Superpixels in Pedestrian Detection from Stereo Images in Urban Traffic Scenarios

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Abstract: Pedestrian detection is a common task in every driving assistance system. The main goal resides in obtaining a high accuracy detection in a reasonable amount of processing time. This paper proposes a novel method for superpixel-based pedestrian hypotheses generation and their validation through feature classification. We analyze the possibility of using superpixels in pedestrian detection by investigating both the execution time and the accuracy of the results. Urban traffic images are acquired by a stereo-cameras system. A multi-feature superpixels-based method is used for obstacles segmentation and pedestrian hypotheses selection. Histogram of Oriented Gradients features are extracted both on the raw 2D intensity image and also on the superpixels mean intensity image for each hypothesis. Principal Component Analysis is also employed for selecting the relevant features. Support Vector Machine and AdaBoost classifiers are trained on: initial features and selected features extracted from both raw 2D intensity image and mean superpixels intensity image. The comparative results show that superpixels- based pedestrian detection clearly reduce the execution time while the quality of the results is just slightly decreased.

1 INTRODUCTION

The high rate of road accidents in the world has motivated the development of more efficient driving assistance systems in order to reduce the number of accidents with injuries and fatalities. The driving assistance systems that have implemented functions like obstacle detection and obstacle recognition should be robust in various traffic and weather conditions. Although highway traffic scenes are relatively simple mainly containing obstacles such as cars, fences and poles, urban traffic scenarios are much more complex. In urban traffic scenarios several problems occur due to the crowded scenes in which occlusions occur frequently and makes the obstacle detection problem very difficult. Here the pedestrians, which are the most vulnerable traffic participants, appear.

Although pedestrian recognition is a simple problem for humans, it is a relatively difficult problem for artificial vision systems. This is mainly due to the different possible traffic situations, different clothing and accessories they wear. Usually, the pedestrians are recognized in traffic scenes by using obstacles classifiers trained on specific features.

Stereo-cameras are frequently used in computer vision at the expense of other sensors. We use a solution consisting of a gray level stereo-cameras setup that offers the possibility of exploiting both the 2D intensity and the associated 3D points' information.

A very important and motivating aspect for driving assistance systems is that all the processing must be done as quickly as possible in order to achieve real-time execution. This is particularly important because it must give a timely response at high speeds of ego-vehicle. The obstacle detection and recognition algorithms must be complex in order to robustly solve problems but they must be very fast for delivering timely results. These two requirements, that are in a continuous compromise, must be met both as much as possible.

We proposed a novel generation and validation of pedestrian hypotheses based on superpixels. The goal resides in reducing the processing time for pedestrian detection while preserving the accuracy of the results. We use our previous work in superpixels-based obstacle segmentation (Giosan and Nedevschi, 2014) in order to accurately determine the traffic pedestrian hypotheses. Classic features like Histogram of

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Oriented Gradients (HOG) are computed both on the raw 2D intensity image and also on the superpixels mean image for comparison purposes. Principal Component Analysis (PCA) is also employed for feature dimensionality reduction. Traditional classifiers like Support Vector Machine (SVM) and AdaBoost are trained and tested in order to prove that using superpixels for hypotheses validation can strongly reduce the processing time while the quality of the pedestrian detection results is not so affected.

The rest of the paper is organized as follows: in section 2 we present the related work, in section 3 the system overview, in section 4 the superpixel-based pedestrian hypotheses detection, in section 5 the extracted features and the classifiers that are used, in section 6 the experimental results and finally in section 7 we draw the conclusions of this work.

2 RELATED WORK

Superpixels are clusters of pixels based on local image features. SLIC superpixels described in (Achanta et al., 2012) represent a fast approach that can be used for segmenting gray levels images in separate superpixels. They may be used for reducing the complexity of subsequent image processing tasks like obstacle detection. Pedestrian hypotheses are usually extracted from the set of detected obstacles by imposing some pedestrian specific geometrical constraints. The hypotheses are then used for reducing the search space, resulting in a faster pedestrian detection process.

Usually stereovision based approaches are widely used first in traffic scenes obstacle segmentation (Oniga and Nedevschi, 2010) and second for validating the obstacle classification results (Bertozzi et al., 2008). Features extraction and feature-based classifiers represent intermediate steps in obstacles classification. Features are usually extracted from the 2D appearance obstacle images but they can also integrate depth information and optical flow motion information. Obstacle classifiers may be trained directly on the extracted features or on a subset of relevant features (You and Ruichek, 2012). A high quality of the stereo-reconstruction process (Pantilie and Nedevschi, 2012) is absolutely necessary for obtaining a dense and accurate 3D points map. Based on this map, several algorithms like points grouping (Pocol et al., 2008) or density map analysis (Nedevschi et al., 2009) may be used for obstacle segmentation. In comparison with monocular vision based techniques that uses symmetry (Bertozzi et al., 2000), edges (Bertozzi and Broggi, 1998) and textures (Heikkila and Pietikainen, 2006) from intensity information, stereovision based obstacle segmentation approaches (Broggi et al., 2011, Nedevschi et al., 2004, Llorca et al., 2012) are clearly superior.

Methods that divide the image pixels into regions having the properties that all pixels from a separate region are similar with respect to a chosen similarity metric are presented in (Felzenszwalb and Huttenlocher, 2004) and (Xiaofeng and Malik, 2003). A graph where the nodes are the image pixels and the edges represent a neighborhood relationship between pixels is computed. These methods represent the basis of the, nowadays very common and superior, superpixels based image segmentation approaches. In (Giosan and Nedevschi, 2014) we proposed a novel obstacle detection method based on the original scene segmentation in superpixels. The method combined the intensity, depth and motion information within the SLIC superpixels. A novel algorithm was proposed for superpixels clustering into obstacles and obstacles refinement. A method for very close obstacles separation was developed based on the motion vectors analysis of their component superpixels. The results showed a very good obstacles detection with precise segmentation of their surfaces which is particularly useful for subsequent processes like pedestrian detection. Continuing this work, in this paper we propose a novel method for superpixels-based generation and validation of pedestrian hypotheses. The superpixels benefits in the pedestrian detection process are clearly highlighted.

In the literature, several methods use different discriminant features like shapes and edges (Broggi et al., 2000), contours (Hilario et al., 2005), contour templates (Gavrila and Philomin, 1999; Gavrila, 2000; Giosan and Nedevschi, 2009), symmetries (Havasi et al., 2004), Haar features (Papageorgiou and Poggio, 2000), HOG features (Dalal and Triggs, 2005) used for pedestrian detection. Usually these features are firstly extracted on pedestrian hypotheses and then fed into classifiers that are able to distinguish between pedestrians and other traffic scene obstacles.

A lot of different methods exist for feature based obstacle and specifically pedestrian classification (Giosan and Nedevschi, 2012). In (Rivlin et al., 2002, Lun et al., 2007), a SVM classifier is used for recognizing pedestrians and bikes in traffic scenes. A powerful Adaboost classifier built upon some characteristics of rectangular edge description is proposed in (Yi et al., 2010) for high accuracy pedestrian recognition. Neural networks are also used for high-accuracy pedestrian and other obstacles classification (Toth and Aach, 2003). The state of the art in pedestrian detection achieve high accuracy results even from monocular images (Benenson et al., 2012). The benefits of stereo images in regions of interest generation and localization and an evaluation methodology of pedestrian detection is described in (Keller et al., 2011).

3 SUPERPIXELS BASED PEDESTRIAN DETECTION SYSTEM OVERVIEW

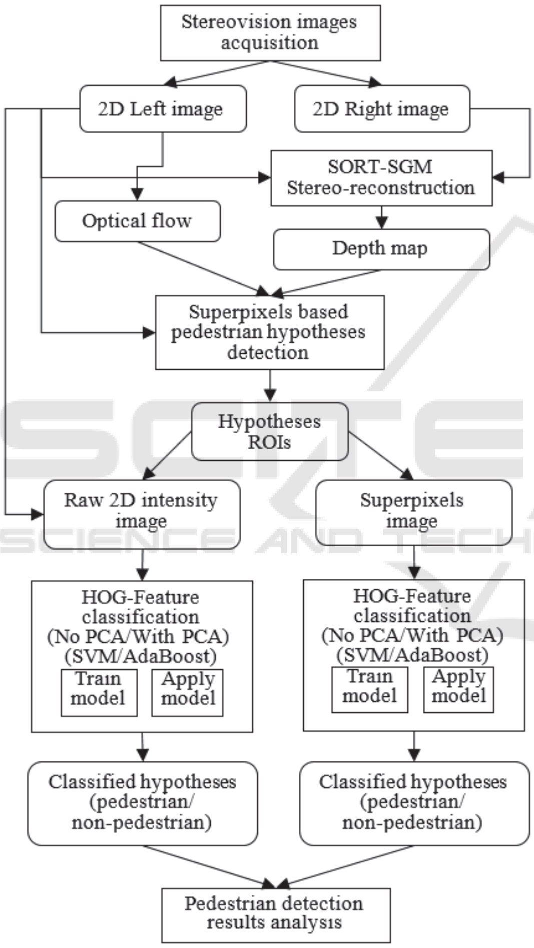


Figure 1: Superpixels-based pedestrian detection system overview.

The structural architecture of the entire system and the flow between its modules that is used for analyzing the influence of superpixels in pedestrian detection from urban traffic scenes is presented in Figure 1.

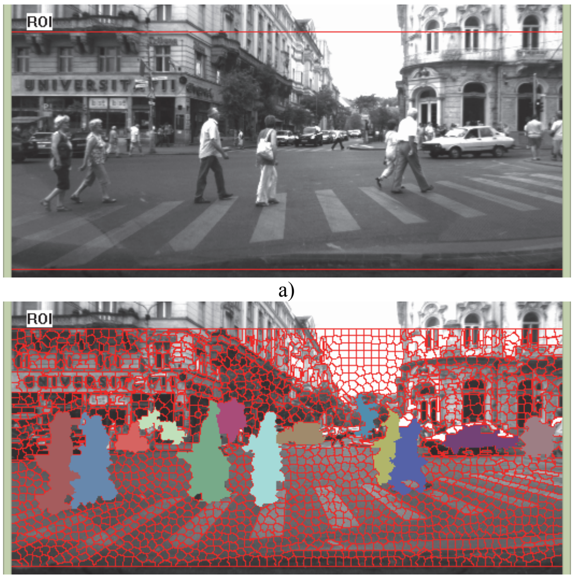
Traffic scenes images are acquired with a stereovision cameras setup. These consist of grayscale image sequences with resolution of 512x383 pixels. The stereo-reconstruction process is achieved by the SORT-SGM algorithm (Pantilie and Nedevschi, 2012) which offers an accurate and dense depth map, crucial for further processing steps. Optical flow is computed by using the Lukas-Kanade approach on good features to track (Shi and Tomasi, 1994). Combining intensity, depth and optical flow information, our superpixels based obstacle detector (Giosan and Nedevschi, 2014) is used for selecting the pedestrian hypotheses. HOG features are extracted both directly on raw 2D and on the superpixels hypotheses intensity ROI images. PCA procedure is or not applied before training two robust classifiers: SVM and AdaBoost. These classifiers are trained on a database containing pedestrians and non-pedestrians instances. Finally, the classification results from all investigated ways are analyzed and the benefits of using superpixels for pedestrian detection are highlighted.

4 SUPERPIXELS-BASED PEDESTRIAN HYPOTHESES DETECTION

We take advantage of our previous work (Giosan and Nedevschi, 2014) for superpixels based obstacle detection. SLIC superpixels are computed in a rectangular region of interest (ROI) defined by the positions and dimensions: (*left*=0, *top*=100, *right*=512, *bottom*=320) (see Figura). A fixed number of N=2000 superpixels segments the established intensity image ROI. A set of intensity, depth and motion features are used in order to cluster the superpixels into scene obstacles (see Figurb).

A modified version of the novel obstacle detection algorithm described by us in (Giosan and Nedevschi, 2014) is proposed for finding only the pedestrian hypotheses that will be further used in the validation (pedestrian detection) process. The algorithm has five main steps, the last one addressing directly the pedestrian hypotheses selection from the traffic scene segmented obstacles:

- Gray-levels SLIC superpixels computation
- Superpixels specific features extraction
- Superpixels clustering in obstacles hypotheses
- Obstacles hypotheses validation and refinement
- Pedestrian hypotheses generation



a)

b)

Figure 2: Obstacles detection: a) intensity image ROI; b) corresponding superpixels-based detected obstacles (with random color for each obstacle).

Pedestrian hypotheses are considered to be those superpixels-based obstacles that meet some geometrical constraints. We define the following constraints for the surrounding 3D cuboid that are satisfied for the majority of pedestrians:

- Height between 1.5m and 2.2m
- Width between 0.3m and 0.9m
- Length between 0.3m and 0.9m
- 2D image ROI aspect ratio (height/width) between 1.0 and 4.0

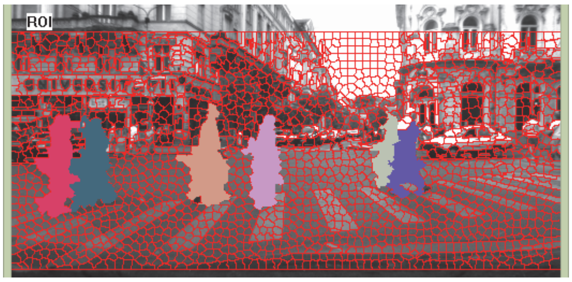


Figure 3: Superpixels-based pedestrian hypotheses (with random color for each obstacle).

In case of traffic scene image presented in Figure 2, the generated superpixel-based pedestrian hypotheses are shown in Figure 3.

5 HOG FEATURES EXTRACTION, SELECTION AND CLASSIFIERS TRAINING

We choose the HOG features for analyzing the influence of superpixels in the pedestrian detection (hypotheses validation) process. These features are extracted both on the raw 2D intensity ROIs and on the superpixels ROIs of the pedestrian hypotheses. A PCA feature dimensionality reduction method is also investigated in speeding up the final classification while preserving the accuracy. Different classifiers are trained both on the entire HOG features set and on PCA selected features. The features are extracted on a training set with pedestrians and non-pedestrians intensity images.

The raw 2D intensity image ROIs (see Figure 4a) of the pedestrian hypotheses are firstly resized to a fixed dimension of 64x128 pixels using a fast bilinear interpolation procedure (see Figure 4b). The resized image is divided in blocks with 16x16 pixels and each block in 8x8 pixels cells. We choose 9 bins for the HOG computation. The resulting HOG feature vector for each instance has a number of 3780 components.

a) b) c) d)

Figure 4: Pedestrian hypotheses: a) raw 2D intensity ROI; b) resized 2D intensity ROI; c) superpixels on resized 2D intensity ROI; d) mean superpixels image.

We choose a SVM and an AdaBoost classifier trained using several feature vectors extracted for pedestrians and non-pedestrians. We also reduce the number of features by keeping only the first 30 principal components out of all 3780 initial features and retrain the previously mentioned classifiers.

In order to investigate the possible advantages of using superpixels in pedestrian detection, we reduce the raw 2D intensity ROIs by resizing it to 16x32 pixels and extract the SLIC superpixels (see Figure 4c). We compute the mean superpixels image (see Figure 4d) by averaging all the intensities at every superpixel level. HOG features are extracted, using the same block size, cell size and number of bins, on the superpixels mean image resulting in a 108 feature vector. Identically to the training process on the raw features previously described, SVM and AdaBoost classifiers are trained first on several instances with all 108 feature vectors and then by selecting only the first 30 principal components.

The classification performance and the processing time obtained by the SVM and AdaBoost classifiers trained on extracted HOG features on initial image and on superpixels mean image, with and without PCA are presented comparatively in the Experimental Results section.

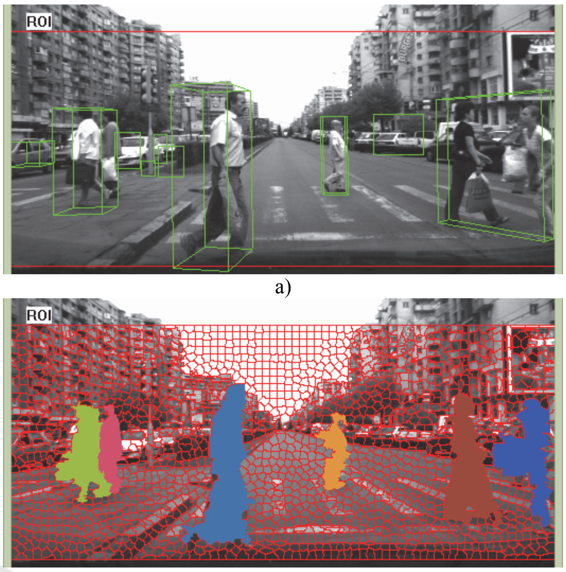
6 EXPERIMENTAL RESULTS

In this section we describe the obtained results for both generation and validation of pedestrian hypotheses. We also highlight the advantages and disadvantages of using superpixels.

Pedestrian hypotheses generation was tested on image sequences from common urban traffic scenarios, where the results seems to be similar to those obtained by other obstacle detection methods. In difficult traffic scenarios with crowded and hanging obstacles, the superpixels-based pedestrian hypotheses generation is clearly superior. A comparison of our method with the pedestrian hypotheses generation approach based on 3D points grouping (Pocol et al., 2008) and density maps (Nedevschi et al., 2009) is presented in Figure. The superpixels-based proposed method offers better hypotheses generation, reducing the number of false detections. It also provides better shape definition which is very important for further validation in the pedestrian detection process.

In the evaluation of the pedestrian hypotheses validation process, we use obstacles instances from our own database containing about 25,000 intensity images of pedestrians and another 25,000 intensity images of non-pedestrians (see Figure).

We trained two classifiers: SVM with RBF kernels and AdaBoost with decision stumps weak learners. All the training procedures were conducted by using a number of maximum 5000 instances selected randomly from our database. The same number of other instances is also selected randomly and used for evaluating the classification accuracy. The processing time is also counted for each experiment.



a)

b)

Figure 5: Pedestrian hypotheses generation: a) by means of 3D points grouping and density maps (pedestrians from the left and right side are wrongly grouped together); b) using the proposed superpixels-based method (pedestrians from the left and right side are clearly separated).

Figure 6: Sample dataset images: pedestrians and non-pedestrians.

The SVM classifier performance obtained in all four proposed scenarios

- I: no superpixels, no PCA
- II: with superpixels, no PCA
- III: no superpixels, with PCA
- IV: with superpixels, with PCA

are briefly presented in Table 1.

Table 1: SVM Classifier's Performance.

Scenario	**Number of test instances**	**False Positive Rate**	**True Positive Rate**	**Processing time (ms)**
I	5000	0.044	0.937	58298
II	5000	0.078	0.898	6499
III	5000	0.056	0.91	5310
IV	5000	0.081	0.868	5605

Plotting the false positive rates and true positive rates for pedestrian detection in all four proposed training/testing scenarios show that there is small decrease in true positive rates of about 4% (see Figure 7) with a small increase in false positive rates of about 3% (see Figure 8Figure) when considering superpixels mean image versus raw image processing.

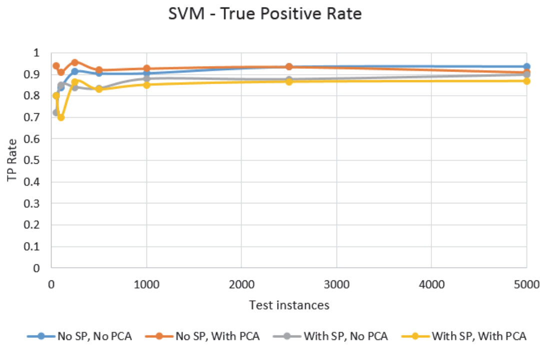


Figure 7: SVM classifier pedestrian detection true positive rates in all four scenarios: with/without superpixels (SP), with/without PCA.

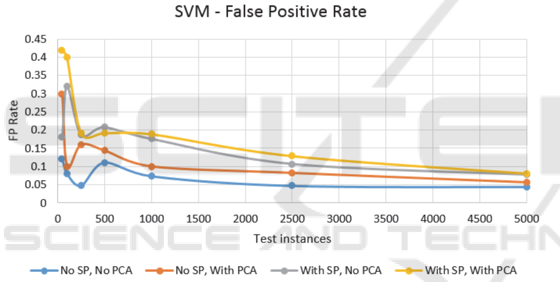


Figure 8: SVM classifier pedestrian detection false positive rates in all four scenarios: with/without superpixels (SP), with/without PCA.

The main advantage is depicted in Figure where the processing time interval seems to be very short (decreased with about 90%) when processing PCA superpixels images versus raw intensity images in pedestrian detection.

The same procedures like in the SVM classifier are applied for training and testing the AdaBoost classifier. The AdaBoost classifier performance obtained in the same four proposed scenarios are briefly presented in Table 2.

Table 2: AdaBoost Classifier's Performance.

Scenario	Number of test instances	False Positive Rate	True Positive Rate	Processing time (ms)
I	5000	0.1136	0.893	7544
II	5000	0.147	0.826	5090
III	5000	0.128	0.872	8660
IV	5000	0.134	0.806	4055

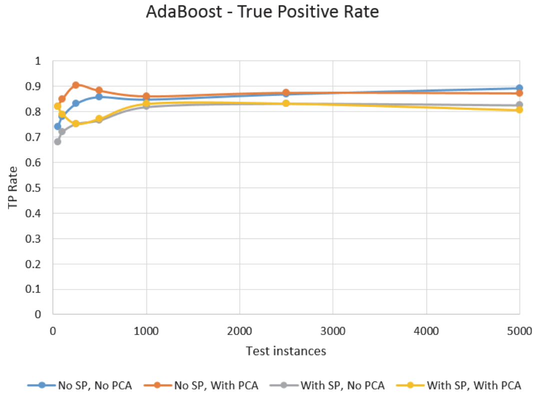


Figure 9: AdaBoost classifier pedestrian detection true positive rates in all four scenarios: with/without superpixels (SP), with/without PCA.

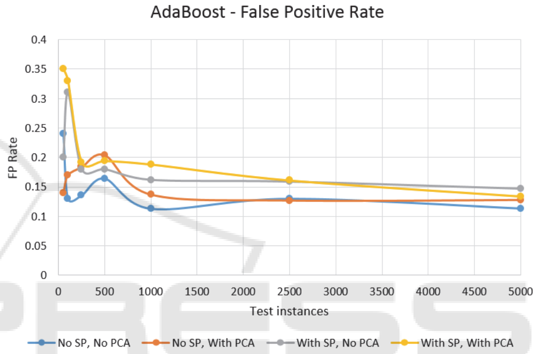


Figure 10: AdaBoost classifier pedestrian detection false positive rates in all four scenarios: with/without superpixels (SP), with/without PCA.

As in the case of SVM classifier, using the AdaBoost classifier in all four proposed training/testing scenarios show that there is small decrease in true positive rates of about 6% (see Figure 9) with a small increase in false positive rates of about 3% (see Figure 10) when considering superpixels mean image versus raw image processing. The main advantage is depicted in Figure 11 where the processing time seems to be shorter (with about 40%) when processing PCA superpixels images versus raw intensity images for pedestrian detection.

The experimental results were obtained by processing images containing pedestrians and non-pedestrians acquired from different traffic scenarios. The initial superpixels-based obstacle segmentation process was performed by our own novel proposed algorithms previously published in (Giosan and Nedevschi, 2014). Generation and validation of pedestrian hypotheses were achieved by the novel described methods in this paper. The system achieves real-time performance running on a single core of an Intel Core i7-4790 processor @ 3.60 GHz.

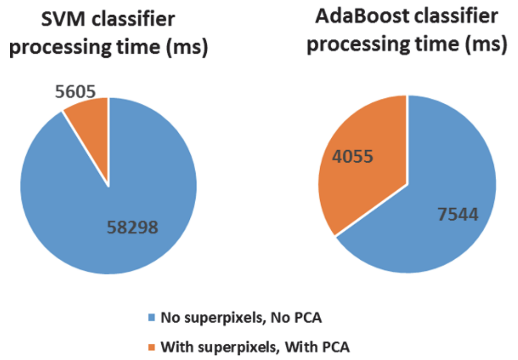


Figure 11: SVM and AdaBoost classifiers processing time: comparison between the extreme scenarios I and IV.

7 CONCLUSIONS

A novel approach for superpixel-based generation and validation of pedestrian hypotheses was described. The proposed superpixels-based pedestrian hypotheses generation method offers better hypotheses generation results even in difficult traffic scenarios. It clearly reduces the number of false hypotheses detections and provides better pedestrians shape definition. The influence of using superpixels in pedestrian detection (hypotheses validation) was also investigated. Classical HOG features were computed both on the raw 2D intensity image and also on the superpixels mean image. PCA feature dimensionality reduction was also employed for speeding up the classification process while trying to preserve the accuracy. SVM and AdaBoost classifiers were trained and tested on random pedestrian/non-pedestrian intensity images. Their classification results were compared in terms of both accuracy and also in terms of processing time interval.

The SVM classification proved that the processing time interval may be decreased with 90% when using superpixels, while the accuracy lost only 3% in false positive rate. The AdaBoost classification proved that the processing time may be decreased with 40% when using superpixels while the accuracy lost also only 3% in false positive rate. The superpixels usage clearly improves the quality of the pedestrian hypotheses generation. Hypotheses validation (pedestrian detection) shows a significant decrease of the processing time while the small loss in accuracy can be neglected.

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