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A Survey on Intelligent Vehicle Safety Systems for Adverse Weather Conditions

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ABSTRACT – Adverse weather conditions involving diminished visibility through rain, snow, fog and reduced traction as a consequence of rainy, snowy, and icy surfaces have been a major cause for traffic accidents throughout the EU in recent years. In conjunction with deficient speed adjustments and improper headway control on the part of the driver, they represent one of the chief causes for traffic accidents in Europe. Intelligent vehicle safety systems (IVSS) have the potential to improve traffic safety. The purpose of this paper is to summarize the state of the art of existing technologies and research for IVSS on the European level and to draw conclusions on the remaining challenges. It will furthermore analyze how a joint deployment of IVSS and paradigms such as car-to-car and car-to-infrastructure communication can further improve the safety.

1. PROBLEM DESCRIPTION AND MOTIVATION

According to recent studies of the European Road Safety Observatory, road traffic accidents annually claim about 43.000 lives and leave more than 1.8 million people injured. The economical damage amounts to estimated costs of 160 billion Euros [1]. Adverse weather conditions involving diminished visibility through rain, snow and fog, and reduced traction as a consequence of wet, snowy, and icy surfaces have been major contributory factors to traffic accidents throughout the EU. In conjunction with deficient speed adjustments and improper headway control on the part of the driver, they represent one of the chief causes for traffic accidents in Europe. Extreme weather conditions are responsible for 39% of all traffic accidents in Germany [2]. On Swedish roads 25% of accidents occur on wet roads, 16% on icy/snowy roads, 10% in rain, 6% in falling snow, 3% in haze/fog [3]. The accident risk on slippery roads is up to nine times higher than on dry road surfaces [4]. While the rates for other causes of accidents, e.g. drunk-driving, slowly decrease, the tendency for traffic accidents in adverse weather conditions is growing. Young, inexperienced as well as old drivers have the highest fatal accident risks during wintertime [5]. Truck drivers are also more accident prone in winter conditions, compared to the average driver [6].

A Finnish study [7], comparing drivers’ estimations of the skidding level of the road surface to information from road weather stations, concluded that the drivers had difficulties estimating road slipperiness. About half the drivers rated the road surface as being very slippery or slippery and about half as non-skidding or mostly non-skidding, independently of whether the road surface actually was skidding or non-skidding. About 65% of the drivers looked for information before the start of their trip and/or during the trip [7].

Intelligent vehicle safety systems (IVSS), being active (e.g. ESC, ABS) or passive (e.g. airbags, passenger belts) or having a direct or indirect impact on the driving behaviour have the potential to prevent accidents and mitigate the outcome of crashes [8]. IVSS can be considered as a subset of advanced driver assistance systems (ADAS) that are particularly concerned with the human safety. Even though there has been a lot of work been done with respect to such IVSSs especially in the focus of European research projects (e.g. Prevent [10], SafeSpot, SRIS [11]), some of them still ongoing, their impact on the road safety in case of hazardous weather conditions is still limited. This observation can be explained through the high purchase costs of IVSS [9] and the fact that only very few IVSSs consider the specific needs that derive from adverse weather conditions, such as diminished visibility through heavy rain, snow or fog and reduced traction. Situations like these require safety systems which notify the driver about potential hazards, possibly complemented by active headway and speed control systems.

For each driving situation there is a maximum speed value at which the driver can manage a given task. Such "appropriate highest speed" values can be calculated theoretically for every situation based on road friction, the slope of the road, curve radius and super-elevation. A reasonable criterion to calculate "appropriate highest speed" values is that the driver must be able to stop the vehicle within the same distance whether on wet and slippery roads or dry roads. The starting point for this method is the stopping distance in normal conditions and at the prevailing speed limit (presupposing that this is based on the road features) on a given road. The speed level which gives the same stopping distance on both wet and dry roads is between 82 and 92% (depending on the friction value) of the speeds on dry roads. On slippery roads these are between 50% and 74% of the speeds on dry roads [3]. Estimations based on Swedish accident data showed that if all drivers always adapt their speed to the prevailing condition of slippery road surface, the number of corresponding injury accidents would decrease by 30-85% depending on the type of road [3].

Information on the prevailing friction in adverse weather conditions therefore is of fundamental importance for IVSSs. However, there are no mature systems to support the driver to estimate friction. Systems like ABS and ESC intervene when the maximum friction is exceeded. IVSSs need input with more detailed information on friction level.

The rest of the paper is organized as follows: Chapter 2 gives an overview about commercialized IVSSs suitable for adverse weather conditions on the system level and summarizes the most recent advancements in European research projects. Chapter 3 considers IVSSs on the individual technology level. Chapter 4 finally gives the conclusions.

2. SYSTEM LEVEL DISCUSSION

IVSS, and in particular those for adverse weather conditions, can be classified as being proactive or reactive and as having a direct or indirect impact on the vehicle or the driver behaviour. Proactive systems anticipate the hazardous situation such as decreased visibility or impending reduced traction as a consequence of snow, ice, fog or rain in advance and engineer appropriate counter measures. A candidate for a proactive IVSS in adverse weather is a surface ice detection system [23]. In contrast to proactive systems, reactive systems provide enhanced control or reduce the loss of control of the situation by optimizing traction or vision. An example for a reactive IVSS is electronic stability control (ESC). A direct impact on the driver or vehicle is given if the hazardous situation of the driver can be mitigated as with ESC, ABS, and ice detection whereas IVSS with indirect impact try to reduce the risk of hazardous situations e.g. by running at certain distances to traffic in the same area such as with intelligent speed adaptation (ISA) or adaptive cruise control (ACC) or by improving the vision of the driver as with night vision systems. Table 1 classifies the various IVSS which qualifies for adverse weather conditions according these criteria.

Table 1 Classification of IVSSs for adverse weather conditions

	Reactive	**Proactive**
Direct	ESC, ABS	Ice detection
Indirect	Night vision systems	ACC, ISA

2.1 Description of existing IVSS for Adverse Weather Conditions

The purpose of ESC is detecting and minimizing skids as a consequence of reduced traction e.g. on wet surfaces by using speed active sensors on each wheel and by engineering individual wheel breaks to control under- and oversteering. ESC is often complemented by anti-lock braking systems (ABS) and traction control systems. The antilock brakes are triggered by a control unit which supervises sensors for steering wheel angle and vehicle rotation in order to keep the intended direction of travel with the actual heading. According to recent studies, ESC has the potential of reducing the number of fatalities by 17% through minimizing the loss of control [13]. In the special case of adverse weather conditions produced by ice or snow on the road surface this rate may even increase to 49.2%+-30.2% [14]. The same investigation also revealed that ESC in combination with ABS increases stopping distances on snow and gravel. It can be expected that a combination of ESC and ABS together with proactive systems will have further positive impacts on the amount of traffic accidents and fatalities.

Night vision systems (NVS) can be considered as reactive IVSS with an indirect impact by improving the driver perception in poor weather conditions. Whereas infrared NVSs are implemented by infrared light sources which enhance the vision beyond the driver perception and inform the driver about obstacles on the road infrastructure, thermographic systems use cameras to capture thermal radiation of the object and display it to the driver. Infrared systems have a limited sensing range of 150-200 m and do not work well in fog or rain. Thermographic systems on the contrary extend the range to up to 300 m and work well in cold conditions. The operation distance, however, requires further improvement to allow for better driver reaction.

Autonomous cruise control (ACC) systems primarily use radar (radar detection and ranging) or lidar (light detection and ranging) sensors to control the headway at which the car is running to the traffic ahead. Whereas ACCs provide means for safely adjusting the headway in respect to the observed weather conditions, laser sensors are known to perform poorly in these conditions while radar sensors are quite expensive, and hence prevent from mass market deployment.

2.2 Summary of the State of the Art in IVSS for Adverse Weather Conditions

The development of IVSS has made significant process in recent years and multiple systems which have been implemented as part of European funded research activities are at the verge of hitting the market. Most of these systems are primarily concerned with the passenger and vehicle safety and only few of them have addressed the complexity under adverse weather conditions.

SEFS - SEFS (Sensor data fusion for automotive safety systems) is an ongoing activity funded by the IVSS Programme in Sweden. Its primary vision is to implement an active safety system exploiting sensor data fusion to reduce cost, system complexity and number of components involved. SEFS utilizes information from all the available sensors in the vehicle and the surrounding environments to improve the driver’s safety.

The Integrated Project IP-PReVENT (Preventive and Active Safety Applications) followed a similar, though broader idea as SEFS and contributed to road safety by developing and demonstrating preventive safety applications and technologies. The preventive safety applications help drivers to avoid or mitigate accidents through the use of in-vehicle systems while taking the driver’s state into account.

As subprojects to PReVENT, WILLWARN (Wireless Local Danger Warning) and SASPENCE targeted safety-of-life applications by developing new concepts for safe speed and safe following procedures. WILLWARN developed a communication-based system that extends the driver's horizon and warns about dangerous situations ahead. Thus, the WILLWARN system provides drivers the opportunity to adapt the vehicle speed and inter-vehicle distance early, leading to a higher situational awareness of potential unforeseen danger. WILLWARN is a representative of an active IVSS with indirect impact. SASPENCE developed and evaluated an innovative system to perform a reliable and comfortable safe speed and safe distance concept, which helps drivers to avoid dangerous situations related to excessive speed or too little headway.

The IVSS project SRIS covered the development of a real-time slippery road information system. It envisioned means for drivers to adjust their driving according to prevailing road conditions through expanded road information in user-friendly devices and applications. The SRIS system collects information from existing in-vehicle sensors about the road condition (ESC, ABS) and other useful information (temperature, windshield wipers, etc.). The information is transmitted to a central database. In combination with weather information from road weather stations improved information about the road condition can be provided. In this way, SRIS combines a reactive IVSS with a direct impact with an active IVSS with indirect impact.

3. INTELLIGENT VEHICLE SAFETY SYSTEMS FOR ADVERSE WEATHER CONDITIONS AT THE TECHNOLOGY LEVEL

Research work done in European projects showed that vehicle information as well as environment information received from sensors can give estimations about weather and road conditions. By exploiting this information, current systems such as ABS, ESC and sophisticated IVSSs like ACC act more precise. In addition, the functionality of upcoming preventive and cooperative safety system applications can be enhanced in several ways. For example, atmospheric and weather conditions are essential features to be considered for computing safe speed and safe distance [15], and therefore important in terms of collision mitigation and collision avoidance.

An increasing number of passenger cars get equipped with several IVSSs to increase safety and comfort for drivers and passengers. In 2009, according to statistics from [16], 72 % of all available car model ranges in Germany offered ESC as standard equipment. Given that systems like ESC require information about the vehicles state, they come with a large variety of different sensors for yaw rate, lateral acceleration, wheel speed and steering wheel angle

[17]. Data from vehicle dynamic sensors or environmental sensors could be used to detect weather conditions and estimate tire-road friction levels.

The hope of future advanced driver assistance systems lies on the exploitation of sensors which perceive the vehicle's environment. At present, vehicle environment perception is done by radar, lidar, cameras, ultrasonic and digital maps in conjunction with GNSSs (Global Navigation Satellite System). Modern IVSSs like ACC brought these kinds of technologies to series development. Initial research work in this area shows that environment sensors can also be used for weather estimation [8].

3.1 Estimation of weather conditions using vehicle information

Conclusions on weather conditions can be drawn implicitly from ego vehicle information about vehicle dynamics and the state of certain driver-controlled assistance systems, such as windshield wipers and fog lights. The research on weather and mainly friction estimation using vehicle information has been addressed within the IVSS projects RFE (Road Friction Estimation), SRIS and within the project FRICTION, including the application in SAFESPOT and APALACI.

RFE investigated the possibilities for estimating tire-road friction by using different estimation approaches. The first approach used the self-aligning torque of tires when they are subjected to lateral forces. This torque was measured with additional steering gear sensors. Since this self-aligning torque based road friction estimation requires lateral forces of around 0.3g before a reliable estimate of the friction can be obtained, it can only be applied in special situations with enough force excitation like cornering. The second solution only used existing sensor signals on a modern car, namely the wheel speeds, the engine torque and rotation speed [18]. In the latter case the algorithm provided reliable estimation results instantly at acceleration on straight-line driving when utilizing 20-50 % of the available friction [19].

The SRIS project (see Section 2.2) was performed within the traffic safety part of the IVSS. In SRIS vehicles sent data on road conditions from existing sensors to a central database. This includes information from ABS and ESC intervention events, temperature and windshield wipers along with associated GNSS positions which are collected at a central point. The information is combined with weather information from road weather stations. As a result, SRIS showed increased possibilities to identify severe road conditions in contrast to solutions that utilize road weather stations only [20].

RFE similar approaches for vehicle information-based friction estimation have been developed in the PReVENT FRICTION project. Two complementing algorithms for friction detection were developed. The first algorithm estimated the yaw rate based on common vehicle and tire models and validated the result with the one directly measured by a yaw rate sensor. The algorithm therefore used in-vehicle standard sensors, including longitudinal and lateral accelerations, braking signal, wheel speed, yaw rate and steering wheel angle. The second algorithm estimated the friction, based on steering torque, similar to the techniques mentioned in the RFE project. The friction estimate worked well during high lateral dynamics with the first algorithm and low lateral dynamics for the second algorithm [8]. Again, the validation showed a minimum lateral acceleration for this type of friction estimate of 3 m/s^2. In addition to standard vehicle information a novel tire sensor, was evaluated. The basic idea was to find a correlation between tire carcass deformations and global tire forces. The lateral and longitudinal movement of an IR-diode, glued to the inner liner of the tire, is determined, and thus the specific point of the tire contact patch. The tire sensor technology allows recognizing aquaplaning situations [8].

In WILLWARN (see Section 2.2), two types of hazards, mainly influenced by weather conditions, have been addressed: reduced friction and reduced visibility. A simple friction estimation algorithm has been developed. It uses longitudinal and lateral acceleration as well as slip control events in turn and acceleration situations during ESC/ABS/TCS intervention. To detect reduced visibility the state of lights (front/rear fog lights and high beam), wipers, rain sensor and temperature were used [21]. The reduced visibility detection therefore relies on human activation of certain vehicle components.

3.2 Estimation of weather conditions based on environment perception

Since vehicle information only allows an implicit estimation of environmental weather conditions, they do not necessarily achieve required performance levels. Further types of sensors need to be investigated that offer a direct environment perception in a large field of view.

In the RFE project, a sensor technology for road surface analysis has been investigated. The optical Road Eye sensor unit was used. It was based on optical techniques measuring and analyzing infrared light that is reflected from the road's surface ahead of the vehicle in short distance (500-1500 mm) at different wavelengths. Laboratory tests showed that the Road Eye sensor is able to discriminate between a road surface that is dry, covered with ice or with snow. Following this classification procedure an estimation of friction was obtained from a database of probable values. From several test runs in winter conditions on prepared test tracks the "hit rate", defined as the percentage of the estimates where the measured reference friction was within the friction range obtained from the Road Eye classification, was only 60% [19]. The road surface classification achieved good results, except for wet surfaces.

Further environment perception sensors have been investigated within the FRICTION project. The project mainly concentrated on sensors which can supply classification probabilities of weather and road conditions. Friction estimation is derived from this classification and based on different studies on how different road conditions affect tire-road friction. Additional environmental sensors investigated in FRICTION were laser scanner, a polarization camera prototype (called IcOR) and radar technology. Laser scanners utilize the lidar time-of-flight method as a measurement principle and perform angular range scans. The sensing beam is for example guided over a rotating mirror. Laser scanner, such as the IBEO AS ALASCA and LUX are capable of multi target detection. With this feature, laser scanners are able to discriminate between targets like raindrops, snowflakes, fog and objects on the road. Thus, laser scanner can provide probabilities for rain and snowfall as weather conditions [8].

Another sensor used in FRICTION was the IcOR polarization camera. It makes use of differences in polarization effects at light reflection from mirror-like surfaces (ice or a wet patch). The amount of vertically polarized light compared to the horizontal plane reduces. The analysis was extended by a granularity estimation that detects smooth surfaces like ice or more granular surfaces such as snow or asphalt. However, the system does not include any dedicated illumination system, but relies on ambient illumination from external light sources. The IcOR system was able to detect icy or wet road approx. within 70-80 % accuracy depending in environmental conditions. The system is able to detect ice approx. up to 50 m in front of the vehicle [8].

A study of radar technology for road surface condition detection was also carried out in FRICTION. Measurements from a 24 GHz forward looking monostatic radar were recorded at both laboratory and field experiments. The experiments illustrated that relative backscattering is a good indicator for radar based road condition recognition. The results look promising, but further experiments and evaluations need to be applied. Current automotive radars could be modified by adding a dual polarized antenna and electronic modifications [8]. The provision of reliable friction estimates was tested in [12] and reached an availability of approximately 90% of driving time. The tests were limited to asphalt roads and a few road conditions and research work should continue to be able to cover various conditions.

4. CONCLUSIONS

Today, adverse weather conditions are one of the main contributory factors to traffic accidents. Car drivers have difficulties in estimating the road surface slipperiness and therefore to adapt their speed accordingly. If drivers would always adapt their speed to prevailing conditions of slippery road surfaces, the number of injury accidents could be decreased considerably. Intelligent Vehicle Safety Systems can assist drivers in critical situations and prevent accidents or mitigate their outcome. Largely unnoticed is that currently only very few systems are able to recognize weather conditions, while information on the prevailing friction, for example, is of fundamental importance for IVSSs. Thus, most of the current systems, being active or passive, do not consider adverse weather conditions in their acting behavior. Even though the impact of current IVSS in adverse weather conditions is positive, it is still limited.

Recent research projects on the European level showed, that by using only on-board vehicle sensors from ABS and ESC systems, the tire-road friction can be estimated at least in certain normal driving situations. However, the accuracy and availability is limited. By integrating new sensor technologies for environment perception, such as radar, lidar and camera systems, and fusing the data of all sensor types, these properties can significantly be improved. In addition to that, new sensor technologies allow an estimation of visibility and detection of situations like aquaplaning.

More research is needed on the development and adaption of sensor technologies for adverse weather conditions and the fusion of sensor data to detect and estimate weather conditions properly. The cooperative driving paradigm and use of Car2X communication therefore will be essential in future research projects. The influence of adverse weather conditions and adoption of this information in current and future IVSS must further be analyzed. On the part of the driver more investigation regarding HMI solutions respecting adverse weather conditions is necessary. To choose appropriate warning and acting strategies accurate positioning and the upcoming Galileo GNSS also need to be in focus of future research work.

REFERENCES

[1] European Road Safety Observatory: “Annual Statistical Report 2008 based on data from CARE/EC”, 2008.

[2] Federal Statistical Office of Germany: “Ursachen von Unfällen mit Personenschaden 2005-2008”, from http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Statistiken/Verkehr/Verkehrsunfaelle/Tabellen/Content50/UrsachenPersonenschaden,templateId=renderPrint.psml, 2008.

[3] Várhelyi, A. Dynamic speed adaptation in adverse conditions. IATSS RESEARCH, Vol.26 No.2, 2002, pp 52-59.

[4] Schandersson, R. The relationship between traffic accidents, road conditions and winter road maintenance. A study on accident risks in different ice and snow conditions based on insurance reports. (In Swedish) VTI meddelande 496, 1986, Linköping, Sweden.

[5] Roine, M. Accident risks of car drivers in wintertime traffic. 1999. VTT publications 401, thesis. http://www.vtt.fi/inf/pdf/publications/1999/P401.pdf

[6] Peltola, H., Rajamäki, R., Malmivuo, M. Speeds during wintertime and heavy vehicles. 2004. Report. In Finnish. Ministry of Transport and Communications Finland. http://www.lvm.fi/fileserver/Julkaisuja%2067_2004.pdf
[7] Sihvola, N., Rämä, P. Drivers' opinions about road weather conditions and road weather information – interviews during winter conditions. In Finnish. Finnish Road Administration 16/2008. 62 pp. + app. 10 pp. ISSN 1457-9871, ISBN 978-952-221-069-2, TIEH 3201096. Helsinki 2008. http://alk.tiehallinto.fi/julkaisut/pdf2/3201096-v-kuljett_kasityk_kelista.pdf
[8] Koskinen, S., Peussa, P. ed. Friction project final report. Deliverable 13 for the European Commission. 2009, Tampere, Finland.
[9] Technical Research Centre of Finland (VTT):" Intelligent Vehicle Safety Systems Offer Considerable Potential For Improving Traffic Safety", Finland, 2008. http://www.sciencedaily.com /releases/2008/12/081209085626.htm
[10] Adell, E. and Várhelyi, A. "Development of HMI Components for a Driver Assistence System for Safe Speed and Safe Distance", in Proceedings of the 13^{th} World Congress and Exhibition on Intelligent Transport Systems and Services, 2006.
[11] SRIS – Project, Slippery Road Information System, http://www.sris.nu/index_en.aspx
[12] Koskinen, S. Data Fusion Based Estimation of Tyre–Road Friction to Enhance Collision Avoidance. PhD thesis, 2009, VTT Technical Research Centre of Finland.
[13] Technical Research Centre of Finland (VTT) (2008, December 10). Intelligent Vehicle Safety Systems Offer Considerable Potential For Improving Traffic Safety. ScienceDaily. Retrieved March 4, 2009, from http://www.sciencedaily.com /releases/2008/12/081209085626.htm
[14] Burton, D., Delaney, A., Newstead, S., Logan, D., Fildes, B. "Evaluation of Anti-lock Breaking Systems Effectiveness", Royal Automotive Club of Victoria Report, Australia, 2004.
[15] Alonso M, Garayo P, Herrán L. Defining safe speed and safe distance towards improved longitudinal control using advanced driver assistance systems: functional requirements of the SASPENCE system. In: Road Safety on Four Continents.; 2005.
[16] Hummel, T., Kühn, M. "Unfallforschung kompakt: Untersuchung zur Verfügbarkeit von ESP in Pkw 2009", Berlin, Germany, 2009.
[17] Mörbe M. Fahrdynamik-Sensoren für FAS. In: Winner H, Hakuli S, Wolf G Handbuch Fahrerassistenzsysteme. Wiesbaden, Germany: Vieweg+Teubner; 2009.
[18] Svendenius J. Tire Modeling and Friction Estimation. Control. PhD thesis, Department of Automatic Control , Lund University, 2007.
[19] Andersson M, Bruzelius F, Casselgren J, et al. RFE - Road Friction Estimation. Project report, 2007.
[20] Sjölander P. SRIS - Slippery Road Information System. Project report, 2008.
[21] Noecker G et al. WILLWARN. Final project report. 2007.
[22] Wi-Roads project – Mobile WLAN Systeme, University of Rostock, Germany, http://wwwra.informatik.uni-rostock.de/103.0.html
[23] Jokela M, Kutila M, Le L. Road Condition Monitoring System Based on a Stereo Camera. 2009:423-428.