In-vehicle stereo vision system for identification of traffic conflicts between bus and pedestrian

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Abstract

The traffic conflict technique (TCT) was developed as “surrogate measure of road safety” to identify near-crash events by using measures of the spatial and temporal proximity of road users. Traditionally applications of TCT focus on a specific site by the way of manually or automated supervision. Nowadays the development of in-vehicle (IV) technologies provides new opportunities for monitoring driver behavior and interaction with other road users directly into the traffic stream. In the paper a stereo vision and GPS system for traffic conflict investigation is presented for detecting conflicts between vehicle and pedestrian. The system is able to acquire geo-referenced sequences of stereo frames that are used to provide real time information related to conflict occurrence and severity. As case study, an urban bus was equipped with a prototype of the system and a trial in the city of Catania (Italy) was carried out analyzing conflicts with pedestrian crossing in front of the bus. Experimental results pointed out the potentialities of the system for collection of data that can be used to get suitable traffic conflict measures. Specifically, a risk index of the conflict between pedestrians and vehicles is proposed to classify collision probability and severity using data collected by the system. This information may be used to develop in-vehicle warning systems and urban network risk assessment

Introduction

Improvement in road safety knowledge is associated with a better understanding of the link between road features and road users and their dynamic interactions observed directly on the road in the short time prior a collision. Nevertheless, given the variability and complexity of road users behaviors and performance, as well as the random and rare nature of crashes, challenges still remain in quantifying these relationships basing only on crash data

In this framework, the traffic conflict technique (TCT) is a promising methodology of field observations to quantitatively describe the interactions between road users involved in a critical event for safety, not only in the occurrence of a crash, and the use of geo-referenced stereo sequences and tracking procedure constitutes an innovative tool in TCT applications. For this reason, in the context of a national research program on a new concept urban bus, a geo-referenced stereo system was developed to identify and analyze traffic conflicts between vehicle and pedestrians crossing in front of the bus. Such a system can support bus driver task in the event of a potential collision by the activation of real time warnings. Moreover, the conflict data can be stored for naturalistic studies of driver behavior during critical events (conflicts, near crashes, collisions). In urban area crash interactions between bus and pedestrian is one of the main sources of accidents involving a bus and cause of concerns for the transport agencies due to the high cost and social impact. Therefore, the market penetration of such equipment offers the interest of looking to a vehicle segment characterized by high investment cost and managed by a limited number of operators.
The field of application (i.e., intelligent transport system (ITS) for bus safety), the methodology (i.e., traffic conflict technique) and the novel equipment (i.e., stereo system with GPS) are presented in this paper together with a pilot implementation on the bus-pedestrian interaction to evaluate the effectiveness and potential use of the proposed system.

terms of their impact on reliability, profitability, and safety (TRB, 2011). At the present time, despite the great interest showed by operators to equip new and old bus fleets, little information based on their effective operation under real traffic condition is available in order to relate their working parameters to unsafe events and to perform qualitative and quantitative warnings for the driver.

Based on present experiences (Shankar et al., 2008), great emphasis is given to inside vehicle measurements monitoring driver performance and vehicle dynamics (e.g., braking, steering, pedal use, safety belt use, eye tracking, lane departures, lane position, hours of service, driver fatigue, driver alertness, turn signal use, and GPS coordinates). Video records are usually used to qualitatively analyze the outside vehicle environment (e.g., weather and light conditions, presence of other road users and conflicting vehicles). Less to no quantitative outside vehicle measures is usually acquired (e.g., distance of the opponent vehicles, obstacles or vulnerable road users). Due to the complexity in the correlation between the recordable data and the collision event, surrogate measures of safety provided by traffic conflict technique can be used to overcome this problem.

Surrogate measures of safety: traffic conflict techniques

The Heinrich Triangle theory (Heinrich, 1932) was founded on the casual relationship that no-injury accidents preceded minor injuries. The second basic idea of the Heinrich Triangle is that because near-accident events occur more frequently than accidents, their occurrence rate can be more reliably observed. Another advantage of this approach, with respect to traditional crash analyses, is its proactive evaluation (i.e., it is possible to identify the safety deficiencies prior to accident occurrences and to adopt preventive countermeasures).

The TCT is founded on the Heinrich Triangle theory, assuming that the appropriate traffic conflict (TC) factors can be defined as measures of near-crash events. A TC is defined as an observable situation in which two or more road users approach each other in space and time to such an extent that there is risk of collision if their movements remain unchanged (Hanowski et al., 2000; Hyden, 1987). Traffic conflict measures, such as time to collision (TTC), address the first condition of surrogate measures, namely the common factors that are shared with safety (Hayward, 1972). The shortest TTC illustrates the idea that events closer to the base of the triangle precede the events nearer to the top. However, the limitations of the TC measures are due to the often unproven relationship between the surrogate events and the crash occurrence. Many researchers have broached this thorny subject, suggesting that validity problems were at least partially due to the quality and coverage of the accident data (Chin and Quek, 1997; Zheng et al., 2014) and reporting the need for validation in relation to the diagnostic qualities of the TCT (Hyden, 1987). Thus, other authors (Migletz et al., 1985) indicated that TC studies can produce estimates of crash occurrences that are as good as those based on crash data but require a significantly shorter period for data.
From this point of view, the reliability of conflict measures can be improved by the use of objectively defined measures, for example, through processes involving video analyses (Songchitruksa and Tarko, 2006). Video-automated conflict analysis has been advocated as a new safety analysis paradigm that empowers the drawbacks of survey-based and observer-based traffic conflict analysis determining great benefits on safety management (Ettehadieh et al., 2015; Saunier and Sayed, 2014). In this framework, the target of the paper is to present a novel application of an in-vehicle stereo system that can be used to improve collection of data and development of traffic conflict measures.

Pedestrian crosswalk risk index

During a traffic conflict, when the opponent road user is a pedestrian crossing the street, to take into consideration both the chance of occurrence and the severity of a potential collision, a risk index (Cafiso et al., 2011) can be computed. Due to the dynamic evolution of the conflict, at each instant $i$ of the conflict phase ($TTZ_{\text{duration}}$), vehicle speed, position and distance from the conflict point have to be monitored (Fig. 1(a)) and time to collision of the vehicle $TTC_v$ has to be compared with its stopping time ($T_s$) to evaluate the actual possibility to avoid the collision (Fig. 1(b)).

The $TTC$ of the vehicle is obtained from the following equation, by considering as reference system the Cartesian one of the stereo vision equipment installed in the vehicle (Fig. 1(a)).

$$TTC_v(i) = \frac{D_v(z_i) + \sqrt{D_v(z_i)^2 - V_v(i)^2}}{V_v(i)}$$

where $TTC_v(i)$ is the vehicle time to reach the conflict area at instant $i$, $D_v(z_i)$ is the distance between the vehicle and the conflict area along the $Z$ axis at instant $i$, $V_v(i)$ is the vehicle speed at the instant $i$.

In the present application, a reaction time $T_r \approx 2.0$ s and a deceleration rate $a_b \approx 5.4$ m/s$^2$ were chosen as case study. Both these values were assumed taking into consideration the expected behavior of the bus driver with a mean reaction time and a low deceleration rate due to the care for the passengers inside the bus. In the practical applications these values can be varied to increase the system sensibility (e.g., higher reaction time and lower breaking deceleration). These $TTC$ of the pedestrian are calculated to check whether a pedestrian can arrive and remain into the conflict area in time to collide with a vehicle

$$TTC_{INp}(i) = \frac{D_x(i) + \sqrt{D_x(i)^2 - W_v^2}}{V_p}$$

where $TTC_{INp}(i)$ is the pedestrian time to reach the conflict area at instant $i$, $TTC_{LEAp}(i)$ is the pedestrian time to leave the conflict area at instant $i$, $D_x(i) \approx D_v(x_i) + D_p(x_i)$ is the gap between the vehicle and the pedestrian along the $x$ axis at instant $i$, $W_v$ is the width of the conflict area assumed equal to vehicle width, $V_p$ is the average crossing speed of the pedestrian.
It is possible to consider the following conflict circumstances, which determine the conflict occurrence and severity:

A) $\text{TTCv}(i) > \text{Ts}(i)$: vehicle may stop before reaching the conflict area.

B) $\text{TTCINp}(i) < \text{TTCv}(i) < \text{TTCLEAp}(i)$: potential collision between vehicle and pedestrian if their movements remain unchanged (traffic conflict);

C) $\text{TTCv}(i) < \text{TTCINp}(i)$: vehicle will cross the area of conflict before the pedestrian goes in (no traffic conflict);

D) $\text{TTCv}(i) > \text{TTCLEAp}(i)$: vehicle will cross the area of conflict after the pedestrian leaves it (no traffic conflict).

Table 1 shows the grade of chance of collision (CC class).

<table>
<thead>
<tr>
<th>Event</th>
<th>Probability</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{TTCv} &gt; \text{Ts}$</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>$\text{TTCv} &lt; \text{Ts}$</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
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If DT(i) is a measure of collision probability, in the event of a collision the severity of the consequences for pedestrian increases proportionally to the square value of vehicle speed $V^2 v(i)$ (Rosen et al., 2011).

Therefore, with DT(i) and $V^2 v(i)$, it is possible to compute the risk of the conflict as product of collision probability and severity, at each time of the conflict phase.

Where $\text{RI}(i)$ is the risk index at time i, $\text{DT}(i) \equiv \text{Ts}(i) \times \text{TTCv}(i)$ is the gap between the stopping time and the time to collision. Because, the seriousness of the risk also depends on the extension of the time duration (TTZ) and both DT(i) and Vv(i) vary during the conflict phase, the overall RI value for the entire conflict is given by the following formula $\text{RI}_{\text{tot}} = \int_{\text{TTZduration}} \text{RI}(i) \, \text{d}i = \int_{\text{TTZduration}} \text{DT}(i) 
\times \sqrt{V^2 v(i)}$ (6) where TTZduration is defined as the time interval from the beginning to the end of the high CC class (i.e., phases A and B) (Fig. 1(b)).

Stereo system

In computer vision, stereoscopy is a technique used to reproduce the appearance of three-dimensionality from images similarly to what the human visual system does (Read, 2015). When looking at a scene, the human visual system “fuses” the two images, acquired...
separately by the two eyes, into stimulus which are useful to reconstruct and perceive the depth of the observed scene. Thus, by broadcasting two separate views for the left and right eye, 3D can be perceived. In practice, however, it is more desirable to send only one camera view together with side information. This information can be represented by a matrix of the same size of the image, usually called depth-map. Benefit of this format is the ability to synthesize novel views and that depth-maps are highly compressible due to their characteristics. In practice, depth-maps are stored as gray scale images that show distance instead of texture. This means that an object located close to the camera turns out bright while a faraway located object looks darker and vice versa.

The biggest problem in stereoscopy is to find the correspondences between points belonging to the stereo images which are needed to compute the depth of the related 3D points (Llorca et al., 2010). Stereo vision technique is not the focus of this paper and vision issues related to the application were analyzed by the authors in previous papers.

Conclusions

The paper presents a novel application of in-vehicle stereo vision and GPS system for detection and evaluation of traffic conflicts. A case study with in field experiment, was useful to show practical applicability of the system in bus-pedestrian conflicts, but potential use can be extended to different traffic conflicts in the field of vision of the system (e.g., rear end collision) and road users (e.g., vehicle, motorcycle, bikes). Indeed, the system is able to identify any spatial information of objects in the video frame with the added value, when compared to traditional radar equipment, to turn out in real time a depth-map where spatial data are provided together with shape and color attributes of the object. These attributes, not available with other systems, can be used to carry out additional useful information for object recognition (e.g., pedestrian versus vehicle, red light versus green light lamps) and tracking (e.g., object trajectory and speed). Collected data can be used for naturalistic studies of drivers' and opponent road user behaviors during critical events (conflicts, near crashes, collisions). Moreover, recording and mapping the traffic conflicts provides data for both identification of high risk location along the bus route and monitoring of bus driver risk propensity and awareness. Moreover, the hardware and software performance of the system could be used in real time to activate in vehicle system for warning and driving assistance. In view of these applications, results pointed out as raw data acquired by the system (i.e., vehicle speed, distance and speed of the target) when used to carry out suitable traffic conflict measures (e.g., TTC) can improve the performance of the system by discriminating between false alarm and actual critical events.

References


