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Adaptive Pedestrian Detection in Infrared Images using Background Subtraction and Local Thresholding

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Abstract

Infrared (IR) imaging is the order of the day with potential real life applications such as surveillance, defence, non-military applications and so on. Low contrast, poor illumination due to capturing devices and moderate to low environmental conditions are the general characterizations of IR images. In addition, the occlusion of objects make the detection more challenging. The objects considered in this paper are pedestrians. A simple and efficient single image handling pedestrian detection method is proposed in this paper. The two major tasks in the proposed method are background subtraction model and local adaptive thresholding. The major contribution of the paper is the adaptive calculation of the required parameters based on the image characteristics. Experiments are conducted on the standard OSU thermal pedestrian database to show the robustness of the proposed method. The proposed method attain detection rate of 90% under various environmental conditions which is superior than the other existing single image handling methods.

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Keywords: Pedestrian detection, local adaptive thresholding, infrared imagery, background subtraction.

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1. Introduction

In the field of infrared imagery, pedestrian detection is a vital and important task. It provides necessary information for many different applications such as night vision, target acquisition, tracking, surveillance and monitoring[1]. The pedestrian detection in IR images is more challenging than in the visible images because IR sensors can be used 24×7 for image acquisition whereas visible sensors depend on sun light or any other external light source(s). IR images has low signal-to-noise ratio (SNR) [2, 3] and hence cannot provide proper visualization of the objects captured. IR image looks like either very dark or bright white – based on the cloud presence in the environment. Thus, non-pedestrian objects and background information interrupt the detection. The IR images capture the heat generating objects and are temperature dependent in general. Based on the surrounding temperatures, heat generating objects may appear as bright intensity regions or merge with background information. In view of these reasons, pedestrian detection in IR images is very difficult.

In the recent past, researchers focused on pedestrian detection methods. From the literature available, the pedestrian methods are categorized based on the input. These methods are based on either a single image or on a sequence of images. In this paper focus is made on single image based pedestrian detection. Several methods exist for pedestrian detection based on single image. These methods are classified into filter based, thresholding methods, wavelet based, template matching methods and saliency detection methods. The filter based method includes median subtraction filter[4], max-mean filter[5], max-median filter[5], matched filter[6], quadric correlation filter[7], two dimensional least mean square filter[8], bilateral 2-D least mean square filter[9]. These filters fail to detect pedestrians during low contrast and heavy clutter background conditions which are prevalent in IR imagery. The thresholding methods include threshold selection from gray-level histogram[10], thresholding using entropy of histogram[11], improved image thresholding[12], shape resolving local thresholding[13], iterative thresholding[14], local thresholding[14]. These thresholding methods have problem of discontinuity in pixels and thus pedestrians are not properly detected. Detecting small pedestrians in heavy noise fails and false alarm rate increases. The wavelet based methods include Hilbert-wavelet transform[15], double-density dual-tree complex wavelet transform and wavelet entropy based[16]. The wavelet based methods have problem when targets appear in cluster or when targets are cluttered with the background or when the target is small and background noise is more. Template matching methods include improved template matching[17] and scale invariant template matching[18]. These matching methods fail to detect the shape of the pedestrian and are sensitive to noise. Saliency detection methods include directional saliency-based method[19] and saliency extraction method[20]. The saliency based methods have problems like time consuming due to generation of the saliency map from given image, false alarm rate increases for small pedestrian combined with the background noise.

To address these issues, in this paper, a novel and an adaptive pedestrian detection method is proposed. The proposed method is based on single image but not on sequence of images. The proposed system consists of three stages — background subtraction model, high-boost filtering and local adaptive thresholding. Background subtraction model is used to suppress the background and increase the SNR value of an image. High-boost filtering is used for sharpening the edges. Finally, for pedestrian detection, local adaptive thresholding using Gaussian function is done.

The major advantage of the proposed method is that there is no need about any prior information about the input image and it is image dependent i.e., the parameters are calculated based on the input image under study thereby increasing the pedestrian detection rate. The claim is justified by comparing the results of existing methods with the proposed method by subjective and objective evaluation in Section 3.

The rest of the paper organized as follows. In Section 2 proposed methodology is described in detail. In Section 3 experimental results and performance analysis are presented. Finally, Section 4 concludes the work highlighting the possible extensions.

2. Proposed methodology

The block diagram of the proposed method is shown in Figure 1. The steps involved in the proposed method are as follows:

1. Read the given infrared image $f(i, j)$.

2. Pre-processing the input image by background subtraction model using equation (2).
3. Enhance the edges of the pre-processed image by high-boost filtering using equation (3).
4. Pedestrian detection by performing adaptive local thresholding using equation (6).

2.1. Background subtraction model

In IR image, pedestrian object can be dim, low signal-to-noise ratio (SNR) and heavy complex background due to climate conditions, light scattering, optical defocusing, lens anomaly, detector tilt, distortion of mirror, imperfect illumination, atmospheric changes and so on. In order to overcome these, a background subtraction model is designed in this paper. The background subtraction model is discussed here.

Let $f(i,j)$ be the gray-scale input infrared image, which has the formation as defined in equation (1).

$$f(i,j) = X(i,j) + Y(i,j) \tag{1}$$

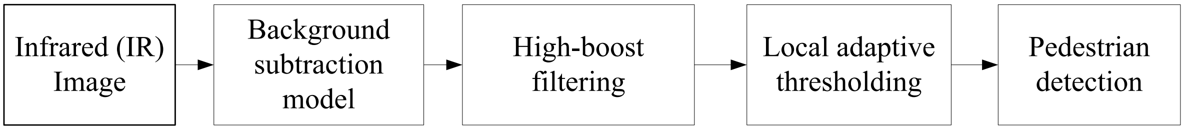

Fig. 1. The block diagram of the proposed method

where $X(i,j)$ denotes the foreground information of an image and $Y(i,j)$ represents the background information of an image. Background subtraction model works based on the pixel properties of the image. The goal of this model is to suppress the background information of the image. The background suppression is done by evaluating the gray-scale of background using peak of the histogram and then subtract it from the image pixel. It is defined in equation (2).

$$f_X(i,j) = \begin{cases} f(i,j) - P_e, & f(i,j) \geq P_e \\ 0, & otherwise \end{cases} \tag{2}$$

where $f_X(i,j)$ represents the foreground of the image, P_e is the estimated peak histogram of image. After the subtraction of background, pedestrian objects are elevated, SNR value is increased and background is suppressed.

2.2. High-boost filtering

The background subtraction reduces the intensity levels in the image. The objects of interest i.e. pedestrian objects get reduction in the intensity levels. The other problems that may arise during background subtraction are the shape and textural properties. To retain these properties, high-boost filtering is used.

Basically, high-boost filter[21] deals with the high frequency components of the image feature such as sharpening without removing low frequency components. Hence, to improve the edges of objects from the background subtracted image, it is employed. It is defined in equation (3).

$$f_{XE}(i,j) = f_X(i,j) * H(i,j) \tag{3}$$

$$H(i,j) = \begin{bmatrix} 0 & -1 & 0 \\ -1 & G+4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \tag{4}$$

where $H(i, j)$ is the high-boost mask, $f_{XE}(i, j)$ is the enhanced image, $f_X(i, j)$ is the background subtracted image, G is the boost coefficient of an image and $*$ is the convolution operator. By varying the value of the boost coefficient G increases an overall gray-level intensity value of the image and it is useful to brighten the image. If value of G is less than 1 then the contribution of the $f_X(i, j)$ in the gray-level intensity value increase is less. If the value of G is 0 then the mask is equal to Laplacian filter mask resulting in high spatial frequency component. If value of G is 1 then the contribution of the high-boost filter is very less. Hence, $G > 2$ works fine for image enhancement.

2.3. Local adaptive thresholding

In general in IR image, objects has a higher temperature than the background[22]. The background is suppressed and foreground objects are enhanced using above steps. So, the foreground objects has the maximum gray-level intensities in an image. To detect only the true targets, local adaptive thresholding[23] is designed with two steps.

1. To eliminate the false target, adaptive thresholds (T and T_1) are defined by Gaussian distribution function parameters (μ and σ).

$$T = \mu - k\sigma$$

$$T_1 = \mu + k\sigma$$

   where k is the scalar, μ is the mean of $f_{XE}(i, j)$ and σ is the variance of $f_{XE}(i, j)$.
   Adaptive Calculation of k : The value of the k is adaptively calculated. For the adaptive calculation of k, various experiments are conducted on $f(i, j)$ using the maximum intensity value of image, minimum intensity value of image, standard deviation of image, variance of image, entropy of image, first and second order moments etc. Since the input images are characterized by low illumination and low signal-to-noise ratio, these trial cases could not get good results. Based on these trials, it is observed that the value of k is calculated using entropy.Entropy[24] is a statistical measure that can be used to characterize the texture of the input $f(i, j)$ image. It is defined in equation (5).

$$k = -\sum_{i=1}^{L-1} p_f(i) \times \log_2 p_f(i) \tag{5}$$

   where p_f is the probability of number of occurrences of i in the $f(i, j)$ image, L is the maximum gray level of pixel in the image.
2. To detect the brightness pixels from the image, equation (6) is used.

$$F(i,j) = \begin{cases} 0, & if\ T \le f_{XE}(i,j) \le T_1 \\ 1, & otherwise \end{cases} \tag{6}$$

   where $F(i, j)$ is the resultant pedestrian pixel.

3. Experimental Results and Performance Analysis

The performance of the proposed method is tested on OTCBVS[25] Benchmark collection of IR images — OSU Thermal Pedestrian Database. The database contains 360 × 240 size images of Ohio State university campus walking area. The images were captured in both day and night over many days using Raytheon 300D thermal sensor with 75mm lens camera. A total of 10 classes of pedestrian images, with 284 images having 984 pedestrians are available in the database. These images covers a variety of environmental conditions such as heavy rain, light rain, mostly cloudy, partly cloudy, sunny day, foggy, windy weather and so on. In addition, pedestrians appear in many complicated poses such as standing still with backpacks, walking, running, holding umbrella etc.

3.1. Subjective evaluation of results

Figure. 2 shows the sample results obtained from the proposed method compared with the Wang method[23], maxmedian filter 3×3[5], top-hat transform[26] and max-median filter 5×5[5]. Column (a) represents the sample original images of class 1, class 5, class 6, class 7, and class 8 respectively. Column (b) indicates results of the proposed method. Column (c) shows result of the Wang method. Column (d) shows the result of the max-median filter 3×3. Column (e) displays the results of the top-hat transformation[26] and Column (f) shows the result of the max-median filter 5×5 respectively. From Figure. 2, it can be easily perceived that the proposed method shows acceptable results in pedestrian detection than the other methods.

The graphical abstract of the proposed method is shown in Figure. 3. Figure. 3(a) represents the original image, Figure. 3(b) is the background subtracted image, Figure. 3(c) is the high-boost filtered image, Figure. 3(e) is the local adaptive threshold applied an image, Figure. 3(f) show the detection result of the proposed method.

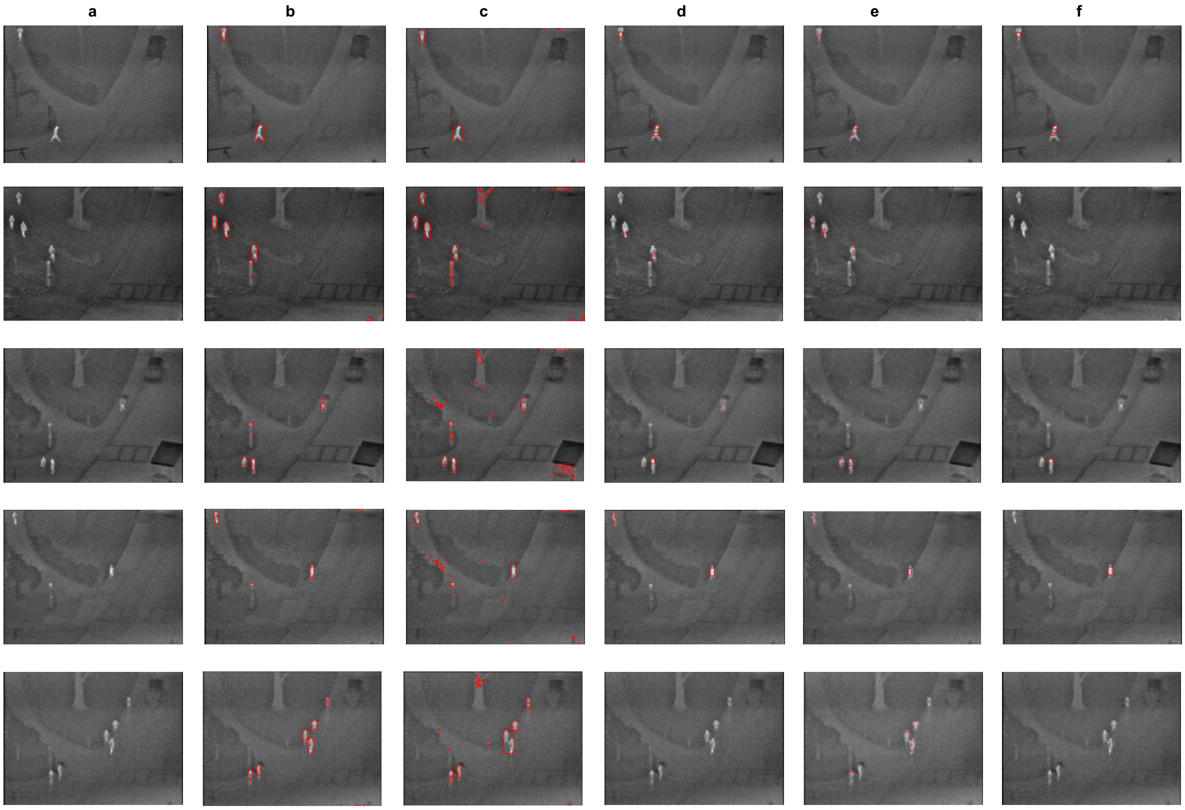

Fig. 2.Comparison of results for some sample images (a) Original IR image (b) The results of proposed method (c) The results of Wang method (d) The results of max-median 3×3 (e) The results of top-hat transformation (f) The results of max-median 5×5

3.2. Performance analysis of proposed method

To show the performance of the proposed method[27], it is compared with two different categories of detection methods such as single images and sequence of images. The performance of the proposed method outperforms with the single image methods such as Wang method[23], max-median filter 3×3[5], top-hat transform[26] and max-median filter 5×5[5]. Objective evaluation has been done on the resultant images using statistical measure – probability detection rate (PD)[2]. This is defined as ratio of no. of true pedestrian detected (#TPD) and total no. of pedestrians (#TNP) multiplied by 100 in equation (7).

$$PD = \frac{\#TPD}{\#TNP} \times 100 \tag{7}$$

Table 1 gives the detection rate of 10 classes for the proposed method compared with the Wang method[23] and other methods. From the Table 1, it is observed that the proposed method has higher detection rate than the other mentioned methods.

The quantitative performance of the proposed method is also analyzed with feature descriptor based methods for sequence of images using PD and positive predictive value (PPV). PPV is defined as one minus ratio of false positive (#FP) and total no. of pedestrians (#TNP) multiplied by 100 in equation (8).

$$PPV = 1 - \frac{\#FP}{\#TNP} \times 100 \tag{8}$$

The PD or sensitivity describes the probability of pedestrians correctly detected. The high sensitivity value corresponds to a high detection rate of pedestrian. The PPV reports to the fraction of detections that actually are pedestrians. High PPV value corresponds to a low number of false positives.

Table 2 gives the detection rate of 10 classes for the proposed method compared with the Davis method[28], Zelin Li method[29] and Wei Li method[30]. From Table 2, it is observed that the proposed method has lower detection rate than Davis method[28] and Zelin Li method[29] but performs better than Wei Li method[30]. The three methods that are compared are basically falls under sequence of image based methods. The prevalency among these methods is that they process the gradient image rather than the original image and extract features from it. The proposed method deals with the original image and spatial image processing operations but still the results are closer to these methods.

Table 1.Comparison of PD values between the proposed method and other methods

Class	Methods				
	Proposed method (%)	Wang method (%)	Max-Median 3 X 3 (%)	Top-hat (%)	Max-Median 5 X 5 (%)
1	88.9861	87.8801	81.6820	80.6067	63.4562
2	96.3690	91.9047	95.4166	96.1904	96.6071
3	68.2056	26.4906	12.3671	13.4230	2.1739
4	100	100	100	96.7592	96.8515
5	95.4244	93.8302	92.9606	86.4389	91.3664
6	88.5648	87.6388	62.0370	59.5679	36.5277
7	87.2294	85.8225	12.1212	39.0692	2.2727
8	92.4900	91.5476	66.1408	53.8789	23.7202
9	98.6301	97.2602	93.1506	86.9863	56.1643
10	78.8889	49.2361	49.5424	39.5833	13.9583
1-10	90.9337	81.1610	66.5418	65.2503	48.3098

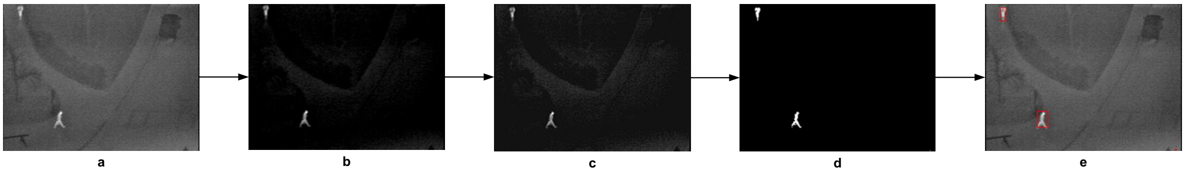

Fig. 3. Graphical abstract of the proposed method (a) Original image (b) Background subtracted image (c) High-boost filtered image (e) Local adaptive threshold applied image (f) detection result

Table 2.Statistical comparison of the proposed method with [28], [29] and [30] methods (#TP: True Positive; #FP: False Positive)

Experiment	Methods			
	Davis method[28]	Zelin Li method[29]	Wei Li method[30]	Proposed Method
Single image				✓
Sequence image	✓	✓	✓	
#FP	6	4	41	51
#TP	930	961	845	894
PPV (%)	99	99.6	95	93
PD (%)	95	97.8	86	90

4. Conclusion

In this paper, a novel and an adaptive method for pedestrian detection is proposed. The contributions of the paper are background modeling and local adaptive thresholding using adaptive calculation of parameters from the input image. Background subtraction model is developed to separate the foreground objects from the background using pixel intensities of the image. Secondly, to enhance the edges of the foreground, high-boost filter is used. Finally, pedestrians are detected based on local adaptive thresholding. The efficacy of the proposed method is evident from the subject evaluation results as well as objective evaluation with around 90% of pedestrians detection rate compared to the other single image existing methods.

In future, it is planned to improve the performance of the proposed method with higher detection rate and low false positives on par with sequence image methods.

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