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Distributed Simulation Architecture for the Design of Cooperative ADAS

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ABSTRACT: It now seems essential to take into account the information concerning the distant road environment. This extended perception is necessary to ensure an efficient capacity to predict events and thus to react appropriately. Moreover, information should not be managed only on surrounding moving objects (local perception) but also on both the configuration of the distant road infrastructure and the weather conditions in which the different actors of the road system evolve. This implies to develop and to implement of cooperative systems combining embedded processing, processing on the infrastructure (road side unit) and communication media to make the link between the different information sources. In this paper, this type of cooperative application is presented in the framework of the DIVAS's project. Moreover, a dedicated distributed virtual architecture is proposed in order to prototype, to test and to validate such type of cooperative application.

KEY WORDS: Perception, Risk assessment, Cooperative system, Distributed simulation architecture, Sensors simulation.

1. Introduction

To address the problem of road safety and risk reduction, many studies have been conducted since over 10 years. The first step in the development of these solutions was to be able to develop the most efficient driver assistance functions. These functions whether they active or informative rely on sensors and information sources which are embedded in the vehicles. The main objective of these safety applications was to properly react to close and unexpected events (collision avoidance, lane departure avoidance ...). However, most of these applications must be very reactive and rely only on a limited capacity to anticipate events. This is mainly due to the short range of the exterioceptive sensors embedded in the vehicle (camera, laser scanner, radar ...), their rate and the processing time of the different algorithms which rely on them. For these reasons, it now seems essential to take into account the information concerning the distant environment. This extended perception is necessary to ensure an efficient capacity to predict events and thus to react appropriately. Moreover, information should not be managed only on surrounding moving objects (local perception) but also on both the configuration of the distant road infrastructure and the weather conditions in which the different actors of the road system(vehicle, motorcycle ...) evolve. This implies to develop and to implement cooperative systems combining embedded processing, processing on the infrastructure (road side unit) and communication media to make the link between the different information sources. The French DIVAS project addressed this issue by taking into account the geometry of the infrastructure and the weather conditions, in order to warn properly the drivers in case of an incoming risky area. The DIVAS project in shortly presented in section 2. In the section 3, we present a simulation software architecture allowing implementing quickly and efficiently this type of complex cooperative distributed application. In this simulation platform, the processing is distributed on several computers dedicated respectively to in-vehicle processing (embedded architecture) and roadside processing (architecture on the road infrastructure). Communication between these different computers is used to send warnings and information between the different actors of the scene. The presented application estimates the visibility conditions in a specific area and warns the driver in case of an inappropriate behaviour. To validate this virtual architecture, some results in real conditions with actual data using the same application will be shown in section 4.

2. Context of the research: DIVAS project

2.1 Context and objective of the DIVAS project

The DIVAS project (Dialog between Infrastructure and Vehicles in order to improve the road Safety), has for main goal to design and to prototype an exchange information mechanism between the infrastructure and the vehicles in order to provide to drivers an integrated index dedicated to the self safety all along a road route. This index must take into account the road surface state, the current weather condition, and the road surface geometry. The DIVAS project has developed the full system and has studied the different consequences of such a system (figure 1). This evaluation has been made not only on a technological point of view but also with a sociological aspect (acceptability, credibility).

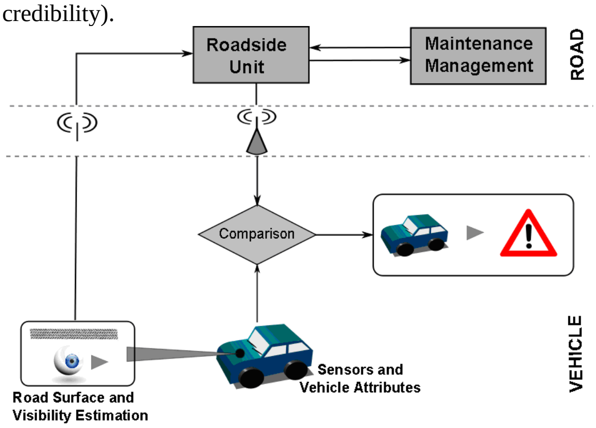

Fig. 1. Overview of Vehicle/Infrastructure Integration in the DIVAS Project.

The following sub section presents the technological aspects and challenges tackled in this project. These aspects are focused on:

- The infrastructure with the processing of the weather conditions.
- The vehicles with the embedded sensors processing and vehicles control.
- The merging of the different information coming from both the infrastructure and the vehicles

2.2. Meteorological Visibility

Definition

Fog is thick cloud of microscopic water droplets suspended at ground level. When light propagating in fog encounters a droplet, the luminous flux is scattered in all directions. The amount of energy that is lost along the way is described by the optical density k, known as the extinction coefficient. It depends on the droplet size distribution and the concentration. The proportion of energy transmitted between two points in fog is known as the transmissivity T and decreases exponentially with distance d (Beer Lambert's law):

$$T = e^{-kd} \quad (1)$$

The effect of light scattering in the presence of fog is to modify this information by an overall reduction of contrasts as a function of distance. This effect is generally described by the meteorological visibility V_{met}, defined as the greatest distance at which a black object can be recognized in the sky against the horizon (CIE, 1987). Using (1) with a contrast threshold of 5% yields the following approximate relation between V_{met} and the extinction coefficient k:

$$V_{met} \approx \frac{3}{k} \quad (2)$$

Road Meteorology

According to [1], the road visibility is defined as the horizontal visibility determined 1.2 m above the roadway. It may be reduced to less than 400 m by fog, precipitations or projections. Four visibility ranges are defined (<50, 50-100, 100-200, 200-400).

2.3. Data Sources on Meteorological Visibility

Roadside Sensors

Road Visibilitymeters

Devices were developed for road applications, primarily for conducting measurements under conditions of thick fog. They enable quantifying the light scattered within a sufficiently wide and well-defined solid angle [2]. In order to carry out such measurements, a light beam is concentrated on a small volume of air. The proportion of light being scattered toward the receiver would then be:

$$I = AI_0 Vf \;\theta\; e^{-kd} \quad (3)$$

with I the intensity scattered in the direction of the receiver, A a constant dependent on power and source optics, I_0 the source intensity, V the scattering volume, f(θ) the value of the phase function in the θ direction, k the extinction coefficient and d the length of the optical path between emitter and receiver. Generally speaking, the optical path d is small and the transmission factor e^{-kd} is assimilated to 1 and f(θ) is proportional to k, with () thereby becoming:

$$k = \frac{1}{A'}\frac{I}{I_0} \quad (4)$$

where A' designates a constant that depends on device characteristics. According to [3], the accuracy of such sensors is about +/- 10-20\% over the field range. On the other hand, the small size of the scattering volume makes measurements highly sensitive to non-homogeneities in the fog. Moreover, such sensors are not able to run other applications, contrary to a video-surveillance system. This is the topic of the next section.

Road-Side Camera

The apparent luminance of the road surface L is given by Koschmieder's law [4] which adds to (3) a second term corresponding to the atmospheric veil:

$$L = L_0 e^{-kd} + L_f (1 - e^{-kd}) \quad (5)$$

where L_0 denotes the intrinsic luminance of the object and L_f the atmospheric luminance.

Assuming that the road is locally planar, the distance of a point located at the range d on the road can be expressed in the image plane assuming a pinehole camera model by:

$$d = \frac{\lambda}{(v - v_h)} \quad (6)$$

where $\lambda = \frac{H\alpha}{\cos(\theta)}$ and $v_h = v_0 - \alpha\tan(\theta)$. θ denotes the pitch angle of the camera, while v_h represents the vertical position of the horizon line (see Fig.2). The intrinsic parameters of the camera are its focal length f, and the size t_p of a pixel. We have also made use herein of $\alpha = \frac{f}{t_p}$. H denotes the sensor mounting height. In a foggy image, the intensity I of a pixel is the result of the camera response function f applied to (5). Assuming that f is linear, (3) becomes:

$$I = f(L) = Re^{-kd} + A_\infty (1 - e^{-kd}) \quad (7)$$

where R is the intrinsic intensity of the pixel, i.e. the intensity corresponding to the intrinsic luminance value of the corresponding scene point and A_∞ is the background sky intensity. After a change of d according to v (), one obtains the following by taking the second derivative of I with respect to v:

$$\frac{\partial^2 I}{\partial v^2} = 0 \Rightarrow k = \frac{2(v_i - v_h)}{\lambda} \quad (8)$$

where v_i denotes the position of the inflection point of I(v). V_{met} is deduced using (). To be able to solve (8), we need to segment the road surface. In this aim, we apply a three steps process:

- Computation of a background model of the scene to filter all moving objects on the road surface
- Manual rough segmentation of the road area to reduce the search area
- Adaptive region growing in the background model restricted to the manually segmented area

Having the road surface, measuring the median intensity on each line of the area of interest allows to obtain I and then compute its inflection point v_i. A full description of this process is proposed in [5]. A sample result is given in Fig. 3.

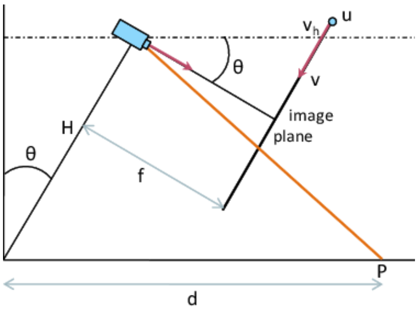

Fig. 2. Modeling of the camera within the road environment. v_h: image line corresponding to the horizon line in the image.

Fig.3. Daytime fog detection by roadside camera: (a) fine weather daytime image; (b) daytime foggy weather: meteorological visibility distance estimation represented by the horizontal red line.

In-vehicle Sensors

Fog Lamps Status

Front fog lamps are intended to increase the illumination directed towards the road surface and verges in conditions of poor visibility due to rain, fog, dust or snow. As such, they are often most effectively used in place of dipped-beam headlamps, reducing the glare back from fog. Based on [6], the usage of fog lamps during daytime increases with deterioration in weather conditions, with the usage reaching 50% of all installed fog lamps during moderate-to-heavy fog. This indicates that, during daytime, drivers adjust the usage of their lamps in response to weather conditions, which is not the case in night-time. Based on these statements, the status of the fog lights can be considered as a fog sensor in daytime.

Camera-based Sensor

The principle of this sensor is the same than in the road-side system. However, the implementation as well as the accuracy of the system are different. First, the camera is moving. No computation of the background model and no manual segmentation of the road surface are possible. We used the implementation proposed in [7]. Second, the expected accuracy of camera sensors is not so good than the road-side camera we specified. Indeed, the classical resolution of automotive cameras is smaller (640x480), as well as the mounting height of the sensor (≈ 1.4 m).

Fusion of Data Sources

The roadside camera along with the aforementioned processing algorithms is the main RSU environmental sensor. Data which comes from passing vehicles (e.g. wipers status, fog light status…) are complementary. To give a coherent view on the visibility conditions in the vicinity of the RSU, we need to fuse the different data sources.

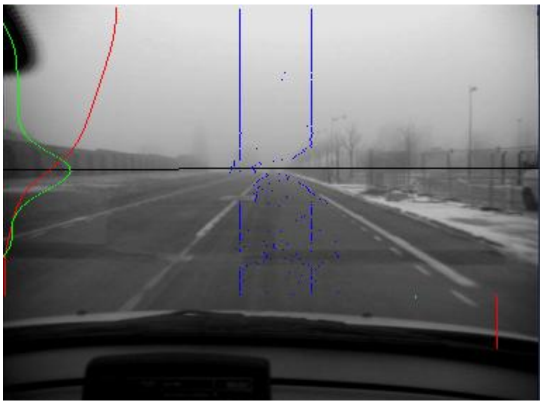

Fig. 4. Fog detection and characterization by in-vehicle camera. The visibility distance (V_{met}=125m) is depicted by the horizontal black line.

In this aim, the visibility range is then the spatial barycenter of the different sensors outputs. The corresponding uncertainty of the measurements is the sum of:

- The uncertainty of the sensors themselves.
- The uncertainty coming from the distance to the data sources.
- The uncertainty coming from the status of fog lamps of the vehicles on the road section.

The interesting reader is referred to [8] for the technical details of the method.

2.4. Data Aggregation for Advisory Speed Determination

Knowing that low speed crashes and high speed ones should not be considered as equally dangerous, the method accounts for potential severity of crashes using a generic scenario of accident and curves relating speed at the instant of crash to severity of injury. The static, semi-static and dynamic information are thus fused onboard in real-time. The reference speed is modulated depending on environmental and geometric highway characteristics. The difference in speed is determined so that the global injury risk is the same in adverse conditions as in ideal conditions [9].

Existing approaches have been proposed by [10] and [11] and consists in computing the driving speed which allows the driver to stop completely his vehicle before hitting an obstacle. This strategy has three main limitations. First, an obstacle may be located anywhere or in case of emergency braking the driver may run off the road and hit a closer obstacle. Second, this approach is too cautious since it aims at preventing every contact with a potential obstacle. Third, by adapting such a cautious approach, resulting speed can be very low. The consequence is a low efficiency of the system since the drivers will not follow the recommendations (Blum, 2006).

The risk is usually defined as a combination of incident probability and severity. A generic scenario of accident is defined: during an emergency situation, the driver performs an emergency braking and may hit a rigid obstacle. An equiprobability of hitting the rigid obstacle is assumed. If accidents at difference distances occur, the gravity of each incident can be estimated knowing the speed at which the incident occurs. The vehicle is assumed to be completely stopped after having hit the obstacle, delta-V being the speed at which the incident occurs. Delta-V is good indicator of the severity of the incident for the vehicle driver. Crash severity statistics proposed by [12] are used, which link the severity of accidents with delta-V in case of frontal collisions.

By combining emergency speed profiles and the crash severity statistics proposed by [12], the probability of being slightly injured, heavily injured or killed with respect to the distance can be estimated. The initial speed of the driver is modulated in degraded road conditions so that the total risk remains the same in degraded road conditions as in reference conditions. In this aim, the V85 speed profile is considered as a reference speed along a road itinerary in ideal conditions (dry road, good atmospheric visibility) for a vehicle which is not constrained by the traffic (i.e. its time headway is greater than 5 seconds). The probability of being killed in reference conditions is plot in green.

This strategy, which has been explained so far for a single point, can be extended to a complete itinerary [9]. At each moment, the advisory speed is determined by taking into account the actual road conditions so as to maintain the safety margin of the driver. Fig. 5 shows the results obtained along an actual road itinerary. The V85 speed profile on a dry road is shown in green. The advisory speed is shown in dotted blue lines. The speed based on the cautious approach of [10] or [11] is shown in gray.

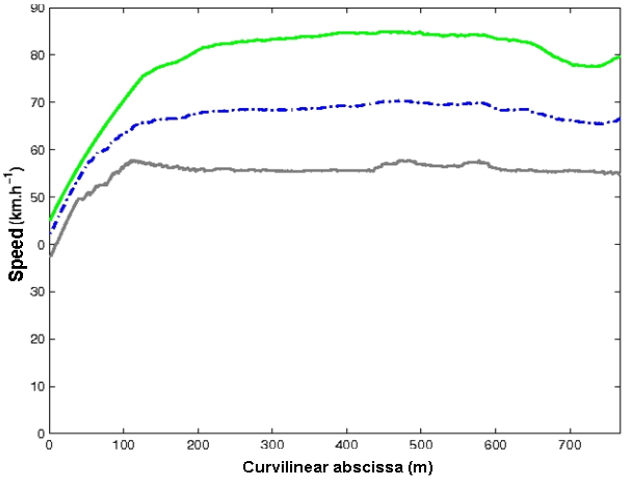

Fig. 5. Speed profiles observed or computed. Green curve: V85 speed profile observed on a secondary road. Dotted blue line: our advisory speed. Gray: cautious approach.

3. Distributed Simulation platform for ADAS prototyping

3.2. The SiVIC platform

For several decades, we observe an increasing number of research projects focused on road safety improvement and risk reduction on dangerous driving area. In a first time, these researches were mainly focused on vehicle local perception (perception granted by embedded sensors) and on vehicle capacities to react to an unsafe situation.

For some years, it clearly appears that local perception is not sufficient. Its extension is become essential to minimise risks and maximise driving safety. To achieve such improvement in driver assistance, it is essential to deploy new technical means, not only on vehicles but also on infrastructure. Unfortunately, this kind of deployment is often long, difficult and expensive.

That's why it appears inevitable, in the first step of driving assistance conception, to use simulation platforms. They allow modelling of unsafe driving situation and embedded technical means in vehicles (sensors, telecommunications, and displays). The aim of this kind of platform is mainly to provide needed virtual means required to prototype and evaluate new driving assistance (local perception, distant perception, vehicle control, inter-vehicle communication, and vehicle-infrastructure communication).

These virtual prototyping platforms are required to provide the following functionalities:

- Simulation of road environment.
- Simulation of embedded sensors.
- Simulation of telecommunications.
- Realistic modelling of mobiles (vehicle, motorcycle, pedestrian, ...) .
- Simulation of weather condition (rain and fog) (fig 6)

The "*Simulation of Vehicles, Infrastructure and virtual embedded sensors*" (SiVIC) was developed at LIVIC (IFSTTAR) to meet these objectives [14].

Fig 6. SiVIC platform: degraded weather conditions

Currently, the platform SiVIC is operational and user-friendly, providing a large set of functionalities which allow a fast driving assistance prototyping using a large variety of embedded sensors. Indeed, this simulation platform can reproduce very accurately the reality of driving situations, the physical behaviour of vehicles and embedded sensors in vehicle (see figure 7)

.

Fig 7. SiVIC platform: modelling and simulation of embedded sensors.

SiVIC also provide a powerful platform to evaluate reliability and robustness of perception or control algorithms. By allowing real-time experiment and extreme driving scenario, innovative approach for ADAS and PADAS conception can be complete without expensive implementation.

Moreover, SiVIC can be used to efficiently present research objectives in a professional way. It can also be used in a large

variety of domain to study any kind of problematic. The interconnectivity of SiVIC platform and RTMaps one provide a solid framework to advanced prototyping, perception algorithm validation and control system. Indeed, this coupling allows the fast and complete development of applications such as Software In the Loop (SIL) including virtual vehicle prototype with embedded proprioceptive and exterioceptive sensors. The real-time information coming from vehicles and sensors are provided by SiVIC to RTMaps. In RTMaps, this information can be used as input for perception or command algorithms. In the same way, instruction can be send from RTMaps to a virtual vehicle in SiVIC in order to control it. This chain design is particularly efficient since the algorithms developed in RTMaps using SiVIC data can be directly integrated in real hardware. Then virtual materials are likely to be considered very close to real hardware (real vehicle, real sensors).
There is no doubt that a platform like SiVIC coupled with RTMaps represent a real advantage in the first steps of driving assistance conception. This kind of software solution provides an undeniable support in development of complex, cooperative and advanced systems (Vehicle-vehicle, vehicle-infrastructure). Some of these applications, prototyped with the SiVIC platform, have presented in [15].

3.3. A distributed solution for complex prototyping

The proposed solution relies on a data distributed architecture in which SiVIC instances share state vector objects:

- A SiVIC instance in charge of an aspect of the simulation (for instance the vehicle model) publish on DDS the corresponding state vector;
- Another instance which needs this information retrieves from DDS the corresponding state vector.

The data distributed mechanism has been developed in an external C++ library called "*libdds*". This library manages the publication and subscription to raw data frames (octet arrays). A DDS data is identified by IP address or DNS alias of computer which publish it and a name as string. We can notice that the DDS library can also be used to share information other than state vector of SiVIC entities (sensors, etc...).
"*libdds*" relies for network communication on C ENet (http://enet.bespin.org) and operates on peer-to-peer logic: each computer is as a client which consume information as a server publishing information on DDS. The choice of using ENet provides lower latency than TCP, minimizing desynchronization between SiVIC instances and provides a larger flexibility on quality of service management (optional frame robustness, etc). "*libdds*" also provides improved communication performance inside a same computer by using IPC mechanisms. The raw data frame exchanged with DDS by SiVIC are managed by a new plug-in "*sivicDDS*" which manages, for an instance of SiVIC in which it is deployed, the listing of all simulated states that we wish to publish on DDS or we wish to retrieve form DDS. The general architecture is presented in the following scheme (figure 8). The red arrow indicates the publication of data on DDS, and the blue arrow represents the consumption of shared data.

3.4 Event management

In order to manage and to handle possible events coming from the result of algorithms, an event mechanism and event variables have been implemented. These events can be used both from SiVIC or from an external application like RTMaps, Matlab or third party applications. In this paper, only two specific events will be used: the *ddsless* and the *ddsgreater* events. These two variables will allow to control a variable message sign in SiVIC from an application implemented in RTMaps. This application provide an order in relation with the current level of road visibility (figure 9). In this case, the event source could be called "visibility". Several differents symbolic event name can be defined in same time.

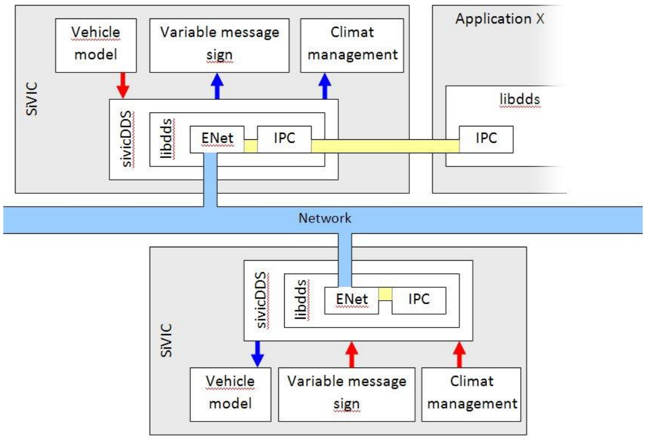

Fig. 8. Distributed architecture: DDS bus

Fig. 9. Control of the Variable Message Sign from a Road Side Unit and the « *visibility* » event.

1. Application in DIVAS context

4.1. General simulation architecture

In the DIVAS project, the global real architecture has been implemented in real area. A part of the expected functionalities have been presented in the section 2. But in order to prototype, to test and to validate this set of functionalities, a distributed virtual architecture based on the SiVIC platform has been assembled. This virtual platform had for main task to demonstrate and to prove the relevance, the efficiency and the reliability of the DIVAS's functionalities in a controlled environment. In this paper the high level application consist to alert the driver in order to adapt the vehicle speed in function of the current visibility.
The demonstrator must implements 2 instances on two different computers. The 2 computers are link with a generic network handling the intern objects and resources of SiVIC (fig 9):

- The first computer centralizes the processing made on the infrastructure (sensors in the infrastructure, weather condition management, variable message sign) and for the road traffic;

- The second computer take in charge the processing dedicated to the ego-vehicle as well as the embedded functions.

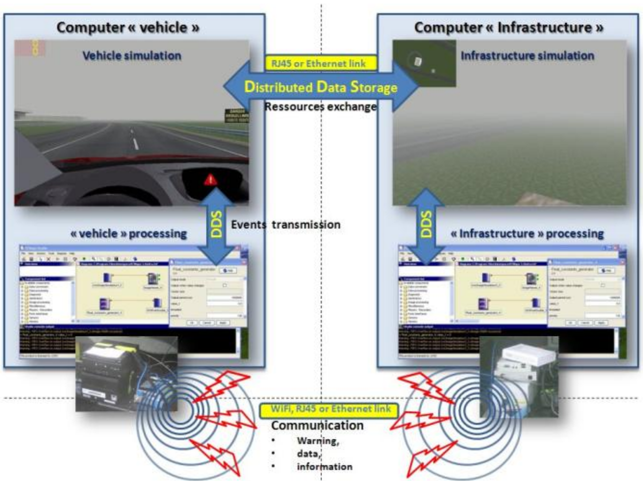

Fig 9. Safe speed results from previously detected visibility distance

In the infrastructure, a camera detects the level of visibility by foogy condition and provides an alert with the activation of a variable message sign. Moreover, the application in the Road Side Unit sends an alert message toward the ego-vehicle.
In the ego-vehicle, a message can be received from the Road Side Unit, but an embedded architecture can also provide the same type of information on the visibility level. From this information, a control/command device will provide an order to the embedded actuator of the vehicle in order to adapt the vehicle speed according to the current visibility. This application is presented in the next section.

1.2. Speed profile computation

As described before, the problem with the association of a speed recommendation is twofold. First, we need to define a safe speed to cross the difficulty associated with the fog. Next, the driver must be warned before arriving on the difficulty to adapt his speed safely. So we define a safe speed profile.

Definition of a safe speed

The worst event that could be considered, in order to define a safe speed, is an appearing, none moving, obstacle at the visibility distance. Once the obstacle appears, the driver, after a given reaction time T_r, brakes with a strong deceleration γ, here positive. Then the stopping distance, D_{stop} could be expressed as:

$$D_{stop} = V_0.T_r + \frac{V_0^2}{2.\gamma} \quad (9)$$

where V_0 is the speed of the vehicle when the obstacle appears. However the previous equation, commonly used to evaluate stopping distance, could be questionable, especially that foggy condition is often associated with a wet road, so a decreased road friction. We will now describe the assumptions that are made, and explain if they are reasonable.

This equation is a simplification from:

$$D_{stop} = V_0.T_r + \int_{tV=V0}^{tV=0} V_0 - \gamma(t).t.dt \quad (10)$$

The deceleration of the vehicle is mainly generated at the tire road interface. The force is generated by the difference between the speed of the vehicle and the speed of tire, τ. The first question for a strong braking is that the vehicle is equipped, or not, with an ABS (*AntiBlockierSystem*) that could regulate the braking action optimally. If the vehicle is not equipped then the braking goes up to a blocked tire which decreases considerably the performance. Most of the modern vehicle are now equipped with an ABS. Moreover, European car manufacturers have decided, since 2004, to equip new vehicles with it and it becomes mandatory in 2011. We then make the assumption that the vehicle is equipped. The second hypothesis is that the deceleration is constant in time. Burckhardt, in [19], described the mobilized friction, μ during a braking as:

$$\mu = (c_1.(1 - e^{-c_2.\tau}) - c_3.\tau).e^{-c_4.\tau.V}.(1 - c_5.F_z^2) \quad (11)$$

where F_z is the normal force. So, even with a constant longitudinal slip τ and a constant normal force, the mobilized friction depends on the speed of the vehicle. During a strong braking, this mobilized friction increases in time. It is a conservative hypothesis to consider the deceleration as a constant, below the maximal possible deceleration. So, in the following, we will use equation (9) to describe the stopping distance. In order to avoid a collision, this stopping distance must be below, or at the limit, equal to the available visibility. The maximal speed is then:

$$V_{vis} = -T_r.\gamma + \sqrt{T_r^2.\gamma^2 + 2.\gamma.D_{vis}} \quad (12)$$

The figure 10 shows the value of the safe speed for previously detected visibility distance. The reaction time is set at *1.2s* and the maximal deceleration at *0.5g*. On an usual French countryside road, the maximal legal speed is *90km/h*. The road portion between the position *800m* and *1600m* presents a safe speed that is lower than the normal legal speed.

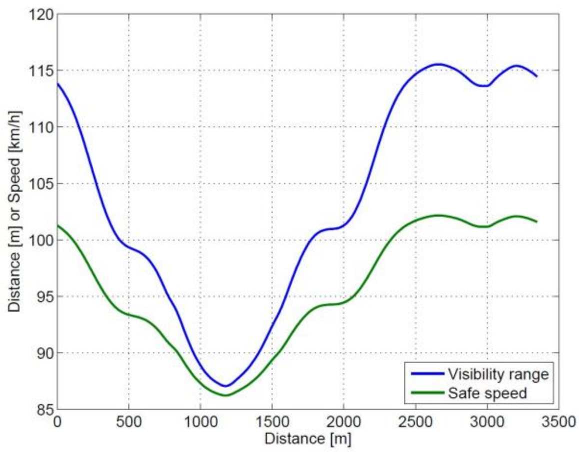

Fig 10. Safe speed results from previously detected visibility distance

Definition of a safe speed profile

In order to define a safe speed profile to reach the speed defined previously, we have to take into account several parameters describing the road surface, the vehicle dynamic and the driver behavior. The safe speed profile is computed using the equations described in [20]. However, the process is modified in order to take into account the visibility distance and the speed associated. First, the limit condition is computed from both visibility distance condition (V_{vis} in equation (12)) and the safe dynamic condition:

$$V_{dyn}^2 = \frac{g}{\rho}.\left(\left(1 - \frac{H}{L_f}\right).\mu_{lat}.\sqrt{1 - \frac{\theta}{\mu_{lon}}} - \emptyset\right) \quad (13)$$

where ρ is the curvature of the road at the considered position, θ is the slope of the road and ϕ the bank angle. μ_{lat} and μ_{lon} are the desired mobilized friction, respectively in lateral and longitudinal. H and L_f are the vehicle center of gravity height and distance from the front axle. For common light passenger car, the ration is around 0.5.

The speed profile and the deceleration profile are evaluated using the following differential form:

$$1 = \left(\frac{1}{\mu_{lat}} . \frac{\frac{\rho . V^2}{g} + \emptyset}{1 + \frac{H}{L_f} . \left(\frac{V}{g} . \frac{d.V}{ds} - \theta\right)}\right)^2 + \left(\frac{1}{\mu_{lat}} . \left(\frac{V}{g} . \frac{d.V}{ds} - \theta\right)\right)^2 \quad (14)$$

Then the defined safe speed profile now take into account the visibility distance, the road geometry, the road friction and the driver behavior. In the Figure 11, the resulting limit is defined as the minimal speed between both evaluated speeds. All needed data could be provided by the eHorizon (road geometry), sensors on the infrastructure (visibility distance) or set by the user (driver behavior).

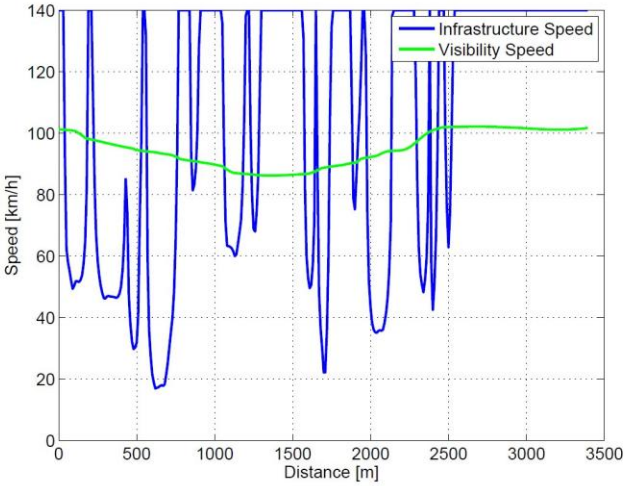

Fig 11. Combined Safe speed and visibility speed

2. Conclusion and future work

In this paper, the prototyping of complex application is tackled. The cooperative system presented is based on the development carried out in the DIVAS project. The goal of this project was to design and to prototype an exchange information mechanism between the infrastructure and the vehicles in order to provide to drivers an integrated index dedicated to the self safety all along a road route.

All stages about this work have been presented both in a real context and in a virtual approach. From the SiVIC platform, we have shown that the prototyping of shared and distributed processing (on infrastructure and embedded in vehicles) is possible and efficient.

This virtual architecture is sufficiently complete and enough powerful in order to prototype, to test and to validate complex and extended cooperative applications.

In this virtual platform, every stage needed for the design of cooperative application is available from sensors simulation, perception algorithm development, data and information communication to the vehicle control and automation.

Moreover, in order to quantify the quality of the developed application, several virtual ground truth sensors are also available. This ground truth also allows validating the data coming from virtual sensors and dynamic objects.

The future work will be mainly focused on the interaction between real and virtual environment. For instance, it will be interesting to have the capability to mix in same time data coming from real and virtual sensors.

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