SAFETY ASSESSMENT OF PEDESTRIAN CROSSINGS WITH VIDEO ANALYSIS

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Abstract:
Poland has the worst pedestrian fatality rate in the European Union. In the years 2007-2011, 7944 pedestrians were killed on Polish roads and about 30% of these victims were hit by vehicles on marked pedestrian crossings. This paper presents preliminary findings from the MOBIS research project which is aimed at developing a method for assessing the safety of pedestrian road crossings using video image analysis. During the project, field tests were conducted on zebra crossings with different safety measures. Pedestrian and vehicle traffic was recorded with several digital cameras at a selected crossing site in Warsaw for 2 months, before and after installation of safety measures which included active signage and speed cushions. The speeds of approaching vehicles were measured and vehicle-pedestrian conflict situations identified using video analysis. Statistical analysis of dangerous situations was conducted in order to develop surrogate safety measures appropriate for pedestrian crossings. Results indicate that both SignFlash active signage and speed cushions reduce mean vehicle approach speeds and have a positive impact on driver behaviour.

Keywords: Pedestrian safety, pedestrian crossing, image analysis, conflict technique

INTRODUCTION
Poland has the highest pedestrian fatality rate in the European Union – 37 pedestrians killed per million of the population. During the years 2007-2011 on Polish roads 7944 pedestrians were killed and 61635 injured. About 30% of accidents involving pedestrians occurred at marked pedestrian crossings where pedestrians should feel safe. Improvement of pedestrian safety is one of the priority goals of the Polish National Road Traffic Safety Programme (2013).

This challenge has been taken up by the MOBIS research project which is aimed at developing and testing a method for assessing the safety of pedestrian road crossings using automatic video analysis. The method is based on detection of traffic conflicts, i.e. situations which could lead to an accident. The number of conflicts is several times higher than accidents – it is estimated that for one pedestrian-vehicle accident there are around 3000 conflicts. Therefore, it is hoped that the proposed method will make it possible to conduct safety assessments based on relatively short observation periods and will provide an objective evaluation of measures used to improve pedestrian safety. The aim of the paper is to present the preliminary findings from surveys conducted in 2013 at the first test site in Warsaw.

In the classical Swedish conflict method developed in the 1970s, conflict was defined as the situation in which two road users approach each other in time and space in such a way that an accident is highly probable if their movements remain unchanged (Laureshyn et al., 2010). In the Dutch conflict technique called “Doctor” (Van der Horst and Kraay, 1986) in
addition to the conflicts as defined above, situations when two road users crossed paths within a very short time are also regarded as dangerous. Conflict identification is based on estimated time to collision at the moment when an evasive action was initiated. This value, called "time-to-accident" together with vehicle speed is used to determine the seriousness of a conflict situation. As these parameters are rather difficult to determine precisely based on automatic video analysis, surrogate safety measures based on parameters other than the number of serious conflicts were proposed by other researchers. In the British method of assessing pedestrian safety (Kaparias et al., 2010), the distance to collision as well as the severity and complexity of evasive action are also considered. The Italian-Spanish method (Cafiso et al., 2011) proposed a new Pedestrian Risk Index which is based on estimated probability of accident occurrence and the seriousness of its probable consequences.

SURVEYS IN WARSAW

Site characteristics

While selecting test sites the following criteria were essential: a sufficiently high pedestrian traffic volume, a significant number of pedestrian-vehicle accidents in the past, land use in the vicinity of the crossing and availability of facilities for test equipment installation. The crossing at the intersection of Wrocławska and Błatona streets, where 6 pedestrian-vehicle accidents were reported from 2006 to 2011, was selected as the test site.

The analysed section of Wrocławska Street is a four-lane undivided road. The zebra crossing has a pedestrian refuge island and is marked properly with vertical and horizontal signs. Traffic surveys performed from 7am to 7pm showed a pedestrian crossing volume of 150-420 persons per hour in both directions.

For each direction a separate vision recording system was installed. It consisted of the following components:

- a digital overview camera (V1) covering an area of the pedestrian crossing and its road approach section of 30-40 m;
- two digital directional cameras (ANPR) (L1, L2) covering road sections approximately 3.5 m wide and 6 m long, located at the beginning of the approach area defined as the detection zone of the overview camera;
- a workstation used for recording and preliminary analysis of the digital video signal taken from the cameras and enabling remote control and diagnostics.

On the plan of the test site (Fig. 1) movement directions are marked as follows: POW in a direction towards Powstańców Śląskich St., and RAD in a direction towards Radiowa St. The picture shows the approximate viewing area of particular cameras – the light (yellow) solid line stands for the overview camera V1 whereas the dark (red) hatched box for the detection area of the directional cameras L1 and L2.

Safety improvement measures used

Two solutions used to improve pedestrian safety were investigated:

- speed cushions – installed on 18.10.2013, removed on 26.11.2013, located on Wrocławska street in the RAD direction, 30 m upstream of the crossing;
- the SignFlash system – installed on 16.10.2013, removed on 10.11.2013, mounted on existing sign poles in front of the pedestrian zebra crossing in the POW direction.

The SignFlash system (SF) is an example of an active signage system. It is equipped with pedestrian movement sensors which activate yellow flashing lights when pedestrians are crossing the road (Czajewski et al. 2013).
Measurement period

The recording system was activated on 23.09.2013 and worked for a total number of 88 days (with some technical break periods) until 19.12.2013. Table 1 presents the average daily number of vehicles registered in particular lanes and directions by the cameras. For both directions a trend of slight traffic growth was observed.

Table 1. The average daily number of vehicles detected (excluding downtime)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>POW-L1</td>
<td>2 456</td>
<td>2 545</td>
<td>2 540</td>
<td>2 660</td>
</tr>
<tr>
<td>POW-L2</td>
<td>1 766</td>
<td>2 128</td>
<td>2 100</td>
<td>2 308</td>
</tr>
<tr>
<td>Total POW</td>
<td>4 222</td>
<td>4 672</td>
<td>4 640</td>
<td>4 968</td>
</tr>
<tr>
<td>RAD-L1</td>
<td>2 906</td>
<td>2 979</td>
<td>2 924</td>
<td>3 257</td>
</tr>
<tr>
<td>RAD-L2</td>
<td>2 225</td>
<td>2 381</td>
<td>2 180</td>
<td>2 323</td>
</tr>
<tr>
<td>Total RAD</td>
<td>5 131</td>
<td>5 360</td>
<td>5 103</td>
<td>5 580</td>
</tr>
</tbody>
</table>

VEHICLE SPEED ANALYSIS

Speed measurement method

Both directional and overview (fish-eye) cameras were used for speed measurements of vehicles approaching the pedestrian crossing. The overview cameras recorded vehicle passes on a section of roadway of about 30 m in length, which allowed determination of their trajectories and speed profiles.

The directional (ANPR) cameras determined vehicle speeds using a frame-by-frame method, i.e. measuring the distance travelled between subsequent frames of the recorded video. The cameras underwent a calibration process in order to determine lens distortion coefficients and the three parameters required to assess vehicle speeds – two camera tilt angles (external parameters) and a scaling factor (an internal parameter dependent on focal length). The measurements were taken at the start point of the vehicle registration plate recognition area. The speeds measured at such a distance do not allow for precise assessment of the drivers’ responses to the events within the area of the crossing (people waiting and crossing, other vehicles), but they allow for analysis of the speed variations during the day and longer periods and also allow for determining the impact on the speed of the safety improvement measures introduced.
Verification with laser measurement

In order to verify the accuracy of the video speed measurements, test-vehicle runs were made by a car equipped with a high-accuracy laser (margin of error of less than 0.3%) (Taubert and Wierzejski, 2013). The test runs were conducted in both lanes in both directions. Over a dozen runs were registered on each lane with different speed profiles. The speed profiles from the laser measurements were compared to the profiles from the video measurements.

The calculated error of the overview cameras measurement was up to 10% for the right lane and 25% for the left lane for the POW direction. This corresponds to several or even more than a dozen km/h. Generally the error has a positive value, decreasing while approaching the crossing and minimal at the crossing. The precision of the speed measurement was then considered acceptable from the point of view of conflict analysis. The measurement errors are minimal in the area of potential conflicts, i.e. at the pedestrian crossing itself. Additionally, an attempt was made to reduce the errors using non-linear correction. Finally, the errors did not exceed a few percent of the real speed. The errors are different for particular directions and even lanes, so that it is necessary to calculate the correction curves for each lane individually. Fig. 2 presents the speed profiles for a single pass, together with a proposed correction in order to get the best fit to the laser measurement. Based on initial calculations the directional camera measurement margin of error did not exceed 3%.

![Fig. 2. Speed profile comparison: video camera vs. the laser measurement](image)

Speed comparison in the analysis period

The results of the directional camera measurements allowed for comparison of the mean vehicle speeds before and after installation of the safety measures, i.e. the SignFlash system and speed cushions. Seven weekdays with similar traffic volumes were chosen for the analysis of both periods. The results (Table 2) show that after installing the SignFlash system mean speeds decreased by 2.7 km/h (6.1%). After its removal speeds rose by 1.3 km/h which indicates the so-called memory effect, i.e. a permanent change of driver behaviour.

In the case of the speed cushions, the speed reduction is significant, as expected, reaching 12.3 km/h (32%). Also in this case a memory effect was observed – after removal of the speed cushions the speeds increased by only 9.8 km/h. A statistical analysis done separately for each lane led to rejection of a hypothesis of equal mean speeds (before and after) with a significance level of $\alpha=0.01$.

An analysis of the standard deviations shows a marginal impact of the SignFlash system on the mean speed dispersion (13.5 before, 13.1 during and 12.6 km/h after) and a great impact of the speed cushions (respectively: 16.2; 9.7; 14.4 km/h).
Table 2. Vehicle speed comparison during the analysis period

<table>
<thead>
<tr>
<th>Lane</th>
<th>Before installation</th>
<th>During operation</th>
<th>After removal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean speed (km/h)</td>
<td>Std dev. (km/h)</td>
<td>Traffic volume (veh/day)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction POW – SignFlash system</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>right</td>
<td>43.8</td>
<td>12.9</td>
<td>2677</td>
</tr>
<tr>
<td>left</td>
<td>47.5</td>
<td>14.2</td>
<td>2269</td>
</tr>
<tr>
<td>both</td>
<td>45.5</td>
<td>13.5</td>
<td>4946</td>
</tr>
<tr>
<td>Direction RAD* - speed cushions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>right</td>
<td>41.3</td>
<td>12.9</td>
<td>3186</td>
</tr>
<tr>
<td>left</td>
<td>33.2</td>
<td>19.7</td>
<td>2364</td>
</tr>
<tr>
<td>both</td>
<td>37.9</td>
<td>16.2</td>
<td>5550</td>
</tr>
</tbody>
</table>

* Lower mean speeds in the left lane result from left-turning traffic

INITIAL IDENTIFICATION OF CONFLICTS

Vehicle and pedestrian detection and tracking in video sequences

Initial vehicle detection is triggered by the ANPR system that localises licence plates, and thus vehicle fronts, in several consecutive frames as shown in Fig. 3. Simultaneously, the vehicle’s position and spot speed at the beginning of the detection zone are calculated. This information is used to initialise the vehicle front localization and tracking algorithm in the overview camera image sequence, where the licence plate detection method fails due to small vehicle dimensions, especially at the farthest range. Through appropriate calibration of the vision system we are able to track and localise fronts of detected vehicles in the Cartesian coordinate system of the street and pedestrian crossing in each video frame or every 40 ms.

The same overview camera employed for vehicle tracking is used for pedestrian detection. This approach is beneficial as it eliminates problems of inter-camera time synchronization and establishing of the common coordinate system – potential sources of error in multi-camera setups. Initially, the online in-camera motion detection algorithm was used for pedestrian detection, but it failed to provide accurate and time-deterministic results - almost half of the pedestrians were missed, and many of those detected featured short and jagged trajectories (due to a long and uneven sampling rate). Instead, an offline background subtraction method based on the Gaussian Mixture Model was successfully implemented. The results were filtered and most false detections were excluded, resulting in mainly correct pedestrian position estimation. It must be noted, however, that due to the large variety of pedestrian appearances and behaviours, as opposed to vehicles, their detection and tracking
quality is lower than for vehicles. Nevertheless, the latest, optimised version of our algorithm enables correct detection and tracking of nearly 99% of pedestrians (when small groups of pedestrians are counted as one) in favourable weather conditions (see Fig. 4).

![Pedestrian detection results](image)

**Fig. 4 Pedestrian detection results**

### Difficulties and remedies

The trajectories of detected vehicles and pedestrians are generated in each frame (every 40 ms) based on the image position of objects of interest and appropriate calibration of the vision system. They are modelled by cubic splines with curvature constraints based on object static and dynamic properties such as admissible position, velocity and acceleration. Owing to significant differences both in the appearance and the dynamics of pedestrians and vehicles, the trajectories of the former are a little less robust, especially in harsh weather.

In favourable conditions (daytime, overcast, no rain, no occlusions) we were able to correctly detect and track nearly 100% of vehicles and pedestrians. These results were just minimally worse for vehicles during strong sunshine (shadows) or rainfall (blurred image), but the negative impact of weather conditions on pedestrian detection was much stronger – some pedestrians were missed and many trajectories of those detected were incomplete. Therefore, in further evaluation we disregarded these corrupted data. Another problem deteriorating the overall detection level were occlusions of vehicles and pedestrians moving close to one another. These situations occur usually in heavy traffic and have no influence on initial detection of conflicts. Efforts are being made to improve pedestrian detection, especially in bad weather conditions.

An interesting error of pedestrian detection was caused by image noise, random light reflections, shadows etc. Owing to high sensitivity of the motion detection algorithm (that would otherwise miss many true positives) such phenomena (called ‘ghosts’) were often identified as pedestrians. In the latest version of the system they constitute approximately 11% of all detections. However, they are easily removed by a random trees classifier trained with several thousand trajectories.

### Detection of dangerous situations

In the first stage of trajectory analysis, three criteria defining potentially dangerous situations were used:

1. Vehicle stopping in front of pedestrian on zebra crossing (yielding to pedestrian)
2. Vehicle deceleration (exceeding $4 \text{ m/s}^2$) during dynamic braking before a pedestrian
3. Smallest distance (less than 2 m) between pedestrian and vehicle, while the latter is moving faster than 30 km/h.

More complex factors based on precise trajectory analysis and potential collision spot prediction will be computed automatically once the entire video data is processed with our latest detection and tracking algorithm. Preliminary conflict statistics with and without the SignFlash system are shown in Table 3. The analysis was conducted for 9 preselected weekdays with comparable traffic and favourable weather conditions.

Table 3. Number of registered events with and without the SignFlash system

<table>
<thead>
<tr>
<th>Sum of events</th>
<th>Vehicle yielding to pedestrians (1)</th>
<th>Vehicle breaking dynamically in front of pedestrians (2)</th>
<th>Vehicle quickly passing close to pedestrian (3)</th>
<th>Other vehicle-pedestrian encounters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without SF</td>
<td>1490 (29.7%)</td>
<td>50 (1.0%)</td>
<td>23 (0.5%)</td>
<td>3457 (68.8%)</td>
</tr>
<tr>
<td>With SF</td>
<td>1844 (30.6%)</td>
<td>90 (1.5%)</td>
<td>23 (0.4%)</td>
<td>4062 (67.5%)</td>
</tr>
</tbody>
</table>

Contingency analysis for the above data performed with $\chi^2$ statistics leads to the conclusion that at a $\alpha=0.1$ level of significance the active signage system did have a positive influence on driver behaviour. Table 3 shows that the SignFlash system would make drivers yield to pedestrians slightly more frequently (increase by approx. 3%). It is worth noting that with the SignFlash system drivers decided to brake dynamically while yielding to pedestrians much more often (increase by approx. 50%). The actual number of records where vehicles pass a pedestrian at not less than 30 km/h and closer than 2 m was exactly the same in both cases, however the percentage of such events dropped by approximately 20%.

**ANALYSIS OF DANGEROUS SITUATIONS**

On the basis of the data obtained from the video analysis a preliminary identification of dangerous situations was done. The situations were divided into three groups (Fig. 5):

- **Situation A** – vehicle slows down or stops close to the pedestrian crossing, as the driver sees a pedestrian in the act of crossing (yielding to pedestrian).
- **Situation B** – vehicle passes directly in front of a pedestrian who is on the zebra crossing (driver does not yield to pedestrian).
- **Situation C** – vehicle passes immediately behind a pedestrian who is on the zebra crossing (driver does not yield to pedestrian).

![Fig. 5 Sketches of the situations analysed](image)

Preliminary results of analyses for the POW direction with and without the SignFlash system are presented in Fig. 6-8. The analysis was performed for 9 selected days of similar traffic...
and good weather conditions. For each event, the minimum distance between pedestrian and vehicle ($D_{\text{min}}$) was calculated and speed of the vehicle at that moment was determined.

Fig. 6 shows the results of analyses of the events classified as situation A (2445 interactions without and 3107 with SF). Drivers were more likely to give way to pedestrians when the SF system was installed and the average vehicle speed was lower in this case.

Fig. 7 shows the results of analyses of situation B events (100 interactions without SF and 125 with SF). The average vehicle speed was lower in almost all intervals of the minimum
pedestrian/vehicle distance when the SF system was operating. For distances up to one metre the calculations were omitted due to the small sample size.

Fig. 8 shows the results of situation C analyses (359 interactions without SF and 403 with SF). A small drop of average speed was observed with the SF system installed.

The most serious conflict was registered on 13.11.2013 (without SF), when a fast driving taxi barely missed a pedestrian by swerving into the pedestrian refuge island (Fig. 9).

![Fig. 9 The most serious conflict recorded](image)

On the basis of the calculated trajectory of the vehicle and the pedestrian, a detailed analysis of the situation shown above was made by calculation of Time Advantage (TA) and Time to Collision (TTC) (Fig. 10). The results were compared with the values obtained from the same situation using the T-Analyst program developed by the University of Lund (Laureshyn, 2013). Minor differences between the two curves result from inaccuracies of the speeds of the two objects.

![Fig. 10 Lund and MOBIS method comparison](image)

**CONCLUSIONS**

The results obtained from video analysis of the material recorded at the test pedestrian crossing site in Warsaw show that both the recording system and the analytical algorithms used allow us to detect and determine vehicle trajectories with sufficient accuracy. However, detection and tracking of pedestrians pose more problems, especially under difficult weather and lighting conditions. An improved offline algorithm allows for a high pedestrian detection rate (up to 99%) and promises to increase the accuracy of mapping pedestrian trajectories.
Analysis of spot vehicle speeds before the pedestrian crossing shows that both the SignFlash system (dynamic signage) and speed cushions cause a statistically significant reduction of the mean speed of vehicles approaching the crossing.

A method has been developed for automatic detection of situations such as: dynamic/abrupt breaking in front of a pedestrian and passing close to a pedestrian at high speed. A reduction in the proportion of such situations during the period when the SignFlash system was in operation suggests that it has a moderate positive influence on driver behaviour and thus increases pedestrian safety.

The method used for determining pedestrian and vehicle trajectories allows for computation of Time Advantage (TA) and Time to Collision (TTC) parameters and the results are comparable to those obtained with the Swedish T-Analyst program. However, these calculations cannot be fully automated. Further research is focused on classification of pedestrian-vehicle interactions using pedestrian-vehicle distance and the relative speed at the moment when that distance is minimal. It is hoped that this approach will lead to a surrogate safety measure for pedestrian crossings which could be computed automatically.

References


