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Novel and efficient pedestrian detection using bidirectional PCA

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ABSTRACT

The detection of pedestrian has attracted much research in the past decade due to the essential role it plays in intelligent video surveillance and vehicle vision systems. However, the existing algorithms do not meet the requirement of real applications in terms of detection performance. This paper proposes a new robust algorithm for pedestrian detection based on image reconstruction using bidirectional PCA (BDPCA). Unlike PCA, since it is a straightforward image projection technique, BDPCA preserves the shape structure of objects and is computationally effective. Due to these advantages, BDPCA is a promising tool for object detection and recognition. The algorithm was tested on two datasets, INRIA and PennFudanPed. Our experiment proved that using BDPCA with vertical edge images was the most suitable for pedestrian detection. The comparison between BDPCA, PCA, and histogram of oriented gradient (HOG) based methods demonstrates superior accuracy and robustness of the proposed algorithm to the others.

1. Introduction

For the past decade, many applications in which detecting people plays an essential role has been developed. Such major applications are video surveillance systems, airport security, driving assistance systems, automatic driving cars, smart home, and robotics. The importance of these applications makes pedestrian detection a topic worthy of studying. Although there has been much effort to outperform pedestrian detection algorithms, the accuracy of the existing algorithms is still far from the requirement of real applications. The reasons why pedestrian detection is difficult can be summarized as follows:

1. Diversity in appearance: The appearance of a human can extremely be varied by changing pose, clothes, or the objects being carried, or viewpoints of camera. In addition, people have a large variation in size. Therefore, a pedestrian detection algorithm has to be able to cope with these variations.
2. Environment diversity: In this research, the environment includes the background where people are detected, illumination, and weather conditions. Since pedestrian detection is used in a wide range of applications, the background can be as diverse and complex as inside a building, campus, airport, road, or urban. This complexity is one of the biggest challenges to pedestrian detection. Due to this wide range of applications, pedestrian detection also suffers from the problem of illumination or weather changing.
3. Partial occlusion: Since people appear in dynamic and uncontrolled backgrounds, partial occlusions surely happen at any time. Therefore, as same as any object detection problem, partial occlusion needs to be considered in developing pedestrian detection algorithms.
4. Camera motion: In some applications, such as surveillance systems or airport security, the cameras are fixed, hence the backgrounds are static. In this case, motion can be used as an efficient cue for pedestrian detection. However, in other applications, such as driving assistance systems, automatic driving cars, or robots, both the camera and the objects in a scene are moving, which makes it difficult to extract pedestrian motion in this case.
5. Real-time processing: The major applications that require pedestrian detection also demands real-time processing as their vital question. Pedestrian detection is an essential part in these systems; however, it is only a single step in the whole system. Thus, it needs to be done as fast as possible to preserve the real-time processing characteristic of the whole system.

Fig. 1 shows difficult cases of detecting pedestrian due to occlusion, pose variation, camera viewpoint, and illumination change. In literature, numerous methods have been proposed for detecting pedestrians from images. This paper provides a brief summary and analysis of the existing methods in Section 2. In addition, it proposes a new method for automatically detecting pedestrians in still images based on Bidirectional PCA (BDPCA). Bidirectional PCA was originated from [1] for image recognition

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Fig. 1. Illustration of difficulties in human detection.

(mainly focuses on the face recognition problem). Unlike classical PCA, BDPCA is a straightforward image projection technique; hence it does not require converting an image to a high dimensional image vector. BDPCA extracts features from an image by reducing the dimension in both column and row directions, thus it requires less computation than PCA [2].

The proposed method includes two steps: training and classification. In the training step, BDPCA is applied to a set of pedestrian images and another set of non-pedestrian images. For each space (pedestrian or non-pedestrian), this step produces a descriptor consisting of the mean image, row, and column projectors, so called, 2D eigen-descriptor. In the classification step, an input image is scanned by a window of a certain size (in this work, 64×180 pixels) defining ROI (Region of interest). And, each ROI, is reconstructed by the 2D eigen-descriptors of pedestrian and non-pedestrian space, then determined whether it belongs to the pedestrian space or not based on reconstruction errors.

This paper implements BDPCA using different source images such as grayscale, edge, and vertical-edge images of the original images, and a complete performance analysis was carried out. The analysis shows that the 2D eigen-descriptor of the vertical-edge image is the most suitable for pedestrian detection. Furthermore, a comparison between BDPCA using the vertical-edge, PCA, and HOG-based methods demonstrates the superiority of the proposed method to the other methods in both accuracy and robustness for detecting pedestrians in unconstrained environment.

The rest of this paper is organized as follows: Section 2 provides a brief summary and analysis of the existing methods for automatic pedestrian detection. Section 3 describes the BDPCA-based pedestrian detection, and Section 4 compares the performance between the proposed method and the existing methods such as PCA and HOG. Finally, Section 5 states the conclusions and future works.

2. Literature review

In general, the process of pedestrian detection is divided into two subsequent steps: ROI selection and classification. There are several approaches to generate candidate ROIs for the classification step. The simplest approach is brute-force window sliding, which uses a fixed size detector to scan across the image at multiple scales and locations. This approach usually suffers from high processing time. In the case of static cameras, background subtraction can be performed to extract ROIs, which yields a significant speedup compared to the exhaustive scanning. However, due to illumination change or color similarity, this method may miss some extraction. Beside these approaches, 3D information obtained by a laser range finder or a stereo camera is also used for ROI selection. Although the 3D-based extraction partly solves the problems of the two approaches above, it is only suitable in the applications for robots or cars where the detection area is relatively small.

Meanwhile, the classification step receives the extracted ROI(s) and classifies them into either pedestrian or non-pedestrian classes. According to the detection cues, the existing approaches can be categorized into two groups, image-based and feature-based approaches.

Image-based approach. This approach simply uses pixel intensity as the feature of classification. Common learning algorithms in this approach are support vector machine (SVM), neural network, and principal component analysis (PCA). In 2005, Tian et al. [3] attempted to develop a nighttime pedestrian detection system using only a normal camera. In this system, the authors assumed that the intensity values of foreground pixels should be larger than a threshold; hence, a thresholding method is used for ROI selection. For comparison, they designed four classification approaches. Three approaches used only a single SVM classifier with the input from one of intensity image, binary image, and intensity gradient image, respectively. The fourth approach used 12 SVM classifiers each of which corresponded to one of pedestrians poses. Their experiments revealed that the single classifier with the intensity image as an input produces the highest performance.

Instead of SVM, Gavrila [4], Oh et al. [5] and Szarvas et al. [6] used neural networks in their systems. Gavrilas system also consists of two stages. The first step extracts contour features and applies a hierarchical template matching (Fig. 2) to efficiently lock onto candidate ROIs. Then, the second step utilizes the intensity features and RBF-neural network (Radial Basis Function) to validate candidate ROIs. Both Szarvas et al. and Oh et al. used the convolution neural network (CNN). Comparing the computational demand of the SVM and CNN-based methods, Szarvas et al.