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A Video-Analysis-Based On Railway–Road Safety System

G.Ranjith, C.Saranya

Abstract— Latest security initiatives in the field of railway transportation propose to implement video surveillance at level crossing (LC) environments. In this paper we explore the possibility of implementing a smart video surveillance security system that is tuned toward detecting and evaluating abnormal situations induced by users (pedestrians, vehicle drivers, and unattended objects) in LCs. Then, a hidden Markov model is developed to estimate ideal trajectories, allowing the detected targets to discard dangerous situations. After that, the level of risk of each target is instantly estimated by using the Dempster–Shafer data fusion technique. The video surveillance system is connected to a communication system (the Wireless Access for Vehicular Environment), which takes the information on the dynamic status of the LC (safe or presence of a dangerous situation) and sends it to users approaching the LC. Four hazard scenarios are tested and evaluated with different real video image sequences: presence of the obstacle in the LC, presence of the stopped vehicles line, vehicle zigzagging between two closed half barriers, and pedestrian crossing the LC area.

Keywords— video surveillance, Markov model, LC.

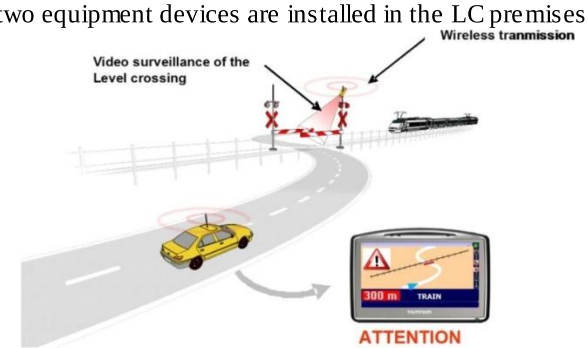
I. INTRODUCTION

Improving the safety of people and road–rail facilities is an essential key element to ensuring good operation of the road and railway transport. Statistically, nearly 44% of LC users have a negative perception of the environment, which consequently increases the risk of accidents . In France, for example, several dramatic accidents have occurred in recent years, involving buses with children onboard. Always, in France, when an accident occurs, the transport operator waits for a road user noticing the accident to use a very old telephone installed at the LC premises to warn the traffic center that something bad is happening at the LC. Then, the operator at the traffic center calls all the approaching trains to tell them to stop immediately without any additional information on what is going on. In the meantime, at the LC level, the situation is becoming worse, because of the wounded users and/or the blocked traffic. This is a "blind" way of managing LC incidents . Human errors cause 99% of accidents at the LCs, 93% of which are caused by road users. It is important also to note the high cost related to each accident, which is approximately 100 million Euros per year in the EU for all LC accidents. For this purpose, road and railway safety professionals from several countries have been focused on providing an LC that is as safer as possible. The initial idea, first carried out in the framework of the SELCAT project and then through the PANsafer project, was to introduce some technological components in the management of LCs.

This architecture can be summarized in two points:

• one equipment dedicated to the detection of potentiallydangerous situations due to video sensing and image processing (this will constitute the main part of this paper);

• one equipment of communication whose role is to send tothe users approaching the LC the status of the LC. These two equipment devices are installed in the LC premises.



The establishment of the communication must be as fast as possible (minimum latency time), the range must be at least 300 m, and the communication must continue to operate even during high speed practiced by the trains (until 160 km/h).

II. RELATED WORKS

The first step of this model consists in robustly detecting and separating moving objects crossing the LC. However, to be efficient, these techniques require further development to distinguish between detected objects. That is why we propose a new technique to detect and separate all moving objects that enter into a given surveillance zone. To obtain separated objects, this method consists in clustering moving pixels by comparing specific energy vectors associated to each target and each moving pixel. The second step of the proposed video surveillance model is object tracking, which starts when there are enough detected pixels belonging to moving objects. The third step of the system is planned to predict ideal trajectories of detected targets such as to avoid potentially dangerous situations. The Gaussian mixture model and the hidden Markov model (HMM) and some of its extensions, such as the hierarchical HMM and the coupled hidden semi-Markov model , are usually used for representing and recognizing

G.Ranjith , B.E EEE-2nd Year, Sona College Of Technology, Salem, Tamil Nadu. (Email: discoverranjith@gmail.com)
C.Saranya , B.E EEE-2nd Year, Sona College Of Technology, Salem, Tamil Nadu. (Email: csaranya7996@gmail.com)

objects' trajectories. However, these methods need a high number of statistical measures to be accurate.

III. Object Detection, Separation, And Tracking

The tracking process starts by computing optical flow of corner points, extracted by Harris operator , using the Lucas–Kanade algorithm consider that these particular points have a stable optical flow. The optical flow of Harris points is then propagated to compute the optical flow of the remaining pixels (see Section III-C). To make the tracking process more robust against noise and to rectify the optical flow for each pixel, a Kalman filter (KF)-based iterative process is designed . This iterative process is carried out as follows.

The output (optical flow) given the KF (see Section III-C) is evaluated with two test constraints. The first test constraint verifies if the proposed solution is inside an optical flow research area (see Section III-B). If the test is positive, the optical flow solution is reevaluated with the second test constraint, which is a similarity test constraint (see Section III-C). If the second test is positive, the proposed solution is retained. If the similarity test is negative, the KF is applied again to reach a new solution. If the research area test is negative, a color intensity optimization algorithm (see Section III-D) is applied to propose a new solution, which is subjected to the two test constraintsConsidering the KF-based iterative process, four iterations are sufficient to track with high accuracy around 60% of the pixels belonging to a detected object. This rate allows performing robust object tracking.

The following sections detail all the steps we have introduced above: object detection and separation, optical flow propagation, Kalman filtering, and intensity-difference-based optical flow optimization algorithm.

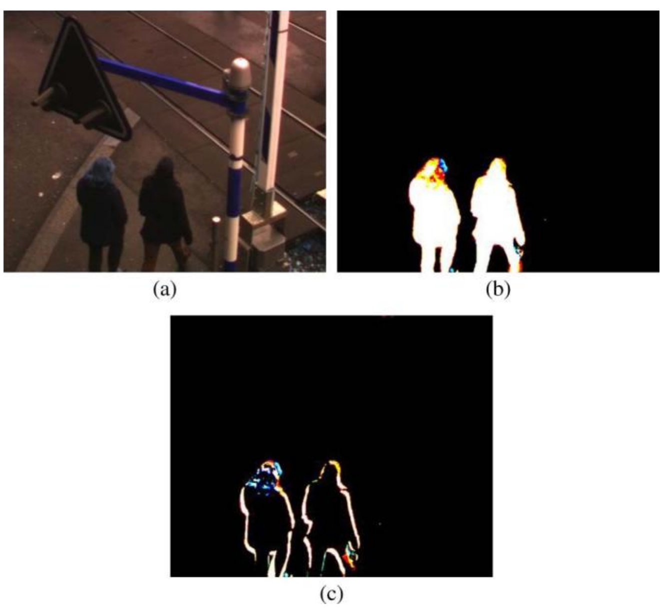


Fig. 4. Detection of moving pixels. (a) Current image. (b) Moving pixels of the objects. (c) Moving pixels situated in the contour of the objects.

IV. Recognition Of Dangerous Situations In LC Environments

The last stage of the model is to analyze the predicted ideal trajectory considering various sources of dangerousness. The analysis is based on Dempster–Shafer theory, which allows combining danger induced by the different sources to obtain a quantitative measure (degree of belief) of danger.

Given a region center, we consider five sources of danger: position, velocity, orientation, acceleration, and distance between the predicted and absolute ideal trajectories. Then, we define a mass assignment for each source of danger. The mass assignment m_p, representing the degree of danger related to the position, is computed from the distance between the predicted position p_{t+tf} at time instant $t + t_f$ and the barrier of the LC. The mass assignment m_v, representing the degree of danger related to the velocity, is computed from the difference between the predicted velocity V_t at time instant t and a prefixed nominal velocity V_N

$$V_N = \frac{D_{\max}}{2 \cdot n \cdot T_{\min}} \tag{31}$$

where $D_{\max}$ is the maximum distance that can be covered by a moving object in an LC environment. It is linked of course to the size of the surveillance area. This distance is taken into account for all the motion directions in the surveillance area: from left to right, from top to bottom. $T_{\min}$ (expressed in seconds) is the minimal time to travel the distance $D_{\max}$. n (images/sec.) is the acquisition rate (number of frames recorded in one second).

The mass assignment m_o, representing the degree of danger related to the velocity orientation, is computed by comparing the orientation of the predicted velocity V_t at time instant t with the orientation of the absolute ideal trajectory. The mass assignment m_a, representing the degree of danger related to the acceleration, is computed from the difference between the predicted accelerations a_t and a_{t+tf} at time instants t and $t + t_f$. Finally, the mass assignment m_d, representing the degree of danger related to the distance between the predicted and absolute ideal trajectories, is computed from the distance between the predicted position p_{t+tf} at time instant $t + t_f$ and the absolute ideal trajectory.

Once the degrees of dangerousness are computed for the five sources, the Dempster–Shafer combination is used to determine the degree of danger related to the considered region center, i.e.,

Danger = Dempster-Shafer (m_v,m_a,m_o,m_p,m_d).

V. Accident Scenarios In LC

Accidents at railway LCs have continuously become a serious road safety problem particularly when it involves fatalities. Research has shown that the major cause of crashes at railway LCs is that the drivers fail to take sufficient care to avoid crash. Situations such as with the presence of an obstacle inside the

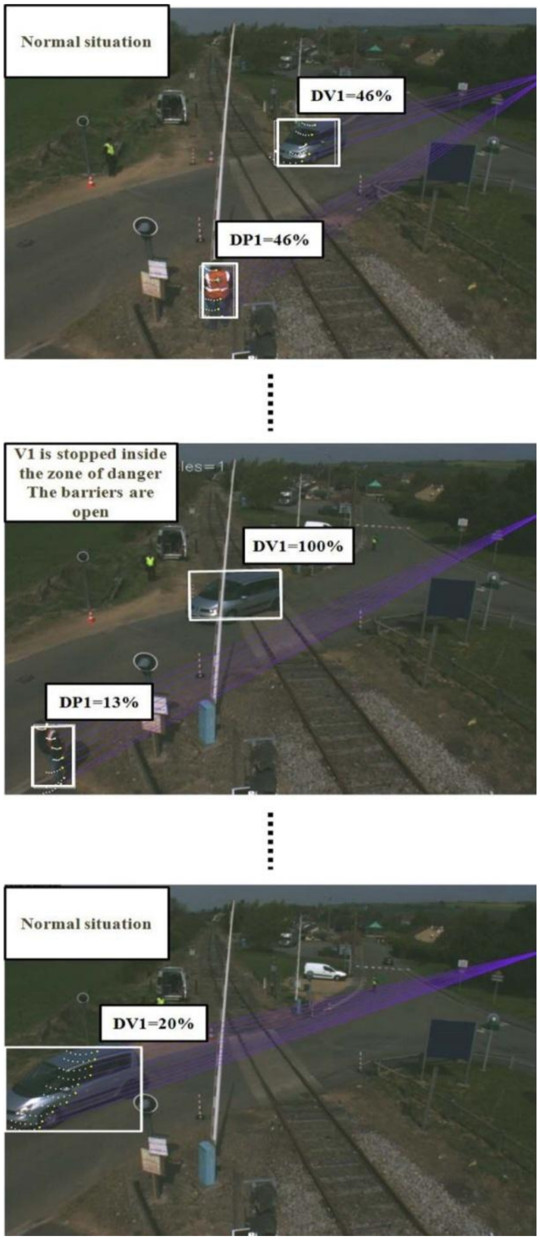


Fig. 16. Presence of obstacle in the LC. DVi represents the danger related to the vehicle number i. DPi represents the danger related to the pedestrian number i.

LC, zigzagging between closed barriers, and queuing across the rail LC can cause catastrophic consequences. To evaluate these three situations acquired in real conditions, we apply the proposed recognition method, and results are experimentally analyzed.

A. A. Scenario 1: Vehicle Stopped

In this scenario, a vehicle crosses the LC while the barriers are open (see Fig. 16). Suddenly, the vehicle stops inside the

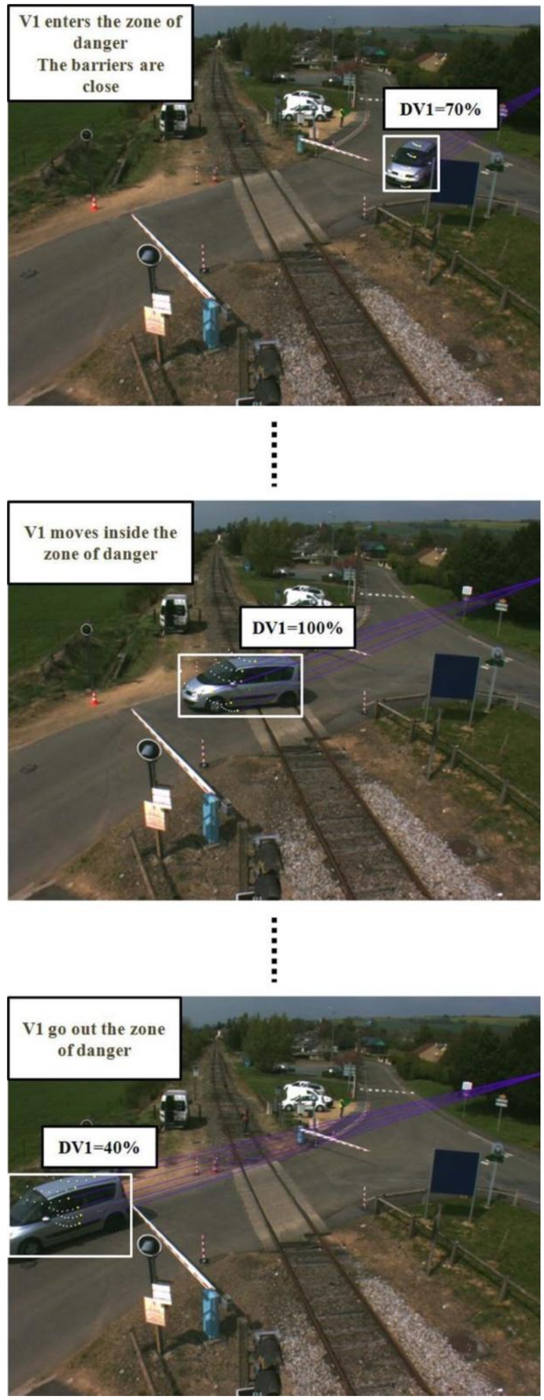


Fig. 17. Vehicle zigzagging when crossing the LC with closed barriers.

dangerous zone and becomes a fixed obstacle. After a while, the vehicle moves and leaves the LC. Fig. 16 illustrates also the results obtained in terms of object detection and tracking and of danger evaluation. One can see that all the moving objects are well detected and tracked during the video sequence. The purple lines in Fig. 16 represent the absolute ideal trajectory of the center of each extracted region from the object. The white points in the figure represent the instantly predicted displacement of the center of the extracted regions.

Concerning danger evaluation, the degree of dangerousness related to the detected vehicle increases when it moves toward

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the LC and reaches 46% during the crossing of the zone of danger (between the barriers). When the vehicle stops in the zone of danger, the stationarity is detected, and the degree of dangerousness takes a value of 100%. Note that during the danger evaluation process of the detected vehicle, a pedestrian moving around the LC zone is detected, and its level of dangerousness is evaluated.

B. B. Scenario 2: Vehicle Zigzagging Between Two Closed Half Barriers of the LC

In this scenario, a vehicle is approaching the LC while the barriers are closed. The vehicle crosses the LC, zigzagging between the closed barriers as illustrated in Fig. 17. Fig. 17 shows also detection results and danger evaluation. The degree of danger related to the detected vehicle continuously increases when the vehicle approaches the LC with abnormal trajectory and reaches 70%. The degree of danger keeps growing when the vehicle starts entering the LC and reaches the maximum (100%). When the vehicle begins to leave the LC, the level of danger progressively decreases.

C. C. Scenario 3: Queuing Across the Rail LC

In this scenario, a first vehicle stops just after the dangerous zone. This situation could occur when the vehicle is obliged to stop because it is broken down for example. Sometime later, two other vehicles find themselves blocked behind the first vehicle, which is motionless. This situation leads to a queue of cars inside the LC (see Fig. 18). Concerning danger evaluation, the degrees of dangerousness related to the two vehicles detected inside the LC progressively increase and reach their maximum (100%) when they are stopped inside the zone of danger. When the two vehicles restart moving, the degree of dangerousness drops to 46% and gradually decreases as the vehicles leave from the LC. Note that, at the end of the video sequence, a pedestrian is detected and tracked, and its related danger is evaluated.

D. D. Scenario 4: Fall of a Pedestrian

In this scenario, as illustrated in Fig. 19, three pedestrians (P1, P2, and P3) are walking around the LC area as the barriers are closed. Pedestrian P3 is stopped in the middle part of the LC, whereas pedestrian P2 is crossing the LC area, and pedestrian P1 is moving inside the zone of danger. Suddenly, pedestrian P2 falls down on the ground and stays motionless. In this scenario, the maximum degree of risk is 100%. The degree of danger 120% is arbitrarily chosen to distinguish stationary pedestrians inside the LC area. Considering that, the stationarity of pedestrian P3 is detected with a level of danger of 120%. The danger induced by pedestrian P2 is continuously increasing to 100%. When pedestrian P2 falls down, he is detected as a fixed obstacle with a level of danger of 120%. When pedestrian P1 arrives near pedestrian P2, the two pedestrians are considered as a global fixed obstacle with a level of danger of 120%. After a moment, the two pedestrians P1 and P2 are getting up, and they separate one from the other. At the end of the sequence, pedestrian P1 is walking toward pedestrian P3, and when they become close to each other, they are detected as a unique fixed object with the level of danger of 120%. At the same time, pedestrian P2 is detected leaving the LC zone, with progressive decreasing of the level of danger. A vehicle is also detected, and its level of danger is calculated when approaching the LC.

E. E. Results Got With the Communication System

Different current communication means have been tested [4]. The best suitable technique of communication is Wireless Access for Vehicular Environment (WAVE), whose norm was adopted in Europe in several steps.

• 5, 9-GHz bandwidth (from 5855 to 5925 MHz) is allocated by CEPT/ECC.

• European Commission adopts applications related to safety in intelligent transport systems (2008/671/EC).

• ETSI standardizes the communication protocol (EN 302571) on the same line than protocols such as WiFi and calls it IEEE 802.11p.

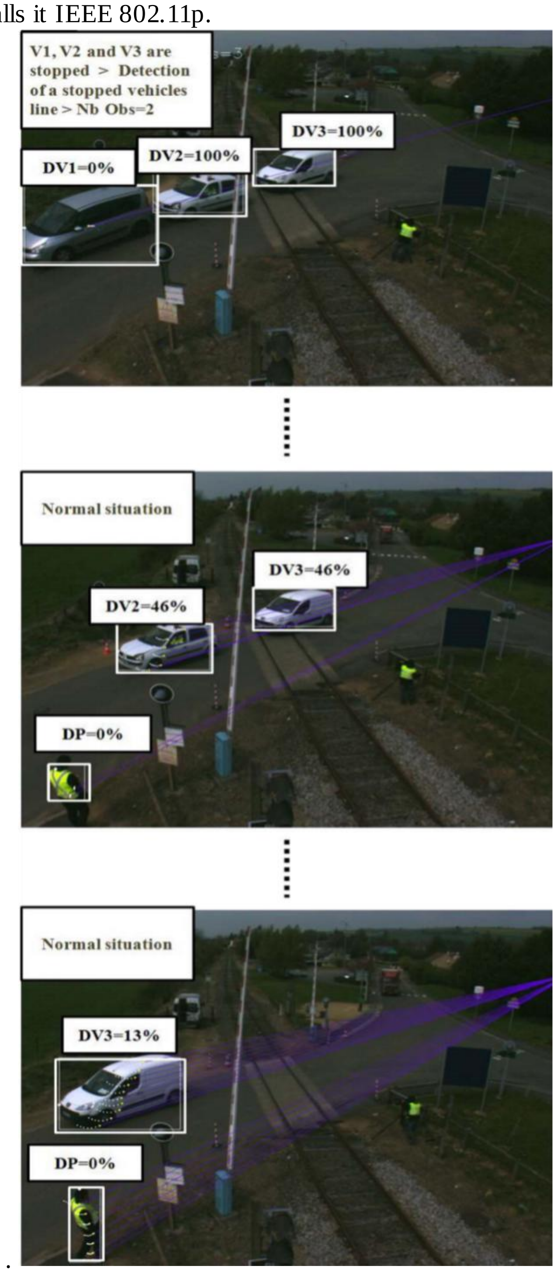

Fig. 18.Presence of stopped vehicles line on the LC.

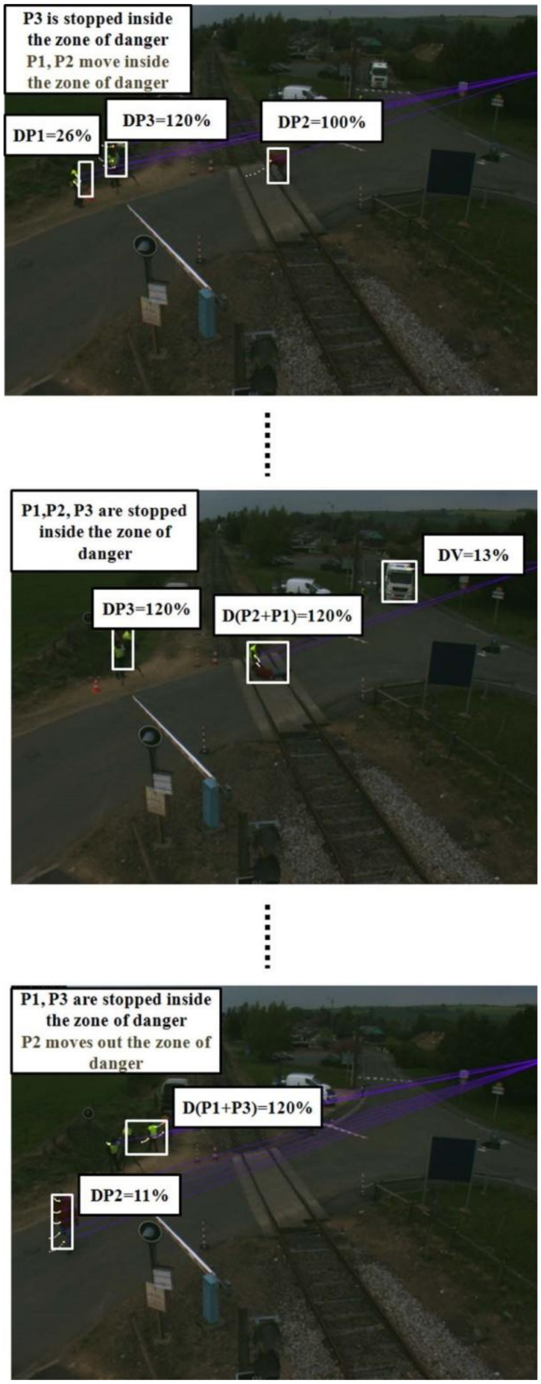

Fig. 19.Fall of a pedestrian.

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The WAVE norm defines the communication/cooperation systems between vehicles (V2V) and between a vehicle and the environment (V2I) to improve the safety of road users. The WAVE norm (802.11p) was used in the framework of the PANsafer project.

The different communication trials around the evaluation LC showed several elements.

• The importance of the quality of the antennas used fromthe LC side and the vehicles' side. The trials showed that from the vehicles' side, the patch antenna 4 presents the best characteristics. This is quite important because the price of such antennas is quite low.

• The quite low quantity of information to transmit betweenthe LC and the cars does not need a very high bandwidth. It seems that the 6-Mb/s data flow, which is the European current standard, is the most suitable for this kind of application.

• A range of around 800 m was obtained. In urban zones, this range is more reduced and strongly depends on the configuration of the buildings.

• Theinfluenceofthepresenceoftreescaninterruptthe communication for a very short moment. Two vehicles' speeds were tested during the evaluation phase: one slow speed (20 km/h) and one average speed (50 km/h). The transmission remains the same whatever is the speed tested.

VI. CONCLUSION

In this paper, four typical LC accident scenarios (presence of obstacles, zigzagging between the barriers, stopped cars line, and fall of a pedestrian) acquired in real conditions have been experimentally evaluated by applying the proposed dangerous situation recognition system. A risk index has been defined to assess the risk of objects detected in LC environment. The method starts by detecting and tracking objects seen in the monitored zone by a video camera. The second stage of the method consists in predicting for each tracked object the ideal trajectory allowing to avoid potential dangerous situations. The ideal trajectory prediction is based on an HMM. The third stage is concerned with the analysis of the predicted trajectory to evaluate the danger related to each tracked object. This stage is performed by considering different sources of dangerousness and applying a Dempster–Shafer-based combination.

From the results obtained by the surveillance system, the LC has the possibility to generate its status at any time. The coupling of the surveillance system and the communication system has been demonstrated in the PANsafer project.

The development carried out on the communication system within PANsafer allows us to define some perspectives in terms of progressive deployment. There are three potential applications that could use the coupling of the surveillance and communication systems as follows.

First Category: Fleets of Critical Road Vehicles Like Buses: If we refer to some catastrophic accidents involving children in buses, equipping some LC with video detection and communication would have been very useful. In this case, it is necessary to equip fleets of buses with WAVE receivers and to return information on the status of the LC to the fleets of buses approaching the LC.

Second Category: Trams and Trains: We think that an emergency system and the possibility for the train or tram drivers to visualize the abnormal status of an LC could reinforce the safety of cohabitation between trams, trains, and road users.

Third Category: Trains via ERTMS: An information transmitted from the LC toward high-speed trains could be displayed in the cabin of the driver through the human–machine interface of the European Rail Traffic Management System (ERTMS) and could constitute a good direction of work to explore.

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