

Optical Road Monitoring of the Future Smart Roads – Preliminary Results

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Abstract—It has been shown that in most accidents the driver is responsible due to being distracted or misjudging the situation. In order to solve such problems research has been dedicated to developing driver assistance systems that are able to monitor the traffic situation around the vehicle. This paper presents methods for recognizing several circumstances on a road. The methods use both the in-vehicle warning systems and the roadside infrastructure. Preliminary evaluation results for fog and ice-on-road detection are presented. The ice detection results are based on data recorded in a test track dedicated to tyre friction testing. The achieved results anticipate that ice detection could work at a performance of 70% detection with the right setup, which is a good foundation for implementation. However, the full benefit of the presented co-operative system is achieved by fusing the outputs of multiple data sources, which is the key point of discussion behind this publication.

Keywords—Smart roads, traffic monitoring, traffic scene detection.

I. INTRODUCTION

FUTURE roads will incorporate a significant amount of seamless electronics for detecting issues and incidents that potentially increase risks in traffic, intended to support safer driving. The equipment will not only run as stand-alone devices, but will interact with passing vehicles to provide early warnings and thus increase the driver's safety margin, giving him an opportunity to adapt his driving behaviour accordingly. The Safespot project¹ is committed to develop new technologies in order to provide early warnings for a driver and so prevent risky driving.

This paper focuses on optical detection methods, which ultimately enable the use of one vision system for multiple

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applications.

II. ENVISIONED ROADSIDE APPLICATIONS

A. Icy Road

In order for the system to be able to warn drivers about the potential dangers ahead, such situations need to be identified. There are various methods for detecting different kinds of events (e.g. ice on the road, fog). Two alternative approaches to perform ice-on-road detection optically are introduced in this paper. The first calculates changes in polarisation planes of back-scattered lighting [1] and the second calculates the amount of light reflected in the medium infrared band (1000 – 1600 nm).

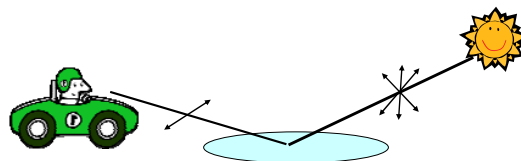


Fig. 1 Ice-on-road detection by utilising the polarisation plane changes of reflected light

When light reflects from a surface, the amount of horizontally polarised light is high compared to the vertically polarised light (see Fig. 1). For this reason drivers are also recommended to wear polarised sun glasses in order to minimise the glare from a puddle or an engine bonnet. The same phenomenon can be used to detect an icy road by subtracting the horizontally polarised light (I_h) compared to the vertical (I_v):

$$R = I_h - I_v \quad (1)$$

If the difference (R) is high, it can indicate a reflecting surface, which could be ice.

An alternative way of detecting ice on the road is to utilise light detection in the near-infrared band. The tests presented below show that ice reflects light effectively in the 1500 nm band while snow appears to diminish the reflection almost completely. The most prominent and robust approach would be a fusion of the previously presented polarisation concept with near infra-red (NIR) imaging.

B. Too-Short Headway

Vehicles driving too close to each other create a serious risk in traffic because they may not be able to react quickly enough in the case of a sudden incident, such as heavy braking by the vehicle in front. By calculating the distance between two cars, the time to collision can be measured and the information passed to the driver, who ought to then react accordingly.

Yao Jan et al. [8] have developed such a methodology for an in-vehicle system. It detects the vehicle ahead by first defining the driving environment and then locating the vehicle ahead. The approach of extracting the edges of a car can be adapted to the road side sensor system using a ready library by YangSky [3].

TrafGo SDK is a developer's kit for visual traffic systems developed by Yang's Scientific Research Institute [3]. The library provides a comprehensive set of operations to automatically recognize and understand events in traffic and to enable monitoring, measuring and controlling of traffic. Such functionality includes pedestrian and vehicle detection as well as recognizing vehicles driving in the wrong direction.

Recognition of too-short headway can be obtained with a TrafGo library, which is capable of providing the speed and position of each vehicle in a frame. Comparison of the position co-ordinates enables the identification of vehicles driving too close to each other. Of course, co-ordinates cannot be compared directly, meaning, for example, that perspective has to be taken into account.

C. Animals on Road

Animals are a considerable risk to road users due to their unpredictable behavior. Especially larger animals such as elk and deer can cause serious or even fatal accidents. E.g. in Finland in 2003, there were nearly 5000 collisions involving deer or elk. Animals are also usually on the move at dusk, during the night or at dawn, when the low light makes them hard to recognize.

Long fence installations are currently used in the northern countries to prevent animals from wandering onto the road. Research has shown that in the process of time, elks and deer in particular can learn to find the weak spots or crossing places for fences. Some gaps in the fence have been equipped with motion detection sensors to alert the drivers if animals have passed the gap. Nevertheless, these places still require a fence. [4]

A roadside sensor setup in those sectors where animal collisions occur frequently might provide cheaper solutions, particularly as prices for detectors and optics decrease. Also these kinds of installations can be moved to different places in response to animals changing their typical crossing points.

NIR and thermal imaging systems provide information that enables the detection of animals (Fig. 2). The main focus has been on larger animals, but the same methodology could be used for detecting smaller animals that could scare and distract the driver. Some car manufacturers (GM and BMW) already offer thermal imaging inside vehicles for the same purpose but as their reaction time is very short the roadside infrastructure

is likely to produce better protection.

Some challenges emerging from the use of NIR cameras need to be considered. First, rain complicates animal detection since both occur in the same wavelength region. The NIR cameras also require active lighting after dark.

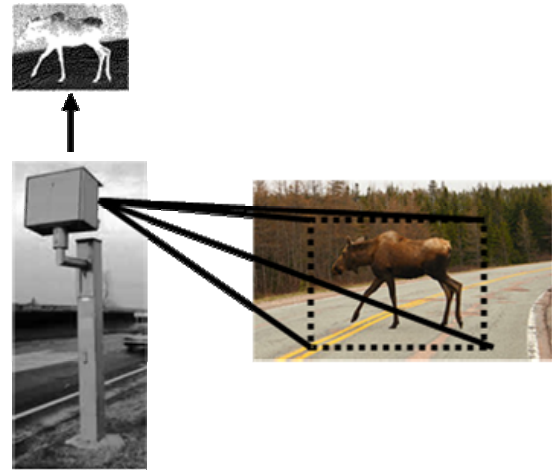


Fig. 2 Animal-on-road detection with an NIR camera and thermal imaging system

D. Foggy Weather

In the case of foggy weather, the visibility range is a critical parameter to communicate to vehicles. Unfortunately, classical visibility sensors are expensive and may not be appropriate. Indeed the small size of the diffusing volume of a scatterometer makes the measurements highly sensitive to non-homogeneities in the fog. We propose to replace these sensors with a simple infrastructure-based camera.

In daytime, the light coming from the sun is scattered by atmospheric particles towards the camera. This airlight A (see Fig. 3) increases with distance. The light emanating from an object R is attenuated by scattering. The direct transmission T of R decreases with distance. Thus, using these notations, the image intensity I in the image is given by:

$$I = T + A = Re^{-kd} + A_{\infty}(1 - e^{-kd}) \quad (2)$$

where A_{∞} denotes the background sky intensity, k the fog density and d the distance. First, assuming a flat world scene, it is possible to estimate k thanks to the existence of an inflection point in (2). In this way, it is possible to detect the presence of daytime fog [5] and to estimate the meteorological visibility distance. Second, the contrast in an image taken in fog degrades with respect to the distance in the scene. It is thus enough to compute the distance to the most distant visible picture element on the road surface to estimate the visibility range [5].

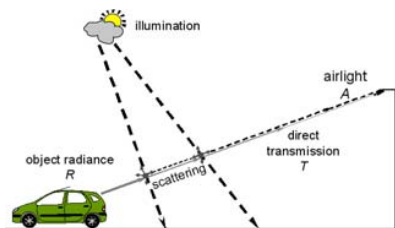


Fig. 3 Modelling of the visual effects of daytime fog

Finally, inverting (2) allows us to restore the image contrast and thus to improve the operational range of the incident detection algorithms which are using the same camera [6].

At night, fog alters the visual signal by scattering the luminous energy along a path from a light source. Part of the energy is scattered back towards the camera off-axis, adding a halo or glow of scattered light around the transmitted signal (see Fig. 4). If there is a public lighting installation in the field of view of the camera, one can detect the presence of a halo around the light sources and thus detect fog presence [9].

These solutions would be more reliable and cheaper than classical visibility sensors.

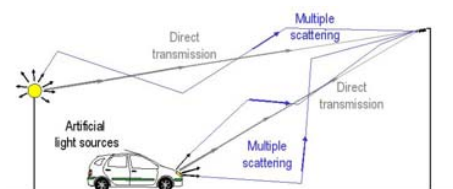


Fig. 4 Modeling of the visual effects of night fog

E. Traffic Junctions

The traffic junction monitoring for INFRASENS will be based on a co-operative pre-data fusion. It is based on wireless communication between vehicles and the infrastructure (V2I) and a laser scanner system developed by Ibeo Automobile Sensor, consisting of at least two laser scanners installed on opposite corners of an intersection (see Fig. 5). It detects road users such as cars, trucks and motorbikes as well as pedestrians in the vicinity of the intersection. In the case of larger intersections, it is foreseen that three or four laser scanner systems would be installed to keep the whole intersection under surveillance.

The applied co-operative pre-data fusion merges the laser scanner's output data with additional vehicle information, which is transferred to the INFRASENS platform using a V2I wireless communication system (see Fig. 5). It transfers not only dynamic vehicle information such as the vehicle's absolute position, velocity and heading, turn signal status and the intended route (taken from the navigation system, if available) but also static information like the vehicle's size and mass.

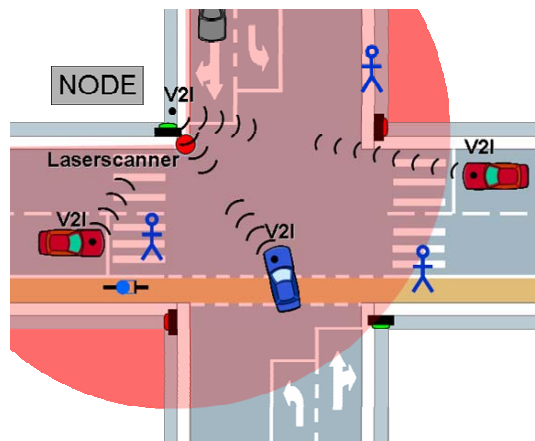


Fig. 5 Co-operative traffic junction monitoring using laser scanners and V2I data (for illustration purposes, only one laser scanner is depicted)

These different data types—not measurable by one single sensor type alone—can be fused and interpreted at a low level, leading to a more reliable and robust detection, tracking and classification of road users within the vicinity of equipped SAFESPOT intersections. This more accurate description of the current intersection scenario enables, in turn, the SAFESPOT alert applications to reliably detect safety critical situations and warn the involved road users in time.

III. SENSOR FUSION SPECIFICATION

The road environment demands much from the sensing equipment due to the eroding effect of dust, dampness, pollution etc. Sensors can also be damaged by road users as well as through road repairs and works. The camera system must be able to withstand a certain wear and tear to limit the number of maintenance operations and costs. However, when the sensor requires maintenance, repair or installation the operation should not excessively disturb the traffic flow. Also, the cost of a sensor should be reasonable in order to maximise the feasibility of widespread deployment.

The camera system needs to be robust and to work in various conditions, e.g. the same system should work for both rural roads and motorways. Further, changing weather conditions should not overly influence the performance of the system.

In order for the roadside infrastructure to produce reliable results for every task at hand, the cameras have to provide accurate data sufficiently rapidly. Some tasks have such a high degree of criticality that the traffic needs to be observed constantly, constituting yet another requirement for the camera system.

Three different kinds of cameras are planned to be utilised in addressing the aforementioned detection problems: a near-infrared camera, a thermal imaging system for animal detection, and a regular CCTV camera for ice and snow detection and for recognising overly short headway.

In terms of infrastructure, a roadside unit (RSU), which is

responsible for collecting and processing the provided data from the above-mentioned road side sensors, is under development. The aim of the algorithms running within this RSU is to support the infrastructure based applications. These applications will generate appropriate warnings and recommendations to the drivers approaching a safety critical roadside situation.

The applications and related sensor systems are linked to a highly dynamic database called the Local Dynamic Map (LDM). The LDM is fed with data by the data fusion process. As the name implies, data fusion is a technique for fusing the data of different sources in order to gain an output which could not be achieved by using only a single source of data. Within the RSU a lot of different types of data and information are collected by different types of infrastructure-based sensing technologies. Dynamic data received by means of co-operation between vehicles and the roadside infrastructure and also static data coming from different external sources need to be considered.

The main aim of fusing the data is to increase the quality of data in terms of reliability, accuracy as well as consistency. Secondly, data fusion techniques are used for closing detection gaps. The impact of a potential breakdown of a single sensor can therefore be mitigated. Thirdly, data fusion provides information that would otherwise not be available because of an inability to measure directly by a sensor or if there is no appropriate sensor technology available. E.g. if there is no appropriate sensor available, spacing between vehicles could be estimated by using their positions.

In order to achieve these goals the fusion process therefore will include object refinement, situation assessment, process refinement or monitoring, and database management [6]. The object refinement aims at combining sensor data to obtain the most reliable and accurate estimate of an object's position, velocity and other attributes and characteristics. The result of the situation refinement is a description or even an interpretation of an evolving situation based on an assessment of relationships among the objects and their relationships to the environment. The process monitoring is a metaprocess that monitors the overall fusion process to assess and improve the real-time performance of the ongoing data fusion. The task of database management is to manage the large amount of information and data relating to the data fusion system. This will include sensor data, supporting data, knowledge bases and interim processing results.

In general there are no limitations as to what types of information are used and in what ways they are fused. At each level, three different types of data fusion will be performed.

- **Competitive fusion:** This type covers the fusion of redundant sensors (two or more sensors of the same type providing the same information about an entity) to increase the reliability in the case of sensor defects.
- **Complementary fusion:** This is the fusion of two or more sensors of the same type covering a non-overlapping or partly overlapping surveillance area

to achieve measurements about objects a single sensor cannot provide. In general, the complementary fusion is complex, though promising in terms of performance optimization of environment perception within INFRASENS.

- **Co-operative fusion:** This type of fusion merges data and information of different sources to achieve information which a single sensor is not able to detect e.g. the spacing could be estimated using the position of two vehicles. Increasing the quality of the output data of a single sensor is also the task of co-operative fusion. Co-operative fusion does not mean that the information from the vehicles is integrated until now.

The task of the ongoing specification phase is to develop a suitable functional and physical architecture for this model of data fusion.

IV. PRELIMINARY RESULTS

A. Ice-on-Road Detection

The histograms below show the ice-on-road detection images, where the lane has already been segmented (the black lines depict the lane position in the test field). Fig. 6 shows how radically the light reflection from an icy surface drops when the polarisation filter is changed from horizontal to vertical. This supports well the assumption that polarisation can be used to detect ice patches on a road.

The first set of tests for detecting ice on a road has indicated promising results. Ice is visible especially in the ~1500 nm band, while snow is dismissed (Fig. 7), which provides an opportunity to extract only icy road patches and ultimately fuse that information with the polarisation scheme presented above.

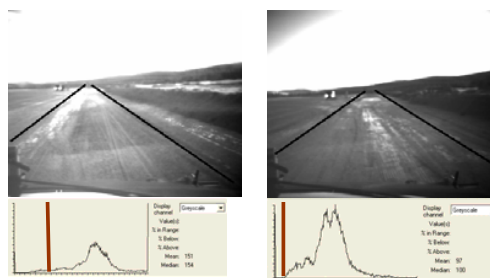


Fig. 6 The histograms of a lane with ice ahead (the brighter area in the middle of the pictures)

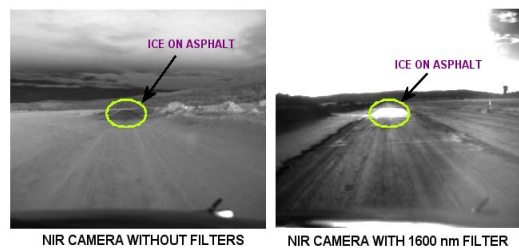


Fig. 7 Ice on road detection with utilising near infrared band

The results in Table I show differences between the horizontal polariser filter compared to the vertical one in the preliminary test sample. As the table indicates, ice reflects horizontally polarised light more than vertical polarised light, though the effect in dry asphalt is smaller.

TABLE I

THE PRELIMINARY RESULTS OF DIFFERENCES BETWEEN LIGHT DETECTED THROUGH THE HORIZONTAL AND VERTICAL POLARISER IN DIFFERENT TYPES OF ROAD SURFACES. THE VALUES REPRESENT GRAY LEVEL DIFFERENCES

	horizontal – vertical
Dry asphalt	29
Ice	59
Snow	50

B. Fog Detection and Visibility Range Estimation

To detect daytime fog, a region within the image that displays minimal line-to-line gradient variation when browsed from bottom to top is identified thanks to a region growing process. A vertical band is then selected in the detected area. Finally, taking the median intensity of each segment yields the vertical variation of the intensity of the image and the position of the inflection point. The position of the latter with respect to the position of the horizon line allows for a decision about the presence of fog. If such is the case, the algorithm computes the meteorological visibility distance. An example is given in Fig. 8.



Fig. 8 Daytime fog detection and computation of the meteorological visibility distance (red line)

To estimate the visibility range, a local contrasts computation algorithm—based on Köhler's binarization technique—is applied to the background image to compute local contrasts above or equal to 5%. This technique finds the threshold that locally maximizes the contrast between two parts in small neighborhoods in the image. The obtained contrast map contains only the static objects of the road scene. When scanning the local contrast map from top to bottom starting from the horizon line, the objects encountered are progressively closer to the camera. Consequently, the algorithm consists in finding the highest point in the contrast map having a local contrast above 5%. In Fig. 9, a sample of a contrast map above 5% is given which is computed for the image in Fig. 8.

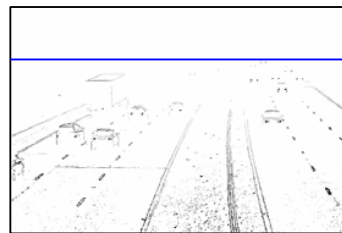


Fig. 9 Visibility range estimation (blue line)

To detect night fog, artificial fixed light sources are first located in the image. It is then enough to look at their intensity variation. If the slope is strong, it can be deemed that there is no fog. Otherwise, fog presence can be deduced. An example is given in Fig. 10.



Fig. 10 The halo around artificial light sources under night-time fog conditions can be used to detect night fog

V. CONCLUSION

The co-operative approach combines information from vehicles and the roadside infrastructure in order to perceive potentially dangerous situations. The co-operation extends the time and place horizon thus enabling the system to notice situations not detectable with in-vehicle systems alone. For example, the co-operative approach can inform the driver about an incident behind a sharp bend, or, by adding temperature and in-vehicle tyre friction measurement as a part of ice detection, it reveals those false alarms due to a wet road surface or direct glares into the camera optics.

In addition to acquiring information relevant to safety, the extension of the time horizon also improves the precision, the reliability, and the quality of driver information, as well as introducing new information sources. Basically, the extension reduces the risk of an accident as a warning received earlier gives the drivers more time to react appropriately.

Once the system has been built it will be assessed in several test sites (Sweden, Italy, Spain-France and Germany) around Europe. The test sites cover different driving environments, such as urban and rural roads. Also, different situations and scenes will be simulated so that the diverse applications can be tested thoroughly.

In the near future, important issues that need to be considered include the designing of a specification for lighting and roadside sensors, specific to the chosen detection algorithms. Lighting is a critical matter since most of the detection methods introduced here use cameras that require

good lighting to work well. Furthermore, the influence of natural lighting and passing car lights on performance need further investigation, especially in the ice detection case.

The next practical step is to develop real-time algorithms in order to detect the presented incidences. Furthermore, the data fusion algorithm needs to be developed to ensure the consistency and robustness of the Safespot applications. In sum, the preliminary results presented by this paper suggest that the possibilities for creating an infrastructure to support safer driving are more than promising.

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