IWAY: Towards Highway Vehicle-2-Vehicle Communications and driver support

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Abstract—This paper describes a novel Alert Manager which merges information coming from: (i) an in-vehicle sensing system, (ii) the road infrastructure and (iii) neighbouring cars to generate more high level and useful information for the driver. It has been developed as a part of the I-WAY system, whose aim is to provide drivers with timely warnings and meaningful suggestions to avoid potential hazards in the driving environment. The Alert Manager is capable of efficient handling of multiple information sources, fusion of complementary data and management of incoming events’ priorities. Moreover, the Alert Manager controls the broadcasting of messages to keep Road Infrastructure and other vehicles updated about potential hazards. We focus on the determination of the dominant risk prevailing in the road environment. The dominant risk is revealed through the individual risk estimation of the dominant risk prevailing in the road environment. The information about potential hazards in the driving environment is capable of efficient handling of multiple information sources, fusion of complementary data and management of incoming events’ priorities. Moreover, the Alert Manager controls the broadcasting of messages to keep Road Infrastructure and other vehicles updated about potential hazards. We focus on the determination of the dominant risk prevailing in the road environment. The Alert Manager was designed and developed. In this work we focus on the implemented Alert Manager which is able to merge different incoming information provided by different sources with the scope to i) efficiently handle message broadcasting, ii) evaluate the dominant risk prevailing in the road environment that the driver should be aware of and iii) produce integrated, high level information from the available data.

I. INTRODUCTION

During the last decades, the development of driver assistance systems is of growing importance as these systems are expected to improve road safety and traffic efficiency. Advanced Driver Assistance Systems (ADAS) are systems that partly support or take over the driver’s tasks. A clear definition of ADAS is stated as follows: They have a direct supporting interaction with the driver or the driver task. Their way of support may vary from informative to controlling [1], [2]. ADAS operate from inside the car, but may be connected to external sources. Several ADAS systems, such as Adaptive Cruise Control (ACC), Lane Departure Warning (LDW) and Intelligent Speed Assistance (ISA) are already popular among car manufacturers, or are being developed. ADAS are in turn part of a technology called Intelligent Transportation Systems (ITS). ITS incorporates intelligence in both roadways and vehicles with the intention to improve the traffic flow. Cooperative road-vehicle systems and vehicle-vehicle systems are also emerging worldwide. Intelligent vehicles and roads are the future standard and specialised research are intensified for the identification of their impact as well as their adaptation to the real user needs for safer and efficient transportation services. The current ADAS are designed to support drivers in maintaining some safety thresholds or ensuring compliance with some formal driving rules, such as maintaining safe time headways in car-following situation or adhering to legal speed limits.

I-WAY is a novel cooperative driving platform that enhances significantly drivers’ perception on road environment by producing high-level and useful information for the driver through the analysis and fusion of real-time data obtained from: (i) an in-vehicle sensing system, (ii) the road infrastructure and (iii) neighbouring cars. The core of this system is I-WAY DSS, a Decision Support System that encapsulates all the intelligence required from an ADAS. The key features of I-WAY DSS are (i) the proactive risk assessment, meaning the preview of an event/situation and provision of notification messages to the driver about potential risks and (ii) the scouting function, meaning the detection of events in the local environment, with the scope to send updated information to the road infrastructure and other cars in the vicinity. I-WAY DSS receives information about i) the surroundings of the vehicle through continuous monitoring of the road scenery with on-board sensors ii) driver state from a dedicated driver monitoring module, iii) vehicle position, speed and heading via GPS, iv) weather and traffic conditions or other incidents on the highway like road constructions, blocks etc. via Road Infrastructure and v) local environment and behavior of other vehicles in the neighborhood. The information is fused so that an enhanced situation assessment is performed and an optimal warning strategy for road hazards is adopted. As optimal warning strategy is considered the delivery of tailored messages to the driver in terms of i) message content (information about the most critical event), ii) message type (notification, warning, alert), iii) message format (text, vocal) and iv) delivery time (considering also repeating messages when necessary). In order to efficiently handle the incoming data and determine the appropriate message content for driver notification, a part of the I-WAY-DSS, called Alert Manager was designed and developed. In this work we focus on the implemented Alert Manager which is able to merge different incoming information provided by different sources with the scope to i) efficiently handle message broadcasting, ii) evaluate the dominant risk prevailing in the road environment that the driver should be aware of and iii) produce integrated, high level information from the available data.

II. MATERIALS AND METHODS

In Figure II we illustrate the architecture of the Alert Manager. The basic layers of the architecture are

1) Communication module
2) Ego-Vehicle Event detector
3) Event Handler
4) Event Manager
5) Decision Maker
6) Alert Generator-Human Machine Interface.

The aforementioned layers are described below.

A. Communication Module

This is the network layer where the communication between vehicles (V2V) and infrastructure and vehicles (I2V...
and V2I) are performed. Each vehicle produces a number of messages related to potential hazards either detected by the Ego-Vehicle Event detector or received as messages by other I-WAY vehicles or the Road Infrastructure. The details of the communication protocol are out of scope of this work and only the range of the wireless communication and the average delay (as a function of distance and relative speed) are taken into account.

B. Ego-Vehicle Event detector

The Ego-Vehicle Event detector is actually the in-vehicle embedded system that is responsible to recognize events and conditions in the local environment of the I-WAY vehicle using on board sensors. It consists of: i) A radar and two cameras that continuously monitor the road scenery. The perception of the road geometry (curvature, number and width of lanes) and potential obstacles (vehicles ahead, fixed front/lateral objects) is accomplished through real time object detection and road modeling. (ii) Vehicle CAN-bus and GPS receiver used to collect specific vehicle parameters such as position, speed, acceleration, braking, and temperature. Using this information a number of events nearby the vehicle is detected (i.e. traffic, road narrow, lane invasion, static or slow moving obstacles etc.) The recognized events feed the Communication Module in order to be broadcasted to other vehicles and the Road Infrastructure (scouting function) and also pass to the Event Handler for further processing.

C. Event Handler

Incoming messages arriving from Communication Module and Ego Vehicle Event Detector feed the Event Handler. different types of events are indicated in Table I). For efficient management we divide them into three categories:

- Non-static events (such as slow moving vehicles, slowing down traffic etc.) Those are reported from other vehicles or Road Infrastructure, but their presence is not guaranteed by the time that the ego-vehicle reaches their reported location.
- Instant Events: Events either detected from Ego-Vehicle Detector (i.e. lane invasion) or received from other cars (sudden braking) occurring in short distance from the I-WAY car.

The first two categories refer to events on the highway that constitute potential obstacles for the ego-vehicle. That is, if the vehicle approaches the event with a speed over a safe limit, this event becomes threat for the driver. Let the obstacle speed (or the safe speed limit) \( u_0 \) and the ego-vehicle speed \( u_e \). The risk measure is considered as the braking effort required in order to reach obstacle’s speed, multiplied by a constant, defined as:

\[
r = c \frac{u_r^2}{2d},
\]

where \( r \) the risk, \( u_r = u_0 - u_e \), \( d \) the distance between ego-vehicle and the obstacle and \( c \) a constant depending on the vehicle and the weather conditions. This constant is common for all events.

The last category of events require an instant warning; thus they are directly forwarded to the Alert generator without Event Manager intervention. The first

D. Event Manager

The Event Manager is responsible for keeping a list of incoming events and sorting them according to their risk. Each node of the list corresponds to a particular event which in turn consists of the following variables:

i) distance (\( d \)): this is the distance between the event and the ego-vehicle.

ii) relative speed (\( u_r \)):the relative speed between ego-vehicle and an obstacle

iii) category (\( c \)):i.e.Static/Not-Static).

iv) type (\( t \)): e.g. Road Works, Road Narrow etc.).

When a new event is received the Event Manager, additionally undertakes the following tasks: Initially the Event filtering procedure removes irrelevant to ego-vehicle events, while the relevant ones (Filter Pass)are directed to the matching procedure. During this procedure the incoming events are compared
with existing events (nodes in the list) and are merged with nodes referring to the same event (Merge). If no merge occurs, the incoming event is added as a new node in the list. The overall procedure is outlined in Table II. Next we describe in detail the Filter Pass and Merge procedures.

1) Filter Pass: This is the function within Event filtering which determines whether the incoming event is worth reported in terms of relevance with the ego-vehicle. This function allows the avoidance of irrelevant information, reducing computational cost.

The criteria to consider an event as non worth reported are mentioned below:

1) The events whose reported position is either backward or in opposite highway direction from the ego-vehicle. Hence, such events are not considered forthcoming hazards.

2) For the non-static events we consider the possibility of not-being valid when ego-vehicle approaches their reported location. To handle this case, an expire horizon is assigned to non-static events, according to relative speed and distance.

\[ t_{\text{expire}} = \frac{u_x}{s} + T_0, \]  

where \( T_0 \) a constant indicating a time margin used to assure the event expiration. When time-to-live of the message in the Event list becomes equal to \( t_{\text{expire}} \), then the message is discarded.

2) Merge: Merge is the function within matching procedure whose main role is the avoidance of keeping multiple nodes in the event list referring to the same event. For instance, suppose a vehicle detecting a narrow road in some distance ahead. If the same event is already a node in the event list (provided from another source through the communication module) we can merge or ignore the message coming from the Ego-Vehicle Event Detector.

Another important feature of Merge function is the ability to provide high level information from individual messages. Consider for example the scenario of a queue of \( K \) vehicles in some distance ahead from ego-vehicle. Each I-WAY vehicle in the queue recognizes a slow moving car in front of it and broadcasts a relative message. Therefore a number of messages with overlapping information is received. This scenario reveals the necessity of an aggregation mechanism which combines single incoming messages about slow moving objects and generates high level information such as heavy traffic.

The usual information coming from other I-WAY vehicles is about obstacles (slow moving cars or fixed objects). Moreover the Ego-vehicle detector is able to detect other vehicles in the vicinity (near lanes) and monitor their relative speed. Using the above information the Merge function can infer Traffic situation using different approaches such as rules or probabilistic inference. In this work a simple rule-based approach is considered:

- i) all highway lanes are occupied by detected vehicles
- ii) the relative speed between ego-vehicle and other cars approaches zero
- iii) the ego-vehicle speed is below a threshold (typical 15 m/s)

If all the above conditions are satisfied then a traffic jam event is inferred.

Another level of merging information is the reasoning about some specific non-static events. For example merging traffic jam (non-static event) with Road works (static event) in near location, we conclude that traffic jam is due to Road Works. Thus the driver is provided with a single message containing high-level information instead of two separate messages.

3) Prioritization: The Prioritization function is responsible for storing the new event in the list (Add Node) keeping the priority order. This involves the re-estimation of all events' risk according to equation (1). The Event list is then re-sorted in descending order. The highest risk event (top entry) is then forwarded to the Decision Maker which decides whether and in which way to notify the driver.

4) Update list: A periodic update of the Event list is performed to ensure that contained events are still relevant according to the ego-vehicle current position (outlined in Table II-D2). The Expired routine determines when the nodes of the Event list are no longer valid and the Delete routine removes them. The events are considered non-valid when the criteria described in section II-D1 are met. These are summarized below:

1) If the event type is static and distance is lower than zero, \( E_d < 0 \).

2) If the obstacle type is non static and \( t_w > t_{\text{expire}} \), where \( t_w \) the time-to-live of the message in the Event list.

If the event is not deleted, we update the distance of the event \( E_d = E_d - E_{uw} \) and recalculate its risk. After all events' risks are updated we re-sort the list.
5) Broadcasting handler: For efficient scouting functionality, a continuous broadcasting of the forthcoming events (nodes in the Event list) is necessary due to communication range limitations. If detected events are broadcasted only once, the currently out of range vehicles will not be updated about potential hazards. Hence, all nodes in the Event List have to pass to the communication module for broadcasting. Using no reduction strategy the total number of messages is a \((\sim 1)\). To confront with bandwidth limitations, we apply a simple reduction strategy: If the position information of an incoming event (message from Communication module) is very close to ego-position with respect to communication range, we consider that other vehicles within the range of the ego-vehicle are already aware of the event and thus, the particular message is not broadcasted.

E. Decision Maker

The main I-WAY goal is to provide driver with tailored messages to the driver about critical forthcoming events. The types of messages vary according to a number of parameters like the severity of a given event (that is interpreted by the braking effort required by the driver until he reaches the safety limit), the driver state (stress and fatigue levels), the local weather and traffic conditions, etc. A sophisticated decision making is necessary to ensure that the driver is aware of forthcoming events well in advance so he has enough time to react while at the same time the alerting system is as less distracting or irritating as possible. The possible actions of the Decision Maker are:

1) No notification
2) Text Message with information
3) Light vocal message
4) Intense vocal message

The Decision Maker is based on Influence diagrams [3] and described in detail in [4].

F. Alert Generator

This module is responsible for composing and forwarding the appropriate messages to the driver through a specially designed Human machine interface.

III. Simulation Environment

A simulation environment [5], [6], developed in C# was used in order to conduct our experiments. A brief description of the environment follows:

A. Vehicle Model

To model the vehicle behavior in a highway environment we used the Intelligent driving model (IDM) [7]. The model can be summarized in the following equations

\[
\begin{align*}
\frac{dv}{dt} &= a[1 - \frac{v}{v_0}]^\delta - \frac{s^*}{s} \\
\frac{ds^*}{dt} &= s_0 + (vT + \frac{v\Delta u}{2\sqrt{ab}}),
\end{align*}
\]

Where,

\[v_0\] the desired speed of the vehicle,

\[s^*\] the desired dynamical distance between tho vehicles

\[s\] the actual gap,

\[T\] the safety time headway when following other vehicles,

\[a\] the acceleration in everyday traffic,

\[b\] the "comfortable" braking deceleration everyday traffic,

\[s_0\] the minimum bumper-to-bumper distance to the front vehicle,

\[\delta\] the acceleration exponent,

\[\Delta u\] the relative speed.

To produce a more realistic model we have expanded the IDM to allow:

1) Lane Change: Vehicles are allowed to change lanes if they are following a vehicle with speed lower than the desired. In a lane highway each lane has a lower and upper speed limit. Each vehicle aims to reach the appropriate lane according to desired speed \(u_0\).

2) Obstacle detection: In each time instance, vehicles detect obstacles ahead in a range \(R\). If an obstacle is detected at distance \(d\) the the actual gap \(s\) in equation 3 is set to \(d\). Otherwise \(s\) is set to a maximum value indicating that no obstacle exists.

3) Potential hazard detection: Vehicles detect obstacles in their current and adjacent(\(\pm 1\)) lanes. We characterize an obstacle as potential hazard if the speed of the obstacle is lower than a predefined threshold. If all adjacent lanes are occupied by slow moving obstacles then we assume that a traffic situation is present. Furthermore, if ego-vehicle is slow moving, it’s status is directly forwarded to the communication module described below.

B. Communications

The basic communication characteristics are the following:

- The communication ranges of V2V, V2I and I2V.

. Vehicles produce three types of messages: i) Obstacle detected by ego-vehicle (Slow Moving vehicles or fixed obstacles) ii) Traffic detected by ego-vehicle when many slow moving vehicles are present in adjacent lanes, iii) events reported by other vehicles. These messages are broadcasted to Road Infrastructure and neighboring vehicles. Whenever vehicles come into range of an I-WAY vehicle or a Road Infrastructure base station a new communication is initialized and messages are received within \(dT\) (latency time). The message delivery fails if the source and target distance exceeds the communication range.

IV. Results

In this section, some initial results for two possible scenarios in a highway environment are provided. The aim of these scenarios is twofold: i) to provide measures about communication characteristics (range, latency) and braking effort gain (involved risk) and ii) to illustrate the merging of
information received from different sources (I-WAY vehicles nearby and Road Infrastructure). In both scenarios the latency of communications is considered constant. In any case if the broadcasting period is set to $T$ and the communication delay is $dT$ we assume that the actual broadcasting period becomes $T + dT$.

A. Scenario A': Slow Moving Vehicle

In this scenario, we consider 10 I-WAY vehicles moving on the highway and a slow moving vehicle present in some distance ahead. Moreover, we suppose that all vehicles are moving in the same lane and lane changes are not allowed. The distance between I-WAY vehicles is initially set to 1.5 km. For comparison purposes, we introduce for each I-WAY vehicle a corresponding Zombie vehicle (conventional car without communication ability). Each Zombie vehicle has the same initial position, speed and IDM parameters (as described in equation (3)) with its corresponding I-WAY vehicle. To illustrate the performance (in terms of mean breaking effort) we consider two cases: In the first case, the speed of the slow moving vehicle is set to 10 m/s and in the second 20 m/s. In both cases, all other vehicles have an initial speed of 35 m/s. Visibility (the maximum distance where an obstacle or a foregoing vehicle is detected) is set to 200 m. Another important parameter is the broadcasting period. This determines how often a vehicle broadcasts critical information.

B. Communication characteristics results

In Figures IV-D, IV-D we provide the mean braking effort of the Zombie vehicles and I-WAY vehicles with broadcasting periods 5, 15, 30 and 60 secs for both cases of slow moving vehicle speed. We observe that the braking effort in the first case is very high (a safe value for normal conditions is 0.2) while in the second case the safety requirement is achieved with a communication range of 600 m and broadcasting period of lower than 15 sec. From the above scenario we conclude that for the second case is almost impossible to ensure safety with only V2V communication. Then we examine the case of I2V and V2I communication. The great benefit is that the communication range for this case is almost unlimited, because when a infrastructure station receives a message from a car it can broadcast it to all other stations using LAN network. In figure IV-D, we provide the braking effort of the I-WAY cars with and without Infrastructure communication and for Zombie cars for comparison. We observe a significant reduction in braking effort. Moreover, in this case we can achieve the safety margin of 0.2 braking effort even in the extreme case of an obstacle with speed of 10 m/s.

C. Event Manager results

In this section, we provide screenshots from the simulation of the Slow Moving Vehicle scenario. In this simulation V2I communication is allowed and information fusion is performed and broadcasted. The simulation illustrates a mini-map of the highway, where the vehicles are indicated as ellipses with an id number assigned, while Road Infrastructure base stations are indicated as ellipses above the highway. In the bottom of the screenshot we provide a log display where the Event list of the ego-vehicle ($id = 0$) is indicated. Early in the simulation when no queue is formed yet, two obstacle messages are sent to the Road Infrastructure when two I-WAY vehicles approached the slow moving vehicle (Figure IV-D). The Road Infrastructure broadcasts this information, which in turn is received by the ego-vehicle. Later when the queue has been formed, the broadcasted messages from individual vehicles are merged and the ego-vehicle infers a queue situation (Figure IV-D).

D. Scenario B': Road Works

In the second scenario, we assume road works taking place in two out of four lanes of the highway. Furthermore near the Road Works event we deploy a large number of vehicles with different speed in order to create a traffic congestion. In this case, the ego-vehicle receives a large number of messages about slow moving vehicles along with a message from Road Infrastructure reporting Road Works in the same area. The Event Manager of the ego-vehicles merges the aforementioned messages producing a high level message i.e. “Traffic due to Road Works”. A screenshot of this complex scenario simulation is illustrated in Figure ???. Also, the log display demonstrating the Event list of the Ego-Vehicle sorted by the estimated events’ risk is provided.

V. Discussion

We have presented a novel Alert Manager capable of i) merging different information sources, ii) fusing heterogeneous data, iii) evaluating individual risks, iv) prioritizing events according to their involved risk and v) producing high level information and reasoning about forthcoming hazards. The aforementioned functionalities lead to an enhanced situation assessment regarding the highway environment. The enhanced assessment is further used by the I-WAY Decision Support system in order to provide driver with an optimal warning strategy about forthcoming hazards.
Fig. 3. The braking effort according to the range of communication for different update intervals and speed of slow moving car is 10m/s.

Fig. 4. The braking effort using/not using Infrastructure and Zombie cars for different broadcast intervals and CR 0.4km.

Apart from Driver notification purposes, the Alert Manager serves as an advanced controller for the broadcasting mechanism of the Communication module, since it determines the number of outgoing messages as well as the broadcasting frequency.

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REFERENCES