



Innovative solutions for improving safety at pedestrian crossings

W. CZAJEWSKI^a, P. DĄBKOWSKI^b, P. OLSZEWSKI^b

^aWARSAW UNIVERSITY OF TECHNOLOGY, FACULTY OF ELECTRICAL ENGINEERING, pl. Politechniki 1, 00-661 Warszawa, Poland

^bWARSAW UNIVERSITY OF TECHNOLOGY, FACULTY OF CIVIL ENGINEERING, al. Armii Ludowej 16, 00-637 Warszawa, Poland

EMAIL: w.czajewski@ee.pw.edu.pl

ABSTRACT

Many pedestrians in Poland are killed or injured while crossing the road. This paper gives an overview of innovative solutions aimed at improving safety of pedestrian crossings: automatic pedestrian detection, dynamic traffic signs and better lighting systems. Among the pedestrian detection systems, video technology with image analysis seems to be the most promising solution for the future – its problems, recent developments and advantages are presented. Pedestrian detectors are already utilized by dynamic traffic signs which include pulsating lights mounted on “pedestrian crossing” signs, activated when pedestrians waiting to cross are detected.

KEYWORDS: traffic safety, pedestrian crossings, pedestrian detection

1. Introduction

Poland currently has the worst pedestrian traffic accident statistics in the European Union. Although there has been reduction in the number of fatalities in recent years, 1408 pedestrians were killed and 10320 injured in 2011. Pedestrians killed on Polish roads constitute 25% of all pedestrian fatalities in the European Union, while only 8% of EU population lives in Poland. In large Polish cities pedestrians constitute over 60 percent of all road accident victims. This alarming situation of pedestrians on Polish roads has been known and reported for many years [16], but actions taken so far improved pedestrian safety only to a small degree.

Accident statistics in Poland are based on the Polish Police accident database – SEWiK (System of evidence of accidents and collisions). These statistics show that about 30,8% of all pedestrian victims of road accidents in Poland were hit on marked pedestrian crossings.

The aim of this paper is to present innovative measures of improving safety of pedestrian road crossings using automatic pedestrian detection. It is hoped that promoting best practices will lead to a reduction of the numbers of pedestrians killed or injured on Polish roads.

2. Pedestrian crossing design

2.1 Signalized crossings

A popular solution of increasing safety at pedestrian crossing is to introduce traffic signalization. Signalized crossings allow pedestrians to cross the road during signal phases when they are not in conflict with vehicles. This significantly improves pedestrian safety.

Use of signalization means that pedestrians cross only during specific dedicated time intervals. Fixed-time signals are the most common – in this solution the cycle time and durations of all phases are pre-determined.

An alternative arrangement is a traffic-actuated signal, where the green light allowing pedestrians to cross safely is activated by pedestrians pressing a pushbutton. In such cases, pedestrian phase is included in the signal cycle (at intersections) or started (at mid-block locations) [5].

2.2 Unsignalized crossings

Signalized crossings described above are rather expensive to build and maintain, therefore by far the most common are

unsignalized crossings. At these locations, pedestrians are more vulnerable, so it is essential to signpost these crossings in such a way that drivers can easily spot them from sufficiently far away.

Polish regulations [20] require that an unsignalized pedestrian crossing be marked with the D-6 traffic sign (“pedestrian crossing”). It should be located 0.5 m in front of the upstream edge of the crossing, facing the oncoming traffic. To enhance its visibility, the sign can be placed on a reflective background. In addition, the surface of pedestrian crossing is demarcated by white stripes painted on the road surface (P-10 horizontal sign “Zebra crossing”). The minimum crossing width is 4 m and the maximum is 16 m [21].

2.3 Speed reduction measures

Sometimes the signage described above is not sufficient to make the crossing safe. Pedestrian crossings can then be designed with additional elements which force drivers to reduce speed when approaching a crossing. Such traffic calming solutions include:

- pedestrian refuge – a curbed traffic islands placed in the center of a road at intersections or mid-block [31], it allows pedestrians to cross in stages and forces vehicles to slow down by bending away vehicle paths, the minimum width of refuge island should be 2 m [22];
- roadway narrowing – this is achieved by curving the alignment of the outer roadway edges at an appropriate length (max 20m) [23] when drivers feel more confined, they tend to drive slower, improving the visibility of pedestrians waiting to cross is an additional advantage;
- raised crossing – raising the crossing surface has a similar effect as the road hump, this solution is used for lower class roads, where there is no public transport bus traffic [21].

3. Pedestrian presence detection

3.1 Detection technology

The simplest and by far the most common method of pedestrian presence detection near zebra crossings is the use of push buttons. However, this solution is not appealing to users and is often ignored by them, which leads to dangerous situations. Therefore there is a need for automatic and passive (i.e. not requiring physical actuation by the pedestrians) method of pedestrian presence detection. This task is crucial for advanced driver assistance systems that implement pedestrian protection as well as for infrastructure solutions that aim to minimize the risk of vehicle-pedestrian conflict. The objective of such systems is to undertake some pedestrian protective actions in case a pedestrian is detected in a potentially dangerous zone in front of the moving vehicle. Most of the conducted research is focused on autonomous on-board (vehicle mounted) systems, however due to occlusions (especially at intersections or pedestrian crossings), such systems often fail to detect a dangerous situation. Therefore, there is a growing interest in passive infrastructure-based pedestrian

detection systems that use stationary sensors at intersections and/or pedestrian crossings and communicate with vehicles or crossing signalization to improve the overall performance of the road safety system [3, 12, 19].

There are five commonly used types of passive pedestrian detection technologies:

- Piezometric - senses a change of pressure on a pressure-sensitive mat,
- Ultrasonic - emits an ultrasonic wave and measures the delay of the returning signal bouncing off an object within the field of view,
- Passive infrared (PIR) – detects the infrared radiation emitted by all objects within the field of view,
- Microwave/Doppler radar - emits a radio wave and measures the change in frequency of the returning signal bouncing off a moving object within the field of view,
- Video analysis – uses machine vision to detect movement and identify pedestrians and vehicles within the field of view.

Pressure-sensitive pads installed at curbside can detect the presence of pedestrians by measuring their weight and are less influenced by weather conditions and other environmental factors than other types of sensors. However they require costly installation and work correctly only if a pedestrian steps directly on them - otherwise they will not detect pedestrians at all.

During preliminary tests of ultrasonic, passive infrared and microwave sensors described in [2] the detection rates varied from 47 to 96 percent and exceeded 89 percent after the sensors were optimally positioned and calibrated. Subsequently, a combination of 2 Doppler radars for cross-walk and 2 infrared devices for curbsides as shown in Fig.1 resulted in 100 percent detection in a long-term testing on 60 crossings.

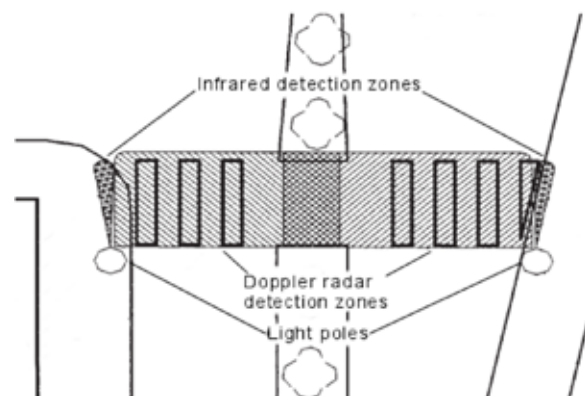


Fig.1. Plan view of pedestrian crossing with marked detection zones

Other sources like [18], however, are less optimistic about the detection rate of the two most commonly used types of sensors: infrared and microwave. They report typical error rates in the 20 to 30 percent range and about 9 to 11 percent when the pedestrian movement area is constrained and/or the pedestrian detection area is well-defined. These results are similar to those reported in [15] and summarized in Table 1 below, where several representative studies were analyzed.

Table 1. Device Accuracy for Different Technologies

Methodology	Detection ratio [%]	
	Controlled conditions	Real application
Passive infrared	93–100	78–98
Microwave	100	58–100
Video	100	79–92

In recent years video-based detection technology has attracted attention of many researchers. It is becoming or already has become the most commonly used method for pedestrian detection in urban traffic scenes as cameras are relatively cheap and provide high-speed, high-resolution and content-rich data [14]. Reviews of video-based pedestrian detection methods, applications and benchmarks can be found for example in [6, 8, 9, 17]. Many projects often combine two or more sensors that provide complementary information about the observed scene and thus increase the robustness of people detection. They include stereo-vision or data fusion of a monocular camera and lidar, radar, IR camera, time-of-flight camera etc. Multi-sensor systems for stationary intersection monitoring are described for example in [11]. Despite the above, cameras working in visible spectrum seem to be the most popular sensors in such systems.

3.2 Use of CCTV and image analysis

The main challenge of a vision-based pedestrian detection system is an efficient detection of people, which is usually quite difficult as:

- the appearance of pedestrians is very highly variable in terms of pose, colors, sizes and viewing angles,
- pedestrians must be identified in usually cluttered and dynamic urban scenes, where occlusions (by other pedestrians, vehicles or infrastructure) and changing lighting and weather conditions (e.g. shadows and snow) often introduce substantial information noise,
- taking into account the above, people detection must be carried out in (near) real-time and provide very high detection rate with minimal number of false positives (false detections).

In spite of the fact, that the nature of on-board and infrastructure-based systems is slightly different, pedestrian detection methods are similar in both cases. Most commonly they are based on machine vision and machine learning principles, sometimes utilizing sensor fusion approach. The most significant difference is that with stationary systems, the sensors (cameras in particular) are not moving, so it is possible to apply advanced techniques of background/foreground separation, which makes further processing easier and more robust.

The processing pipeline of a typical vision-based pedestrian detection system can be divided into the following stages: preprocessing, initial candidate selection, classification and tracking, although some researches (e.g. [9]) show more detailed approach.

3.2.1 Preprocessing

The preprocessing module usually focuses on camera calibration and pose estimation that is necessary for the later stages, especially tracking in real-world coordinates. The most common approach is to initially estimate the intrinsic (optical properties of the camera and lens) and extrinsic (position and orientation with respect to some coordinate system, e.g. center of the pedestrian crossing) camera parameters based on geometrical properties of the observed scene and assume that they remain constant. As long as this assumption usually holds for the intrinsic parameters (provided the lens is not moved or zoomed), the pose of the camera can often change even though the camera is fixed to a road infrastructure. Seemingly rigid objects such as lamp posts or sign posts onto which cameras are often mounted are susceptible to wind and temperature variations, which can cause the construction to shake (wind) or tilt from the initial position (temperature). In the end, the orientation of the camera is changed, which results in blurred image, change of the field of view and incorrect 3D position estimation of observed pedestrians. In such a case, the extrinsic camera parameters have to be constantly updated [4].

Another issue in the preprocessing stage is image exposure/contrast adjustment. This is usually taken care of automatically by camera lens with auto iris feature, but the results are often far from optimal (e.g. bright headlights cause the iris to close and important parts of the image are underexposed). Such poorly contrasted images are quite difficult for many contemporary detection algorithms [9]. An interesting solution to this problem is to use the emerging HDR cameras that provide highly contrasted images in extreme lighting conditions.

3.2.2 Initial candidate selection

Initial candidate selection is the generation of preliminary hypotheses or Regions Of Interest about the pedestrian locations in the image. These candidates are later sent to the classification module for verification, so it is very important that no pedestrian is missed in this stage, as it will not be possible to correct this error in the next phase. On the other hand, almost equally important is avoiding as many irrelevant background regions as possible, so as to reduce the classification time. The typical approach involves the use of a sliding window of various scales that is shifted over the image and selects all the possible candidates. This procedure, although quite simple, generates many spurious regions and further processing is often too complex for real-time applications. In order to limit the number of ROIs some visual cues like color, intensity, edges etc., interest points based on local discontinuities of the image brightness function or cascades of simple classifiers can be used to eliminate unwanted candidates. Another interesting approach is to use stereovision that provides depth information about the observed scene. This allows for example to adjust the ROI size and position during initial scanning taking into account the location of the ground plane.

Motion analysis is another early cueing mechanism used during the initial scanning. It is particularly efficient in

infrastructure-based systems, where cameras are not moving and advanced background subtraction algorithms can be applied [13]. Stationary systems can also benefit from a priori information about the camera-scene geometry and easily eliminate from search such image areas where pedestrians are unlikely to appear (e.g. sky, building walls etc).

3.2.3 Classification

The object classification module is given a list of ROIs that are more or less likely to contain a pedestrian. Subsequently they are binary classified as pedestrian or nonpedestrian, with the goal of minimizing the number of false positives and false negatives. Sometimes the classification output is not binary, but it reflects the probability of a given ROI to contain a pedestrian. This is useful for the non-maxima suppression stage described below. First, some image features are extracted from each ROI, and then a classifier that was previously trained with a set of positive and negative learning samples is applied. The most popular classification methods used for pedestrian detection are: neural networks, support vector machine and boosting. It is difficult to say which approach is the most successful, however it must be noted that the latter one requires significantly longer training times than the other ones.

Regardless of the classifier used, proper feature selection is crucial for successful detection and classification. Perfect features should be discriminative, robust and easy to compute, but these requirements often contradict each other. The most popular features used for pedestrian detection are mainly based on gradients, motion, colors and textures and include: Wavelet/Haar-like features, edgelets, shapelets, local binary patterns, histogram of oriented gradients, motion features and many other. Many researchers combine several features [17] in order to improve the classification compared to a single feature, however the gain obtained is not always significant as features tend to encode similar characteristics.

After the classification, it may happen that several overlapping ROIs containing pedestrians correspond to a single person. The non-maxima suppression process aims at reducing these ROIs to a single one per pedestrian. This is particularly difficult in crowded scenes, where overlapping ROIs of different persons may be mistakenly merged together. Most of the applied algorithms use a standard multi-filtering approach based on the area of overlapping, however more sophisticated methods use a mean shift approach or the confidence level of ROIs to discard the overlapping regions of lower confidence [17].

Many systems contain one more phase that verifies and refines the ROIs already classified as pedestrians. The verification step discards potential false positives based on additional criteria and the refinement step outlines the pedestrian for the subsequent tracking module.

3.2.4 Tracking

The final step of pedestrian detection is tracking which not only serves for trajectory generation, but also increases the overall

detection accuracy by predicting future positions of pedestrians. This information can be used by earlier modules to refine the hypotheses of pedestrian location, speed up the processing and reduce the number of false positives. It is worth mentioning that tracking is not essential for pedestrian detection and many if not majority of projects omit this step.

The two most commonly used approaches for tracking are: Kalman and particle filters. Although the former is definitely the most popular one, the latter seems to be more robust to occlusions and changes in pedestrian appearance or motion patterns.

3.2.5 Overall performance

Although, in the last decade, the problem of automatic people detection in video sequences has drawn attention of many research teams and a huge progress has been made in this area, the state-of-the-art algorithms are still very far from what is expected. Even under the ideal conditions, the rate of correct detections is less than 80% and it drops dramatically for smaller resolutions and/or occlusions [6].

One should note, however, that most research on people detection concerns horizontal or close to horizontal view and there has been relatively little research on top view pedestrian detection. The latter seems to be a little easier to deal with as it minimizes the influence of the most significant problems in contemporary people detection algorithms, namely, occlusions, people scale variations and background changes. Moreover, since top view systems are infrastructure-based, they can apply advanced background subtraction methods and/or stereovision that works well for relatively short ranges (see Fig. 2).



Fig.2. Left and right images from a stereo camera system for pedestrian detection

The reported recognition rate of few top view or almost top view systems [1, 7, 14] is much higher than that for the horizontal view systems. It should be noted, however, that the detection rate cited in [6] concerns unconstrained scenarios and by correct detection the separation of all (partially) visible humans is understood. Such a high precision is rarely requested from a traffic pedestrian detection system, where counting individuals is of less importance than detecting the fact that a number of pedestrians are on or near the crossing.

It is also worth noticing that video-based systems can extract more information from the observed scene than their conventional (infrared or microwave) counterparts. For example, in [13] a system is described that does not only detect pedestrian presence the curb, but also decides if they are actually going to cross the street or are simply passing by or standing there. As a result, it minimizes the number of unnecessary interruptions of the traffic flow. Another application could be to incorporate the video-based pedestrian detection systems in the city monitoring network.

4. Dynamic signage

4.1 Pedestrian presence warning systems

Dynamic or „active” road signage is an interesting solution increasing safety of pedestrian crossings. Such a system involves automatic detection of pedestrians and activation of light signals to warn drivers of pedestrian presence. Thus, drivers are prepared to slow down and more inclined to give way to pedestrians. The aim of such systems is to:

- increase visibility of the crossing,
- increase attention and concentration of drivers,
- force speed reduction of approaching vehicles.

There are several examples of dynamic signage systems based on the above principle. Some of these systems are described and compared below.

The first example consists of pulsating yellow lights mounted on top of an existing D-6 traffic sign “pedestrian crossing”. This system is equipped with infrared motion sensors which activate the yellow flashing warning lights when a pedestrian is detected inside detection zone (Fig. 3). Such systems are available on the market under brand names SignFlash and SeeMe [24, 25].

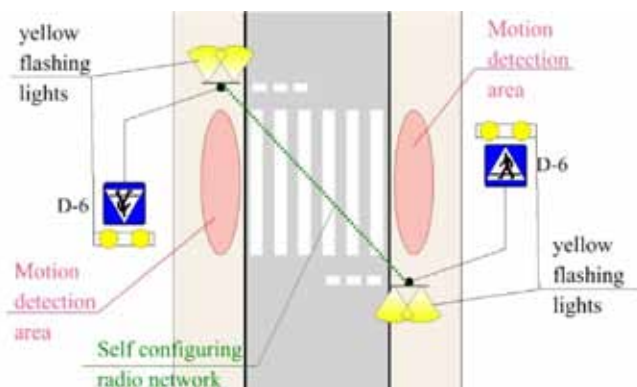


Fig.3. Dynamic pedestrian crossing signage – principle of operation

Another example of a similar system warning drivers of pedestrian presence is called “Välkky”. Instead of yellow flashing lights it has blue-white LED lights, mounted on existing D-6 sign poles. When pedestrians approach a crossing, Välkky warns drivers to keep more attention. [27]. Fig. 4 shows the principle of operation.

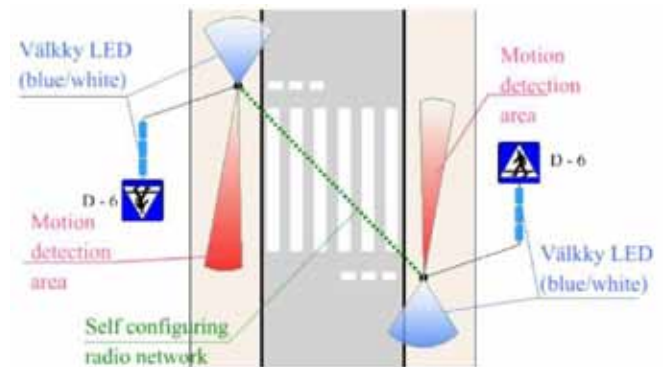


Fig.4. System Välkky – principle of operation

A different solution of a dynamic warning system involves lights embedded in the road surface at the edge of the crossing. Fig. 5 shows an example of such a system: SAFE-2-WALK by Traficon. This system uses video cameras for detecting pedestrians in pre-defined zones. Pedestrian detection activates the warning lights to alert motorists that crossing will be used. LED lights mark the edge of the crossing [30].



Fig.5. System SAFE-2-WALK by Traficon

Comparison of basic features of the systems described above is shown in Table 2.

Table 2. Comparison of selected systems

Type of dynamic system	Type of detector	Light mounting location
SeeMe / SignFlash	infrared	on top of an existing D-6 traffic sign
Välkky	infrared	on existing D-6 sign poles
Safe-2-Walk	video	embedded in the road surface

4.2 Applications in Poland

Systems presented in section 4.1 have recently started to be introduced in Poland. So far, there are no scientific studies to confirm their effectiveness in improving pedestrian safety. However, the response of local communities in areas where they have been installed is positive, indicating their usefulness.

Fig. 6 shows the implementation of the SignFlash system by APM in the village of Czesław, near Kraków [25].



Fig.6. System SignFlash in the village of Czesław

A pilot installation of the Vălkky system has been done in the city of Chorzów at two selected intersections. One of these sites is shown in Fig. 7.



Fig.7. System Vălkky installed in Chorzów on Kaliny St. Source: [28]

5. Improving the visibility of crossings and pedestrians

The problem with conventional street lighting is that it is designed to illuminate the road surface evenly, so that any obstacle on the road appears dark against brighter background. This method is not very suitable for pedestrian crossings which should be illuminated more intensively to enhance safety. This extra illumination will inform drivers that they are approaching a pedestrian crossing. It should illuminate evenly not only the crossing area but also part of the sidewalk where pedestrians wait for the opportunity to cross the road. The light intensity should be such that pedestrians appear brighter than darker background despite all the ambient illumination [30, 26].

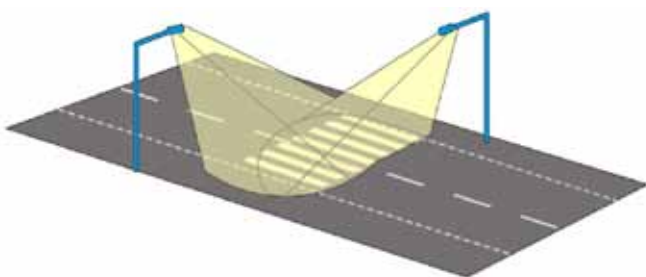


Fig.8. Principle of asymmetric crossing illumination

There are several examples of lighting systems specially designed for pedestrian crossings: “Calypso Zebra” by Schreder, IVS by Thorn, “Futurlux cross-walk” by APM, etc. All of these systems work on the principle of asymmetric illumination (Fig. 8) which helps to illuminate pedestrians not from the top but from the side of approaching traffic.

Solutions developed by Schreder and Thorn make use of metal-halide lamps, with power of between 100 W and 400W [29, 30]. The solution marketed by APM makes use of LED lamps, producing white light of high intensity. This solution is shown in Fig. 9.



Fig.9. „Futurlux cross-walk” lighting system.

In order to increase the visibility of the crossing itself, lights embedded in the pavement can be used. One example of such a system is Levelite [25]. It is similar in appearance to the „SAFE-2-WALK” system described in section 4.1 but the markers are lit permanently and are not activated by pedestrian presence.

6. Conclusions

Despite falling numbers of road accident fatalities, the safety situation of pedestrians in Poland is still very bad. It seems that traditional ways of designing and marking pedestrian crossings are not sufficient to ensure adequate safety improvement for vulnerable road users. New technology of pedestrian detection (especially video-based systems that are quickly advancing due to intensive research) and dynamic signing promise to improve pedestrian safety at road crossings.

Video-based systems are already comparable to conventional solutions and their performance is constantly growing due to research and development in this area. The advantages of video-based systems over the conventional ones in terms of additional functionality make them a promising prospect for practical applications in the nearest future.

Several innovative solutions for improving safety at pedestrian crossings are available on the market and are being installed at selected locations. Dynamic pedestrian crossing signs utilize flashing lights activated by pedestrian sensors to warn drivers of pedestrian presence. New lighting systems improve visibility of pedestrians on a crossing by making use of high-intensity asymmetric illumination. However, the effectiveness of these solutions remains to be scientifically evaluated.

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