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On-board monitoring system for road traffic safety analysis

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A R T I C L E I N F O

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A B S T R A C T

This paper presents a framework for road traffic safety analysis. It is based on a stereo-vision system that, after being installed on-board of public transportation vehicles, collects data of what happens in front of a moving vehicle. The collected data are analysed throughout a process that acquire raw GPS information, video sequences and stereo-based depth maps to compute the surrogate safety measures. These measures are obtained by exploiting the Traffic Conflict Technique in conjunction with computer vision algorithms and a cascade of classifiers. The safety measures are then used for further analysis in order to identify dangerous locations in which an intervention is needed to improve the safety level and prevent accidents. Experiments performed in a real urban environment confirm the effectiveness of the framework.

1. Introduction

Road accidents are one of the leading causes of death, therefore road safety is a crucial and a delicate matter for national governments to be solved. Over the last years, governments have launched a series of initiatives with the intention to significantly reduce road accidents by acting directly on the three basic interacting elements of the road: the human behaviour, the vehicles security features and the road infrastructure. Human behaviour is the most difficult to deal with, because it can be predicted only to a limited extend. The improvements in vehicle safety are dependent on the implementation of new technologies and security features by the manufacturers. Finally the road infrastructure has a key role in safety influencing both human behaviour and vehicles performances. Relevant road infrastructure factors include the quality of the road illumination, the presence and the readability of signs and road markings as well as the quality of the paving [1]. Road safety is hence the final outcome of regulations and prevention techniques that, acting on the above mentioned three basic elements, make roads more secure. A method to objectively measure the safety level of a road may help to choose the most effective intervention. The research for such a measure motivated many studies. All of these can be divided into two main categories: those based on the analysis of statistical data of accidents [1] and those based on road users analysis and inter-operation, called naturalistic studies [2]. Most of the statistical studies are performed by evaluating crash data collected over a long period of time. They focus on rigorous statistical models and can tell something about the level of safety only after a certain number of events has already occurred. However the naturalistic studies can find the causes that can lead to an accident in order to prevent it. The actual difficulty in naturalistic studies is to collect and access the data needed for a good output. Current technologies offer the opportunity to collect data continuously with networks of cameras, wireless sensor networks and on-board monitoring systems. The framework presented in this paper can automatically collect data, while moving on board of a vehicle, and locate dangerous places for road users in order to send alarms to experts and allow a prompt intervention to improve the safety level of the location. To this aim, the framework is composed of a video-based on-board monitoring system that exploits the model of the Traffic Conflict Technique (TCT) to compute safety measures in conjunction with computer vision techniques and classification algorithms. This framework mounted properly on a public bus transportation system, which runs every day the same roads, can create a distributed moving sensor network which continuously collects data directly on the field. Compared to other solutions of the state of the art, the proposed approach provides more information relative to pre-crash and crash events than what is currently available, it is less expensive. Moreover it allows to investigate with few sensors a very large territory and it has safety risk detection with real-time capabilities. Finally it is not based on the analysis of the driver behaviour, but it focuses only on the interaction between road users, making it less intrusive with respect to privacy issues.

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The paper is organised as follows. The state of the art techniques related to traffic analysis approaches are discussed in Section 2. We then introduce the reader to the Traffic Conflict Technique fundamentals in Section 3. The proposed framework is described in Section 4. Section 5 discusses the experimental results obtained considering real data collected in the city of Catania – Italy. Finally, conclusion and directions for future works are given in Section 6.

2. Related work

Efforts to reduce risks and improve safety on roads are made through many strategies that typically involve processes of driver screening and selection, driver training, vehicle maintenance and road safety inspections in addition to the statistical analysis of accident data.

While those approaches have had some success, they are slow and very expensive and often they fail to have a sufficiently broad and reactive view of the reality in order to swiftly identify problems for road safety and thus to prevent accidents [1]. Naturalistic studies have demonstrated to be more reactive in identifying problems for safety [2] and nowadays technologies offer the opportunity better results with systems that can detect problems with safety and automatically trigger an intervention to solve it. It is possible to differentiate between those systems based on static positioned sensors (single or multiple) and those based on sensors mounted on board of vehicles.

In [3,4] many techniques were presented, mostly focused on driver behaviour analysis. Their studies give the inspiration for a possible broad classification of all analysis techniques into: Real-Time techniques, able to identify a safety issue at current time and non Real-Time ones, able to collect and analyse data from numerous samples.

Based on the devices exploited, it is possible to further classify the state of the art techniques into: fixed-position sensor networks and on-board systems.

There is a huge number of studies that use networks of sensors placed in critical positions, specifically to study the traffic flow or the vehicles behaviour [5–8]. These studies use various techniques to collect and analyse video data exploiting the TTC model [6–8] in order to identify pre-crash situations. They are very reliable and have a limited cost. However the positioning factor is crucial because these systems allow you to monitor only areas that already are thought to be dangerous therefore do not help to identify high-risk areas which are not known. In addition roads and the traffic flows constantly change, so fixed-placed solutions need to be constantly upgraded and re-positioned as well.

On-board systems allow to know what happens around the vehicle while moving together with it. Most systems are based on the sensors of the vehicle itself [9] (speed, acceleration, GPS, etc.), while others [10] are video-based and can achieve great accuracy in identifying drivers behaviour. Horrey et al. [11] presented a detailed review of the state of the art of on-board monitoring systems. However, despite they have good accuracy in identifying driver's behaviour their solution lacks in detecting locations where road safety is compromised.

As regards on-board systems, mobile-phone based solutions are promising in terms of being able to collect a very big amount of data exploiting the widespread of mobile devices among people. Among others in [12] mobile phone sensors (GPS receiver and orientation sensor) were used to detect erratic driving behaviour caused by overtaking considering phone as a steering wheel. Another interesting study that uses the three-axis accelerometer sensors of smart-phones was developed in [13]. The system presented by the authors claims to be used to detect and analyse various external road conditions and driver behaviours that could be dangerous to the health of the driver, automobile and the neighbouring public. In [14] the authors proposed a vehicle mounted system which provides a safety index to each driver on the basis of his quality of driving. The android device was fixed to the windshield and captured the audio and video signals (10 s before and after the event) and in order to detect driving manoeuvres like aggressive turn and sudden brake etc., thresholds were defined for the accelerometer in each direction. A similar study was developed in [15] where the authors presented a mobile application that combines the sensors of mobile phone like GPS, accelerometer and microphone to detect the driver behaviour, traffic and road conditions.

While promising mobile-based studies work in extremely unconstrained conditions and with a various quantity of low-quality sensors. Thus the overall quality of collected data is extremely low. Moreover, given the big amount of data, the analysis and insight extraction should be done offline.

Studies conducted in [16] demonstrated the effectiveness of using an on-board monitoring system based on stereo-vision to automatically compute measures useful to compute a level of risk in a detected pre-crash event.

As discussed in [17], the research and development of on-board monitoring systems should ideally: (a) identify and validate behaviours that may be precursors to crashes or injuries; (b) be based on cost-effective ways to monitor behaviour; (c) establish management and driver acceptance of the program.

In this paper we present the implementation of a framework for road safety analysis that satisfies all of the above mentioned conditions and fills the gap in the field of automatic road safety analysis combining high-quality real-time video and sensor data collection and analysis techniques in a mixture of real-time and non real-time analysis.

3. The Traffic Conflicts Technique

The 'Heinrich Triangle' theory [18] provides a conceptual framework to reason about road accidents (Fig. 1). It is founded on the relationship that 'no-injury accidents' precede 'minor injuries' (i.e., events closer to the base of the triangle precede events nearer the top). Moreover the 'Heinrich Triangle' events near the base occur more frequently than events near the top.

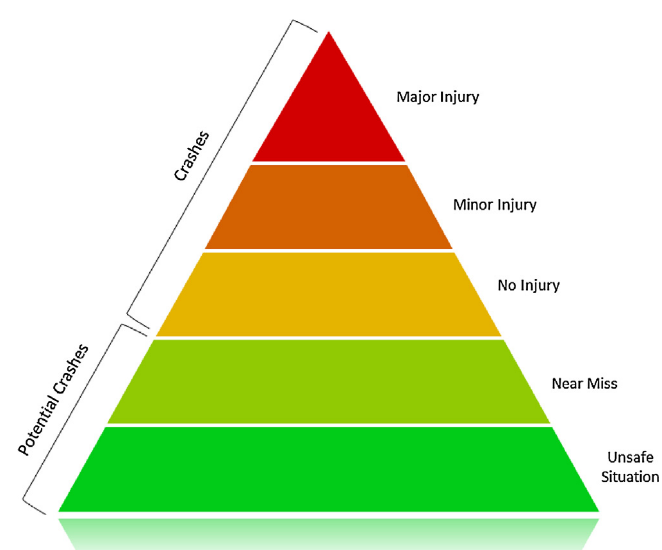

Fig. 1. The Heinrich Triangle describes crash events in terms of injury severity and near crash or potential crash events in terms of risk. Events at the base of the triangle happen more frequently.