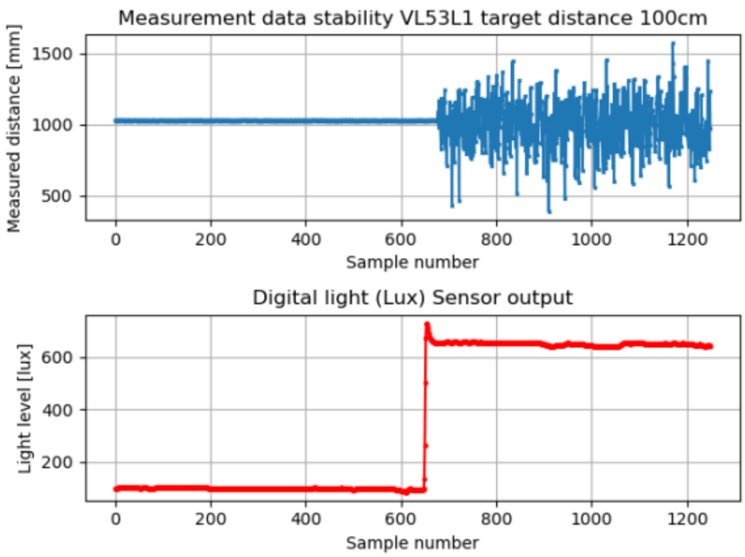


Fig. 10 Effects of a light source on VCSEL TOF measurements.

The aforementioned filters were applied to the measurements made; the performances being analyzed using the Absolute Mean Percentage Error (MAPE) [21]. The results obtained were compared with the performance of a LIDAR sensor. For the LIDAR sensor, the MAPE value was 0.63, and for the VCSEL sensor the best performance was obtained by applying a series of filters, the MAPE value being 2.1. Thus, it was concluded that the performance of a single VCSEL sensor is not enough.

### 4.6. Fusion of ultrasonic sensors and VCSEL using Kalman filter

The next step was the analysis of an ultrasonic sensor to achieve fusion between it and the VCSEL sensor. The merger was achieved using the Kalman filter, the methodology being described in the paper [22]. Each reading from a sensor is given a Kalman filter, resulting in a filtered result for each of the sensors and a dedicated error covariance matrix for each step. If the error covariance of a filter is large, then the filter's contribution to the merged value is reduced. Therefore, the outputs of both filters will contribute to the final merged value, but inversely proportional to their error covariance. In this way, it ensures that outputs with a smaller error will have a greater impact on the result. The performances obtained are presented graphically in Fig. 11.

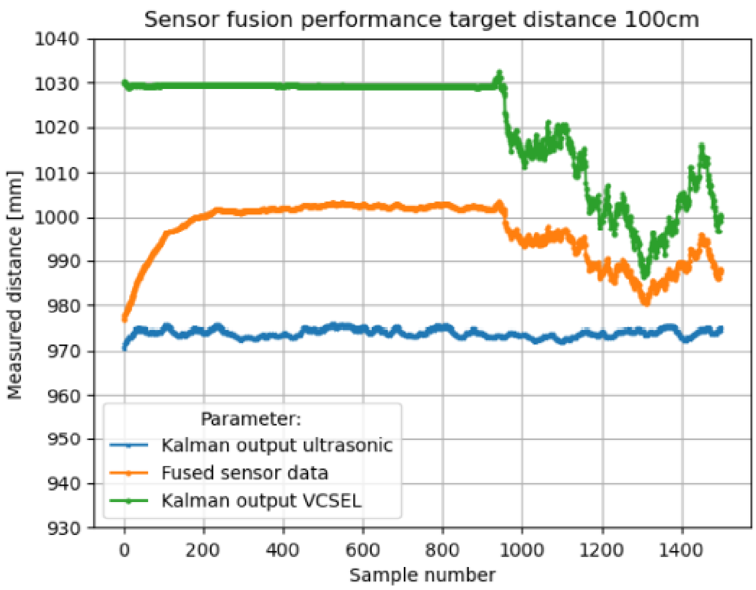


Fig. 11 Application of Kalman fusion block.

The tendency of the VCSEL sensor to overestimate distance, as well as the tendency of the ultrasonic sensor to underestimate the distance to the target object, made the fusion of these sensors have extraordinary results. The MAPE value for the fusion of the two sensors is 0.58. Therefore, by applying filters and software corrections, performance comparable to that of the LIDAR sensor (which can be up to twenty times more expensive than the combination of the two sensors) was achieved. The obtained results confirm that the disadvantages of VCSEL and ultrasonic sensors can be improved by applying well-chosen software techniques.

## 5. Increasing the safety of car traffic in foggy conditions

Chapter five contains a bibliographic study [23] on increasing car traffic safety in foggy conditions. Thus, it summarizes methods and systems found in the literature and considered relevant, which estimate or even improve visibility in adverse weather conditions.

### 5.1. Relevant methods to improve visibility

In recent years, there has been great interest in improving visibility in adverse weather conditions and especially in foggy conditions. The methods are based on image processing algorithms and can be divided into two categories: image processing using a single input image or using multiple images as input. For the case where a single image is used as input, one of the first approaches was presented by Tarel and Hautiere in [24]. Acquiring multiple input images of the same scene [25] is usually impractical in more real applications, which is why the first variant has recently received a lot of attention. Thus, the following are presented: methods based on Koschmieder's law, methods using the Dark Channel Prior principle, image segmentation using a single image/multiple input images, and methods based on artificial intelligence.

### 5.2. Methods for detecting fog and estimating visibility

Most approaches to detecting fog and determining its density to estimate visibility are based on optical power measurements (OPMs), but there are also image processing approaches. The basic principle of the methods of the first category is that infrared or light pulses emitted into the atmosphere are scattered and absorbed by fog particles and molecules, resulting in an attenuation of optical power. There are two methods of detecting the degree of attenuation, based on which the density of fog can be estimated. The first method is based on direct beam transmission, which means that the optical power of the emitted pulses is measured after the light beam has passed through a layer of fog. The second method is based on measuring reflected light when the light beam is scattered by the fog layer. Thus, methods of detecting fog based on measuring optical power by direct or reflected transmission are approached, but also methods based on image processing. Visibility estimation techniques are considered suitable for practical use to increase transport safety of any kind (road, sea, or air), together with adequate maintenance of road infrastructure (traffic management systems, road markings or various signals).

### 5.3. Sensors and systems to detect fog and improve visibility

Currently, vehicles are equipped with a lot of cameras and sensors meant to be used by some specific functionalities of the vehicle. These elements could also be used to detect fog and improve visibility. For example, Tesla Model S has 8 cameras, 12 ultrasonic sensors, and a forward-facing radar sensor with improved processing capabilities for autopilot functionality alone. Any modern intelligent vehicle, present on the roads today, is equipped with various ADAS functionalities and more. Thus, we can mention: lane marking detection systems or traffic sign recognition, warning systems in case of a risk of frontal collision, adjustment and switching of the driving or passing beam, cameras integrated with radar or LIDAR for carrying out distance measurements, etc. These functionalities are based on obtaining useful information from various sensors or cameras, information, which can still be used to detect visibility in foggy conditions.

A laboratory-made demonstrator capable of determining the density of fog based on image processing is shown. An experimental laboratory configuration was used (Fig. 12) to test and analyze different methods (under similar and repeatable conditions) and the results are compared with those obtained from human observers (under the same fog conditions). To determine a mathematical relationship between laser beam attenuation and particle characteristics, fog particles were analyzed using a microscope. The latest experiment presents a comparison between a LIDAR and a Rangefinder, demonstrating that the former can be used to estimate fog conditions. Based on all these results, a system has been proposed that gathers data from different sensors and provides more reliable results related to the visibility distance in adverse weather conditions. Using the configuration in Fig. 12, experiments were conducted to estimate the visibility distance in foggy conditions using laser and LIDAR equipment. The results of technical measurements performed with those devices were validated by the response of human subjects to visibility under the same conditions.


Fig. 12 Experimental system used to estimate visibility in fog.

The viability of the concept has been demonstrated, in relation to the critical functionalities (trace of the laser beam when passing through fog, measurement of the variation of optical power when the laser beam passes through fog, LIDAR measurement in different fog conditions, processing images containing fog) of the system for estimating the visibility distance in fog conditions, through analytical and experimental studies. Thus, in paper [26] were presented the principles of estimating the visibility distance in fog using the tracing/scattering image of the laser beam passing through the fog. The results of laboratory tests (Fig. 13 a, b) prove that the distance traveled by the beam through the fog, up to the total dispersion, depends on the density of the fog.

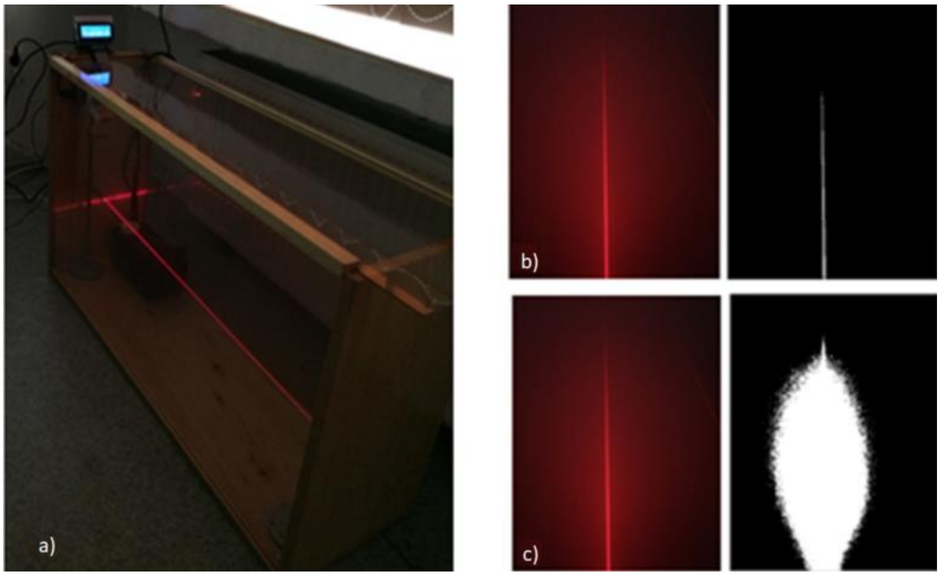


Fig. 13 a) Configuration for estimation of visibility distance based on measurement of laser trace and scattering b) Results for measuring laser beam trace c) Results for measuring laser beam scattering.

The same happens with the form of spread (Fig. 13 c), whose diameter gives information about the density of fog. The estimation of the visibility distance from the variation in the optical power of the laser beam, measured after crossing a fog area, was validated by experiments and analysis of analytical results. What's more, for the first time in the literature, the results were compared to the visual acuity of groups of human subjects reading optotypes from an eye chart under similar fog density conditions. The experimental structure made in the laboratory, shown in Fig. 12, is three meters long and has a volume of 0.576 m3. This stand has been made to be able to create a foggy environment inside it. To create fog, a fog generator was used. During experiments, the fog liquid is monitored using a scale (accurate to 0.1 g) to calculate the density of fog created inside the chamber. Visual acuity was measured in various foggy conditions using an automatic system but also with human observers. Fig. 12 shows, in addition to the overall structure (a), part of the area where the laser source transmits the light beam and the camera that monitors the decrease in visual acuity (b), the indoor fog stand (c) and part of the area with the optical receiver and the diagram with optotypes useful in monitoring visual acuity (d). The experimental aspects of validating methods for estimating the distance of visibility using image processing are developed in [27].

## 5.4. Achieved results

After analyzing the results, there is no method that surpasses all others when discussing improving visibility and fog detection based on image processing. Some methods work by increasing image contrast, others by increasing edge visibility, while others work by restoring the image. It is therefore clear that using a single camera-based method is not sufficient to ensure the reliability of a safety system installed on a vehicle. The solution might lie in using a suite of image processing methods and taking only strengths from each. Of course, the feasibility of such a system is questionable from various points of view, such as computing power, response time, costs, or increased complexity.

Given the demonstrator presented, because image transmission and storage can be problematic, a bibliographic study [28] was conducted on streamlining the process by identifying and using hybrid image compression techniques. In such a system, transmitting and storing images for processing and analysis can be a problem, especially if large files exist. Thus, to avoid various problems such as: high latency, occupying bandwidth, or system load, it is necessary to use image compression algorithms. Since only part of the image is of interest (for which it is desired to maintain quality), a hybrid compression method can be applied. Thus, two areas will be determined, the region of interest (ROI), which contains the scattering of the laser beam and the non-interest area (RONI) containing various information such as background, date of capture, location, etc. (information for which quality is not maintained). The division of the two zones can be done either by defining the boundary rectangles manually, based on statistics or experience, or by using a laser beam scatter detection algorithm. Fig. 14 shows a concrete example aimed at the principle of operation of a hybrid method (based on defining a region of interest) of image compression.

The elementary notions regarding image compression using both hybrid methods based on ROI and classical methods are presented in detail in the paper [28]. Also listed are various performance metrics used to measure the effectiveness of algorithms present in the literature. Based on the study carried out, a compression algorithm suitable for a specific situation can be chosen because it presents the latest ROI-based approaches, as well as the differences between the principles and algorithms used compared to existing classical methods. Commonly used metrics are shown to judge the quality and clarity of images subjected to the compression and decompression process. This study is oriented towards individual compression of ROI areas for automotive applications (autonomous driving, car traffic safety systems, in-vehicle systems to assist drivers) and in the medical field or telemedicine (magnetic resonance imaging, X-ray, CT, ultrasound imaging). Depending on the purpose of the applications in which the images are used, ROI selection and compression can be treated as separate problems, but both topics always require specific analysis.

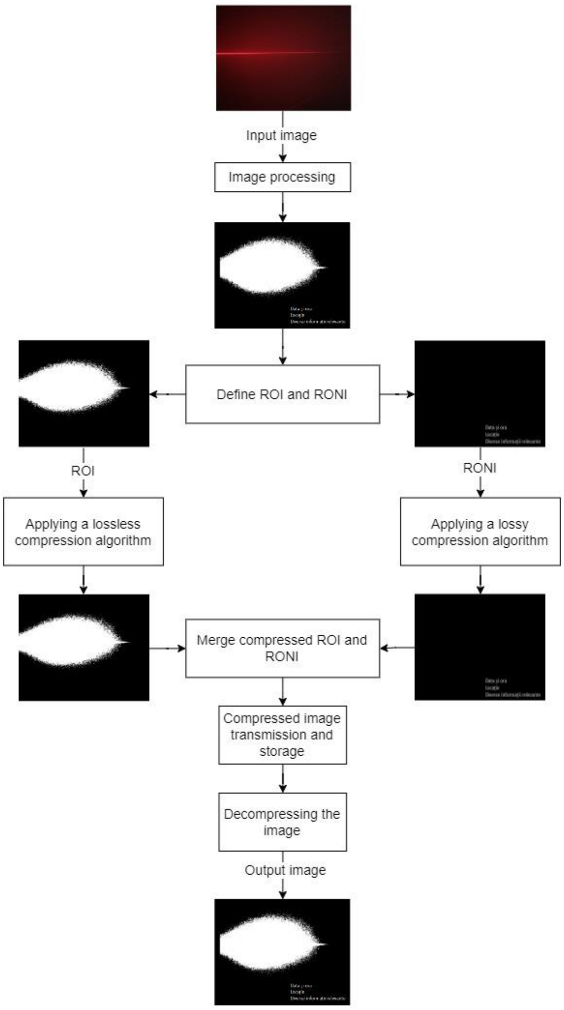


Fig. 14 Application of hybrid compression to images captured by the video camera, used to measure laser beam scattering.

# 6. Conclusions

Chapter six presents the conclusions of the research, focusing on the objectives stated at the beginning of the thesis and on their degree of achievement, validated by the scientific community through papers published in WoS indexed journals and conferences (Web of Science). Thus, each objective is debated, being presented final conclusions, details on the advantages and disadvantages of the proposed systems and directions for future research in the field.

To achieve goal number one, the following were achieved:

- A mathematical model of the digital mobile sunshade was defined, implemented and tested;
- Several scenarios were tested using MATLAB simulations to confirm the principles of such a system. Given the progress made in the field of head-up displays in recent years, it is estimated that it is only a matter of time before such technology is realized at a production cost low enough to benefit both driver and manufacturer;
- Possible solutions for concrete implementation of the digital mobile sunshade were presented, based on the technological achievements existing in the experimental stage (for now), worldwide, but difficult to access (due to costs) for a practical demonstration.

To achieve goal number two, the following were achieved:

- The importance of determining distance in the automotive field was outlined, highlighting existing safety systems that are based on precise measurements of intervals between different elements;

- A complex application for revealing the contour of the environment through which an autonomous vehicle moves, based on LIDAR technology, was presented. The need to know the area through which a vehicle travels is motivated by the emergence of autonomous platforms and the need to transport goods or personnel especially inside warehouses, hospitals or companies using autonomous vehicles or robotic platforms;
- The influence of the outside environment on the VCSEL sensor was analyzed, especially the influence of bright light. Later, corrections and filters such as MAF or Savitzky–Golay filter were applied to diminish and smooth out spikes. The merits of this work consist in analyzing the capabilities of a new sensor for the automotive industry and improving the results obtained by it through software;
- The fusion of VCSEL and ultrasonic sensors was addressed, which allowed to achieve comparable results with a sensor (LIDAR) up to twenty times more expensive than the assembly of the two sensors. Thus, technological and production disadvantages were compensated by the software component. The fusion of these sensors has proven to be extremely useful, especially in situations where the car is maneuvering at low speeds, where precision is important, such as performing parking maneuvers.

To achieve goal number three, the following were achieved:

- A bibliographic study was carried out, in which general aspects were presented regarding the increase of car traffic safety in foggy conditions. Of great importance are the estimation of the visibility distance and traffic conditions (tire condition, existing infrastructure, signaling systems, braking systems, etc.);
- Relevant methods of improving visibility based on Koschmieder's law, the Dark Channel Prior principle, image segmentation using a single input image, image segmentation using multiple input images or artificial intelligence were analyzed;
- A fog density estimation system based on the emission of a laser beam was presented, which was captured by a video camera to process and analyze light scattering;
- Hybrid image compression methods (based on the selection of a region of interest) were analyzed, and implementation examples were provided, thus facilitating efficient image transmission and storage. This analysis is beneficial for any system that relies on image processing.

Synthesizing, the research activity was supported by writing 9 scientific papers, as follows:

- Three scientific papers [7], [23], [28] published in WoS indexed journals (Web of Science), quartiles Q1 and Q2, in the field of the thesis, in which the undersigned has the quality of first author or corresponding author;
- A scientific paper [29] published in a WoS indexed journal, quartile Q1, outside the field of the thesis, in which the undersigned is co-author;
- Four scientific papers [13], [16], [17], [22] published in the volumes of scientific events (Proceedings) indexed WoS Proceedings, in the field of the thesis, in which the undersigned has the quality of first author or corresponding author;
- A scientific paper [14] published in the volume of an unindexed scientific event, in the field of the thesis, in which the undersigned is co-author.

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