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Original Research Paper

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

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HIGHLIGHTS

- A stereo-vision and GPS for traffic conflict investigation is presented for detecting conflicts between vehicle-pedestrian.
- An urban bus was equipped with a prototype of the system.
- A risk index is proposed to classify collision probability and severity using data collected by the system.

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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.

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1. 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.

2. ITS for bus safety

European statistics shows that bus crashes account for only 1% of total road fatalities, but bus represents only the 0.35% of the overall motorized vehicles (ERF, 2010). Because of the low percentage of crashes involving buses and the assumption that public transport improves road safety by reducing the number of vehicles on the streets, public interest in bus safety is not as evident as for other types of vehicles (e.g., passenger cars, trucks, powered two wheels). Nevertheless, the introduction of new technologies, that can be easily and widely diffused in the bus market makes safety improvements challenging and of interest for the transport agencies as revealed by a pool among the operators (Cafiso et al., 2013a,b).

It is generally assumed that new technologies can support safety improvements. In particular, a great deal of attention has been paid to the effects of driver assistance systems on driver performance (Lin et al., 2008). However, challenges still remain in quantifying the effectiveness of these systems in 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 (Cafiso et al., 2013a,b).

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.

3. 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

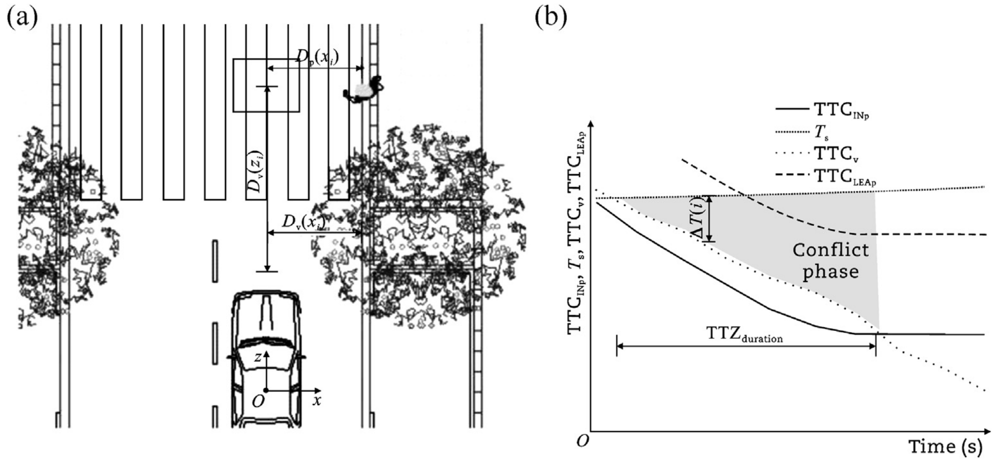

Fig. 1 – Parameters and their trends in computations. (a) Distances involved in a TTC computation. (b)Temporal trend of the quantities involved in the event and conflict area.

collection. 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.

3.1. *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 ($TTZ_{duration}$), 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 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)).

$$TTC_v(i) = D_v(z_i)/V_v(i) \tag{1}$$

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*.

The vehicle stopping time is calculated as

$$T_s(i) = T_r + V_v(i)/a_b \tag{2}$$

where $T_s(i)$ is the vehicle stopping time at instant *i*, T_r is the reaction time of the driver, a_b is the braking deceleration.

In the present application, a reaction time $T_r = 2.0$ s and a deceleration rate $a_b = 5.4\ m/s^2$ 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

$$TTC_{INp}(i) = [\Delta x(i) - W_v/2]/\overline{V}_p \tag{3}$$

$$TTC_{LEAp}(i) = TTC_{INp}(i) + W_v/\overline{V}_p \tag{4}$$

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*, $\Delta x(i) = D_v(x_i) - D_p(x_i)$ 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, $\overline{V}_p$ 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) $TTC_v(i) > T_s(i)$: vehicle may stop before reaching the conflict area.
B) $TTC_{INp}(i) < TTC_v(i) < TTC_{LEAp}(i)$: potential collision between vehicle and pedestrian if their movements remain unchanged (traffic conflict);
C) $TTC_v(i) < TTC_{INp}(i)$: vehicle will cross the area of conflict before the pedestrian goes in (no traffic conflict);
D) $TTC_v(i) > TTC_{LEAp}(i)$: vehicle will cross the area of conflict after the pedestrian leaves it (no traffic conflict).

In the perspective of an application for a warning assistant system to the bus driver, three grades of warning are defined

Table 1 – Grade of chance of collision (CC class).

PC	$TTC_v < TTC_{INp}$	$TTC_{INp} \le TTC_v \le TTC_{LEAp}$	$TTC_v > TTC_{LEAp}$
$TTC_v \ge T_s$	Low	Medium	Low
$TTC_v < T_s$	Medium	High	Medium

in Table 1 basing on the simultaneous combination of event (A) (potential severity) with one of events B (traffic conflict), C and D (chance of traffic conflict). The events corresponding to the first and last columns (circumstances C and D) aren't traffic conflicts by definition, but they are classified equally with low and medium severity, because any change in the speed of bus and/or of pedestrian could lead to a conflict in next seconds. Therefore, in the view of a warning system, this situation needs to be monitored due to the presence of the pedestrian in front of the Bus, even if it is not a TC at present.

Within the high CC class with both $TTC_v < T_s$ and actual traffic conflict (concurrent conflict circumstances A and B), increasing the gap $\Delta T(i)$ between TTC_v and $T_s(\Delta T(i) = T_s(i) - TTC_v(i))$ an increase of the probability of collision may be expected (i.e. the vehicle can't stop). The time variability of $\Delta T(i)$ is showed in Fig. 1(b) during the conflict phase highlighted as shadow area.

If $\Delta T(i)$ 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 $V_v^2(i)$ (Rosén et al., 2011).

Therefore, with $\Delta T(i)$ and $V_v^2(i)$, it is possible to compute the risk of the conflict as product of collision probability and severity, at each time of the conflict phase

$$RI(i) = \Delta T(i) V_v^2(i) \tag{5}$$

where RI(i) is the risk index at time i, $\Delta T(i) = T_s(i) - TTC_v(i)$ 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 $\Delta T(i)$ and $V_v(i)$ vary during the conflict phase, the overall RI value for the entire conflict is given by the following formula

$$RI_{tot} = \sum_{i \in TTZ_{duration}} RI(i) = \sum_{i \in TTZ_{duration}} \Delta T(i) V_v^2(i) \tag{6}$$

where $TTZ_{duration}$ 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)).

4. 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

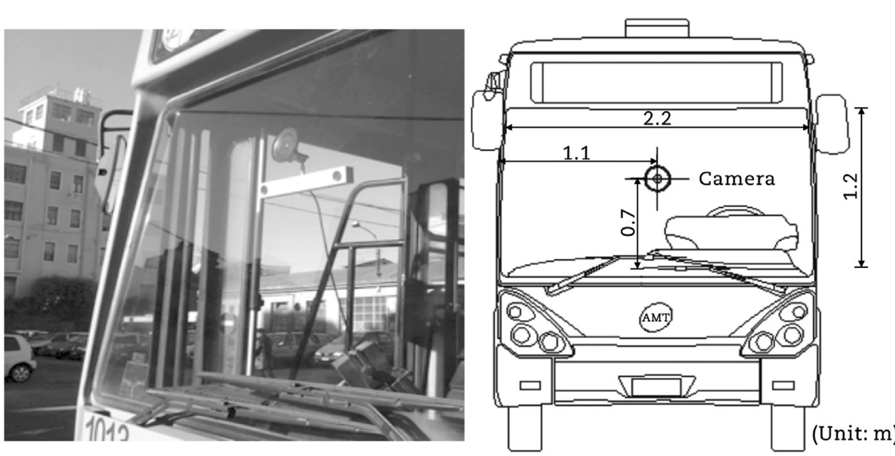

Fig. 2 – Proposal system on urban bus during the experiment phase.

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Table 2 – Datasheet of the EVS hardware used in experiment.

G3 embedded vision system specifications	
Power	11 W typ.: 12vdc or PoE CLASS III
Imagers	Aptina MT9V022 color, up to 60 fps, 752x480 pixels
Lens	83° horizontal FOV
Stereo baseline	33 cm
CPU	Freescale powerPC 8347 @400 MHz
Memory	256 mbytes
Operating system	Linux 2.6 kernel

(Battiato et al., 2013). For interest readers can find more information in Scharstein and Szeliski (2002). In the same way, readers could find interesting information on the use of stereo vision for obstacle detection in Labayrade et al. (2005) and in Perrollaz et al. (2010).

For this pilot application, the TYZX DeepSea G3 Embedded Vision System (EVS) (Labayrade et al., 2005) was employed to acquire stereo images and to obtain the depth-map related to the scene in front of the vehicle. For the case study, this piece of hardware was positioned in front windshield of the bus as depicted in Fig. 2.

The EVS implements a census-based stereo algorithm (Woodfill et al., 2006). As the input pixels enter the EVS, the census transform is computed at each pixel based on the local neighborhood, resulting in a stream of census bit vectors. At every pixel a hamming distance is used to compare the census vectors around the pixel of one view (i.e., left image) to those at 52 locations in the other view (e.g., right image). These 52 comparisons are performed simultaneously making the stereoscopic system very fast at subpixels precision. The EVS processor converts the pixels disparity map to metric distance measurements using the stereo camera's calibration parameters and the depth units specified by the user. In our setting, a stereo cameras with a baseline of 0.33 m and an 83° HFOV lens have been used. This configuration allows the overall system to work with distance in a range between 2.5 m and 50 m with enough precision (i.e., in the range between ±0.01 and ±1.00 m respectively). All the specifications of the EVS used for the experiments are reported in Table 2.

Fig. 3 shows a depth-map computed from the source stereo images (in the figure only the left one is shown). The depth of each point is coded by using gray scale colors from far points (i.e., black) to closer one. White color means that for those points the system couldn't find stereo correspondences useful to infer the depth information. Once the initial frame of the traffic conflict is detected, the obstacle that may have generated the conflict is identified as the closest point to the vehicle in the field of view. The target point is then automatically tracked in the successive frames in order to obtain measurements covering the entire traffic conflict event.

Fig. 4 reports a sequence of frames and the related depth-maps which show the target tracked and analyzed step by step by the system. Basing on the system specification and on in field tests a maximum 3% error can be expected in the estimation of position of the target (x, z coordinates) in front of the bus (Woodfill et al., 2006).

For the application of stereo vision described in this paper, image and depth information must be also geo-referenced. To achieve this requirement, EVS was connected and synchronized to a Bluetooth GPS receiver device placed on the external roof of the bus. A GPS, with a sampling frequency of 10 Hz (MTK II, L1 frequency, 66 Channels, NMEA-0183) was

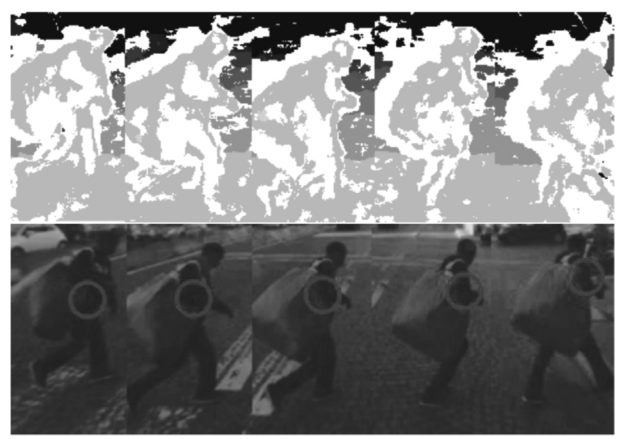

Fig. 4 – Five frames of a pedestrian generating a conflict tracked by the system.

Fig. 3 – Left sensor image and the computed depth-map.

used to collect information on vehicle position and time. During tests, GPS measures are copied directly from the data string stored in accordance with NMEA protocol. The raw data used in this study are.

- Vehicle's speed over ground. Accuracy is estimated in 0.1 m/s.
- Latitude (N) and longitude (E). Absolute position accuracy is 3.0 m (2D-RMS).
- Time is received as GPS time and recorded in the NMEA data in UTC time. Time is accurate to about 50 ns.

Routines have been implemented to synchronize GPS information with every single frame acquired by the EVS as described by Battiato et al. (2013). For a better understanding of working logic and data processing a flow chart is reported in Fig. 5.

The data treatment module computes the behavior of the actors involved in the conflict, in terms of speed and distance on the two axes components, according to the reference system. Specifically, longitudinal and transversal distance of target from the origin of the reference system defined by the stereo cameras, are identified by the way of the depth-map, vehicular speed and position of the reference system are derived from GPS NMEA string.

All data are recorded in a spreadsheet and dependent measures calculated to carry out the TC parameters as described in the previous paragraph.

Fig. 5 shows stereo system and GPS are synchronized for working together and respective data are merged to compute the conflict indices. More specifically, GPS provides speed and location of vehicle with a frequency of 10 Hz. The accuracy specifications of the two systems are in agreement because the main GPS precision is required in the estimation of the speed as part of the risk computation. The smaller accuracy in the positioning of the traffic conflicts is compatible with the needs of map visualization and overlapping of recursive events.

These data can be used both in real time to activate in vehicle system for warning and driving assistance and in post elaboration for naturalistic studies of driver behavior during critical events (conflicts, near crashes, collisions).

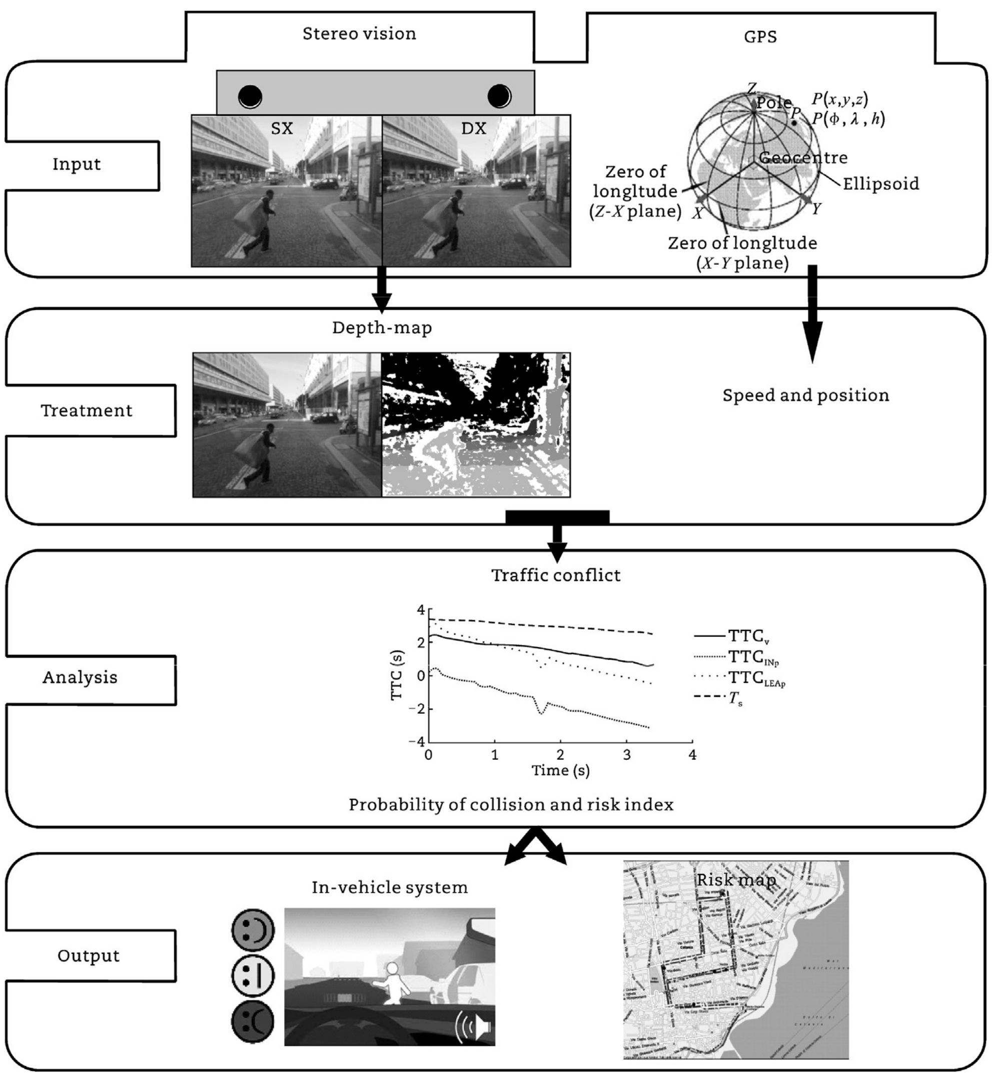

Fig. 5 – Flow chart of the proposed traffic conflict analysis procedure.

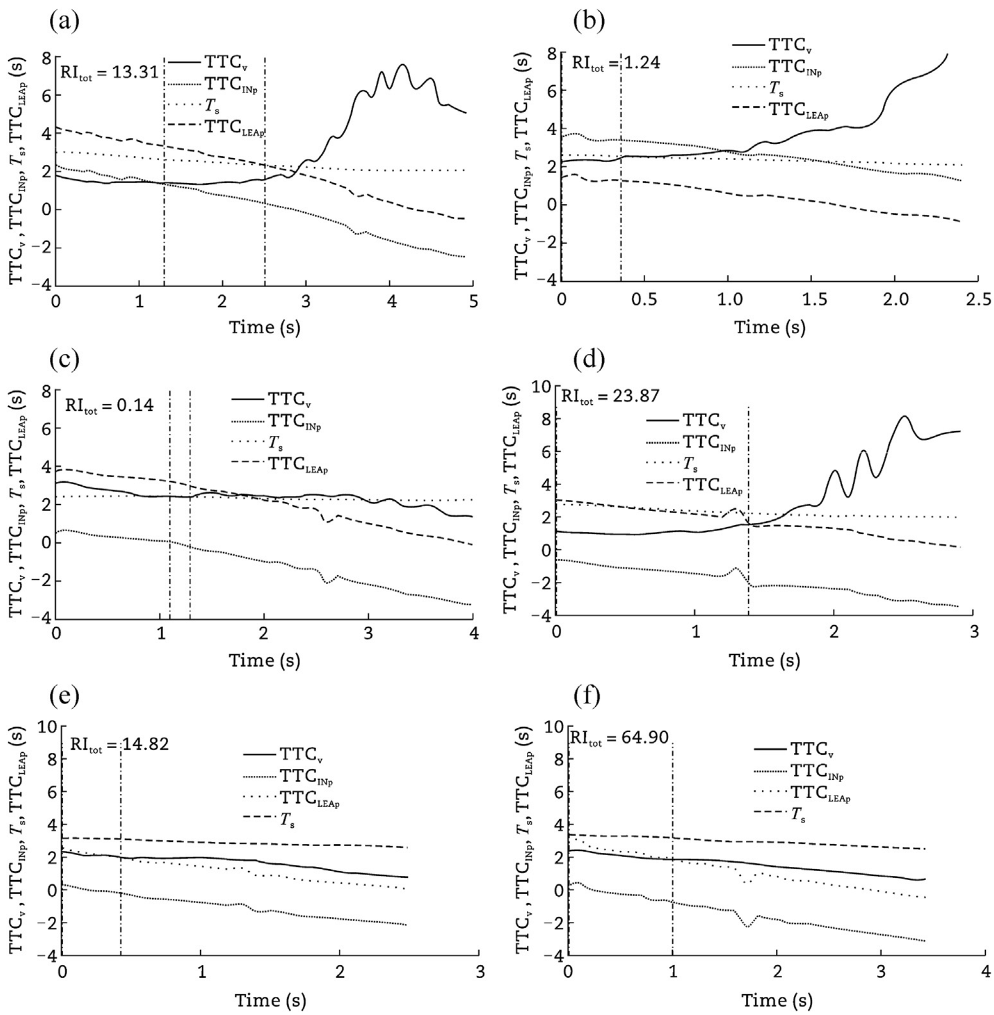

Fig. 6 – TC analysis of unsafe events registered during the survey. (a) Conflict No. 1. (b) Conflict No. 2. (c) Conflict No. 3. (d) Conflict No. 4. (e) Conflict No. 5. (f) Conflict No. 6.

5. Case study

A pilot implementation has been performed on real traffic condition in the city of Catania in Italy. The system has been mounted on a urban bus and about 8 h of acquisition have been carried out. Using the acquired data, TC analysis was performed at pedestrian crosswalks, road intersections and in a car following situations. The performance of the system only in the occurrence of a pedestrian crossing in front of the bus is presented. The computed measures are reported in Fig. 6 for all the critical conflicts ($RI_{tot} > 0$) registered during the survey (the conflict phase is inside the two dotted lines in Fig. 6). RI_{tot} values can be considered for a comparison evaluation of the traffic conflicts. Higher value of RI_{tot} means an increase of both probability and severity of collision. Among the nineteen events between bus and pedestrian identified in the experiment, only six were classified in the high CC class with $RI_{tot} > 0$ (Fig. 6), two of them showed the highest RI_{tot} scores (No. 4 and 6). The system presented in the paper demonstrates the potentialities for application in the field of road safety assessment and in vehicle driver assistant system (DAS), as well.

Locations of identified conflicts and values of RI_{tot} can be used to collect data on frequency and sites of traffic conflict along the bus route. Sites where a traffic conflict was detected can be reported in a map using GPS coordinates. Location and risk value of traffic conflicts along the bus route highlight proactively where a higher frequency and severity of potential crashes is expected basing on the traffic conflict theory (Heinrich, 1932; Hyden, 1987). Development of risk maps, by establishing a routine monitoring system to identify safety gaps in the road network, could be useful to implement safety improvements targeting to specific risks where the needs and potential crash reductions are the greatest (e.g., pedestrian facilities, visibility of pedestrian and motorist, slowing speed vehicle). In this way decision can be addressed using an a priori approach which doesn't need a crash history.

For example, in the presented case study, limited at only few runs of bus line 2–5 in the city of Catania (Fig. 7), results pointed out conflicts between bus and pedestrian are localized more in via Umberto rather than in Corso Italia.

Fig. 7 – Map of traffic conflicts in bus line 2_5 City of Catania, with picture of Corso Italia (top) and via Umberto (down).

These two streets, with reserved bus lane, are both in the downtown and shopping district with similar pedestrian flows, but only Corso Italia, despite is wider in the carriageway, has crosswalks at signalized intersection.

In the DAS application of the system, continuous evaluation of TTC during the bus ride can be used for real time monitoring of interaction between the vehicle and other road users (pedestrian crossing in front of the bus in the presented case study). This information can be used to actuate an in-vehicle warning signal to alert the bus driver. In the following figures (Figs. 8 and 9) the warning activation is represented by face icons (smile, indifferent, pout) for user friendly CC classification low, medium and high (Table 1).

In this field, it's pointed out the simple presence of a pedestrian in front of the bus is not necessarily the cause of alert (e.g., ID 30, 35, and 40 in Fig. 8), because actual bus distance and speed should be adequate for avoiding the collision. Other times, this event has to be signalized to the driver because the collision is possible if the vehicle and pedestrian movements remain unchanged (e.g., ID 1, 6, and 11 in Fig. 9). These results are clear examples that in the design of Activation Design Alert (ADA) the simple detection of a target in front of the vehicle is not necessarily the cause of warning to the driver.

6. 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

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ID	Frame	Time	D_x	D_y	V_v	TTC_v	TTC_{INp}	TTC_{LEAp}	T_s	RI
1	27357	0.0	−3.712	9.798	5.428	1.805	2.375	4.374	3.024	0.00
2	27358	0.1	−3.509	9.426	5.577	1.690	2.190	4.190	3.052	0.00
3	27359	0.2	−3.434	8.832	5.422	1.629	2.121	4.121	3.023	0.00
4	27360	0.3	−3.329	8.139	5.347	1.522	2.026	4.026	3.009	0.00
5	27361	0.4	−3.397	7.786	5.210	1.495	2.088	4.088	2.983	0.00
6	27362	0.5	−3.182	7.292	4.943	1.475	1.892	3.892	2.933	0.00
7	27363	0.6	−3.087	6.753	4.858	1.390	1.806	3.806	2.917	0.00
8	27364	0.7	−3.001	6.615	4.495	1.472	1.728	3.728	2.848	0.00
9	27365	0.8	−2.869	6.135	4.286	1.432	1.608	3.608	2.809	0.00
10	27366	0.9	−3.036	6.301	4.249	1.483	1.760	3.760	2.802	0.00
11	27367	1.0	−2.858	5.801	3.916	1.481	1.598	3.598	2.739	0.00
12	27368	1.1	−2.737	5.679	3.766	1.508	1.488	3.488	2.711	1.71
13	27369	1.2	−2.662	5.211	3.686	1.414	1.419	3.419	2.695	0.00
14	27370	1.3	−2.581	4.946	3.412	1.450	1.346	3.346	2.644	2.78
15	27371	1.5	−2.428	4.554	3.229	1.410	1.207	3.207	2.609	1.25
16	27372	1.6	−2.349	4.409	3.203	1.377	1.136	3.136	2.604	1.26
17	27373	1.7	−2.301	4.200	3.105	1.353	1.092	3.092	2.586	1.19
18	27374	1.8	−2.095	3.851	2.839	1.356	0.905	2.905	2.536	0.95
19	27375	1.9	−2.007	4.058	2.821	1.438	0.825	2.825	2.532	0.87
20	27376	2.0	−1.967	3.692	2.548	1.449	0.788	2.788	2.481	0.67
21	27377	2.1	−1.886	3.539	2.363	1.498	0.714	2.714	2.446	0.53
22	27378	2.2	−1.791	3.408	2.365	1.441	0.628	2.628	2.446	0.56
23	27379	2.3	−1.685	3.323	2.200	1.510	0.532	2.532	2.415	0.44
24	27380	2.4	−1.617	3.281	2.014	1.629	0.470	2.469	2.380	0.30
25	27381	2.5	−1.501	3.092	1.971	1.569	0.365	2.364	2.372	0.31
26	27382	2.6	−1.383	3.221	1.822	1.768	0.257	2.257	2.344	0.19
27	27383	2.7	−1.259	3.211	1.727	1.860	0.145	2.145	2.326	0.14
28	27384	2.8	−1.218	2.837	1.648	1.722	0.108	2.108	2.311	0.16
29	27385	2.9	−1.025	3.264	1.499	2.177	−0.068	1.931	2.283	0.00
30	27386	3.0	−0.917	3.321	1.255	2.646	−0.166	1.834	2.237	0.00
31	27387	3.1	−0.795	3.242	1.283	2.526	−0.277	1.723	2.242	0.00
32	27388	3.2	−0.657	3.342	1.100	3.039	−0.403	1.597	2.207	0.00
33	27389	3.3	−0.464	3.542	0.923	3.839	−0.578	1.422	2.174	0.00
34	27390	3.4	−0.335	3.389	0.896	3.782	−0.695	1.304	2.169	0.00
35	27391	3.5	−0.122	3.515	0.778	4.521	−0.889	1.111	2.147	0.00
36	27392	3.6	0.305	3.505	0.585	5.994	−1.277	0.723	2.110	0.00
37	27393	3.7	0.158	3.402	0.544	6.249	−1.143	0.856	2.103	0.00
38	27394	3.8	0.329	3.429	0.576	5.955	−1.299	0.701	2.109	0.00
39	27395	3.9	0.535	3.527	0.486	7.263	−1.487	0.513	2.092	0.00
40	27396	4.0	0.606	3.395	0.535	6.343	−1.551	0.449	2.101	0.00
										RI_{tot} = 13.31

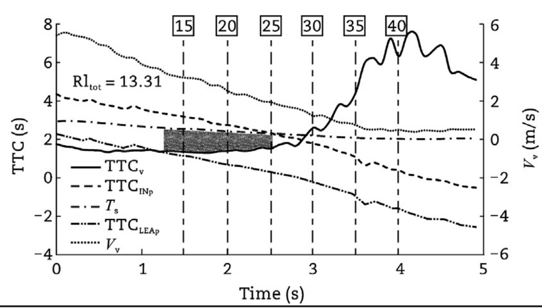

Fig. 8 – Images from conflict No. 1 with alert real time analysis.

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.

ID	Frame	Time	D_x	D_y	V_v	TTC_v	TTC_{INp}	TTC_{LEAp}	T_s	RI
1	27746	0.0	1.327	18.289	7.582	2.412	0.275	2.938	3.43061	5.86
2	27747	0.1	1.514	18.617	7.525	2.474	0.501	3.164	3.41976	5.35
3	27748	0.2	1.157	17.344	7.339	2.363	0.070	2.733	3.38470	5.50
4	27749	0.3	1.048	16.483	7.225	2.281	−0.063	2.600	3.36321	5.65
5	27750	0.4	0.973	15.966	7.237	2.206	−0.154	2.509	3.36551	6.07
6	27751	0.5	0.893	15.396	7.127	2.160	−0.250	2.413	3.34471	6.02
7	27752	0.6	0.850	14.644	7.077	2.069	−0.303	2.360	3.33522	6.34
8	27753	0.7	0.814	14.029	7.012	2.001	−0.346	2.317	3.32301	6.50
9	27754	0.8	0.576	13.236	6.817	1.942	−0.635	2.028	3.28616	6.25
10	27755	0.9	0.606	13.061	6.728	1.941	−0.598	2.065	3.26934	6.01
11	27756	1.0	0.506	12.468	6.454	1.932	−0.719	1.944	3.21766	5.36
12	27757	1.1	0.376	11.787	6.239	1.889	−0.877	1.786	3.17725	0.00
13	27758	1.2	0.263	11.345	6.058	1.873	−1.013	1.650	3.14308	0.00
14	27759	1.3	0.284	10.892	5.868	1.856	−0.988	1.675	3.10723	0.00
15	27760	1.4	0.122	10.514	5.724	1.837	−1.184	1.479	3.07993	0.00
16	27761	1.5	0.115	9.924	5.489	1.808	−1.192	1.471	3.03559	0.00
17	27762	1.6	−0.028	9.547	5.451	1.751	−1.365	1.298	3.02846	0.00
18	27763	1.7	−0.785	9.031	5.297	1.705	−2.282	0.381	2.99942	0.00
19	27764	1.8	−0.220	8.421	5.231	1.610	−1.597	1.066	2.98700	0.00
20	27765	1.9	−0.347	7.969	5.232	1.523	−1.751	0.912	2.98711	0.00
21	27766	2.0	−0.392	7.508	5.143	1.460	−1.806	0.857	2.97034	0.00
22	27767	2.1	−0.573	7.053	5.090	1.386	−2.026	0.637	2.96043	0.00
23	27768	2.2	−0.594	6.427	4.720	1.362	−2.050	0.613	2.89062	0.00
24	27769	2.3	−0.615	6.044	4.706	1.284	−2.076	0.587	2.88784	0.00
25	27770	2.4	−0.734	5.594	4.548	1.230	−2.219	0.444	2.85807	0.00
26	27771	2.5	−0.793	5.124	4.384	1.169	−2.292	0.372	2.82725	0.00
27	27772	2.6	−0.899	4.719	4.255	1.109	−2.420	0.243	2.80288	0.00
28	27773	2.7	−0.952	4.312	4.156	1.038	−2.484	0.179	2.78407	0.00
29	27774	2.8	−1.039	3.940	3.828	1.029	−2.589	0.074	2.72222	0.00
30	27775	2.9	−1.109	3.533	3.747	0.943	−2.674	−0.011	2.70702	0.00
31	27776	3.0	−1.158	3.195	3.672	0.870	−2.733	−0.070	2.69277	0.00
32	27777	3.1	−1.245	2.922	3.454	0.846	−2.838	−0.175	2.65178	0.00
33	27778	3.2	−1.334	2.504	3.397	0.737	−2.947	−0.284	2.64093	0.00
34	27779	3.3	−1.415	2.056	3.245	0.634	−3.044	−0.381	2.61232	0.00
35	27780	3.4	−1.482	2.037	2.905	0.701	−3.125	−0.462	2.54806	0.00
										RI_{tot} = 64.90

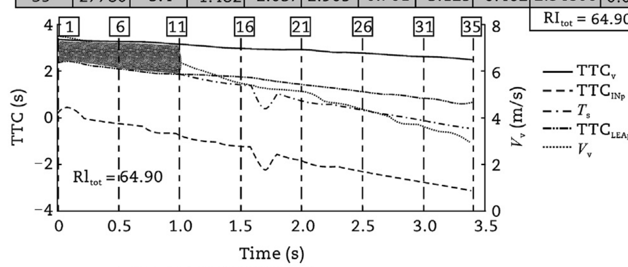

Fig. 9 – Images from conflict No. 6 with alert.

Future works and challenges are addressed to explore the feasibility and practicality of automated detection of pedestrians approaching a bus (or any other equipped vehicle).

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