Zebra-Crossing Detection and Recognition Based on Flood Fill Operation and Uniform Local Binary Pattern

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***Abstract*— Zebra-crossing region detection from a zebra-crossing image is an important and demanding task to support visually impaired people to navigate the street crossing safely in the outdoor environments. In this paper, a zebra-crossing detection and recognition method is presented where zebra-crossing region is detected by employing the image processing techniques such as adaptive histogram equalization, flood fill operation, and Hough transforms and is recognized through the uniform local binary pattern with support vector machine (SVM) classifier. For that, the contrast and sharpness of the zebra-crossing image is improved by the adaptive histogram equalization if the image's intensity value is less than an empirical threshold value. After that, the pre-processed zebra-crossing image is converted to the binary image by using the Otsu's method. Furthermore, the morphological and flood fill operations are applied to the binary image to extract the largest candidate object. The edges of the largest candidate object are detected by utilizing the canny operator. From the edges, the potential longest horizontal edges are estimated by eliminating the vertical edges using four connected method and filtering the small edges using statistical threshold procedure. Finally, the potential parallel horizontal edges are justified as zebra-crossing edge lines by drawing the Hough lines and detect the zebra-crossing region of interest (ROI). Then, the SVM classifier is applied to the detected ROI region to recognize the zebra-crossing region where, rotational invariant uniform local binary pattern is utilized to extract the features of candidate region. Simulation results indicate that the proposed method effectively detects and recognizes zebra crossing regions from various zebra-crossing images. Moreover, it shows superior performance than the state-of-the art methods in terms of recognition.**

Keywords—Adaptive histogram equalization; Flood fill operation; Hough transform; Otsu's method; Support vector machine, Uniform local binary pattern.

I. Introduction

In the current decade, the traffic movements are expanding day by day with the population around the worlds, which needs a more elevated amount of traffic safety. To increase the traffic safety the zebra-crossing detection is the vital issue in the places where no traffic signs alongside the streets. This process is also important for the visually impaired people and autonomous navigation system. As per the present state, numerous people still die while walking across the road. An analysis shows that partially sighted and blind people wait at least three times more than others before crossing a road and among them 6% of attempts are dangerous. For this purpose, we should build up an automotive safety framework to secure the pedestrians crossing.

This section provides the discussion of previous related works and the existing zebra-crossing detection methods that gained significance regarding the automatic navigation system. Still, it is a challenging task for automotive vision due to the extreme variability of targets, various lighting conditions, occlusions, and high-speed vehicle motion. Many researchers have been focused on this problem for the last few years. Numerous approaches have been proposed. For example, in [1], RGB-D (Red, Green, Blue, and Depth) image based method is introduced to detect the crosswalks and traffic signs. Hough lines are drawn in this method to extract the parallel lines and the depth information is used to distinguish the stairs and crosswalks. Furthermore, the distance between the camera and stairs were also estimated by using the depth feature, however, the accuracy of this method is not promising. In [2], Fourier transform and augmented bipolarity based pedestrian crossing detection technique is used for pedestrian safety and the support vector machine (SVM) is used for supervised learning with large data set.

An image base pedestrian crossing detection procedure is introduced in [3]. Here, the pedestrian crossing candidate region is detected by the bipolarity theory followed by de-noising and morphological operation. This procedure provides low accuracy at the low illumination conditions. Earlier, another bipolarity based detection method is introduced in [4][10], where, image segmentation is performed by bipolarity and the image is recognized by the projective invariance. This method does not perform better if the candidate region is not located at the appropriate position, i.e. center.

A zebra-crossing recognizer algorithm is introduced in [5]. Where, the region of the zebra-crossing is detected from the zebra-crossing image with significantly improved accuracy and runtime. Here a rectification matrix is computed which depends on the video camera and accelerometers to group and detect the zebra-crossing line segments.

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A geometrical feature based zebra-crossing detection method is proposed in [6]. In this method, authors detect the zebra-crossing ROI by utilizing a unique geometrical feature, i.e. zebra-crossing horizontal edge segments are arranged in sorted order. The detected ROI is verified by utilizing the vertical vanishing point. Another crosswalks detection method based on the vertical vanishing point is introduced in [7]. Where, the crosswalks region is detected by estimating the group of parallel concurrent lines. Finally, the vanishing point is used to distinguish the crosswalks from other analogous objects. In [8], the zebra-crossing region is recognized from a high-resolution RGB aerial image and DSM data. On-board monocular camera based zebra-crossing detection framework is proposed in [9]. Here, an integral method based on horizontal projection is used to detect the zebra-crossing. An overview of innovative solutions aimed at improving safety of pedestrian crossings: automatic pedestrian detection, dynamic traffic signs and better lighting systems is presented in [11].

In this paper, we have proposed a zebra-crossing detection and recognition method based on the image processing technique and uniform local binary pattern features. The image processing techniques used in this work are adaptive histogram equalization, Flood fill operation, and Hough transformation. Here, the low contrast and low sharpness images are improved by the adaptive histogram equalization. The candidate region is detected by utilizing the morphological and Flood fill operations. From the candidate region, the non-candidate small objects are eliminated by the proposed statistical threshold process. After that, the edge information is detected from the potential candidate region through the Canny operator. The potential parallel horizontal edge lines are estimated by eliminating the vertical edges and removing the small edges through the proposed statistical threshold procedure from the edge image. The potential parallel horizontal edges are justified as zebra-crossing edge lines by drawing the Hough lines and detect the zebra-crossing region of interest (ROI). The detected ROI is recognized by SVM. Where, rotational invariant uniform Local Binary Pattern is used to extract the features.

The rest of the paper is organized as follows. Section II demonstrates the proposed zebra-crossing detection method step by step. Section III discusses the experimental results of the proposed method. Finally, Section IV concludes the paper.

II. Proposed Method

This section demonstrates the proposed method which is divided into two basic parts, i.e. zebra-crossing detection and recognition. The zebra-crossing detection part is divided into six major steps. These steps are: (1) pre-processing and improving zebra-crossing strip regions' contrast and sharpness with adaptive histogram equalization, (2) convert to binary image and extracting the candidate region through the gap filling and the flood fill operation, (3) eliminating non-candidate objects by utilizing statistical threshold process, (4) applying flood fill operation and extracting edge information by applying Canny operator, (5) eliminating non-candidate edges and estimating potential horizontal edge lines, (6) drawing the Hough lines to justifying the zebra-crossing edge lines and detecting the zebra-crossing region of interest (ROI). The detected ROI is sent to the SVM to recognize the zebra-crossing region. For that, rotational invariant uniform Local Binary Pattern is utilized to extract the features. Fig. 1 shows the working flow of the proposed system.

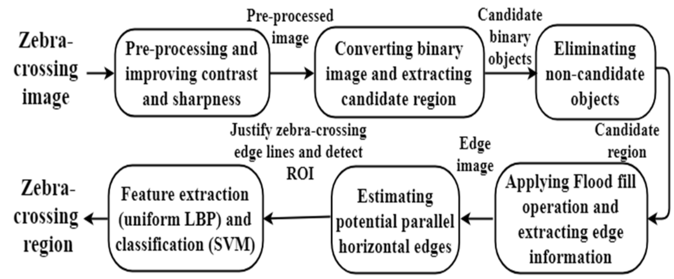


Fig. 1. Proposed zebra-crossing detection and recognition method.

A. Pre-processing and Improving the Contrast and Sharpness of the Image

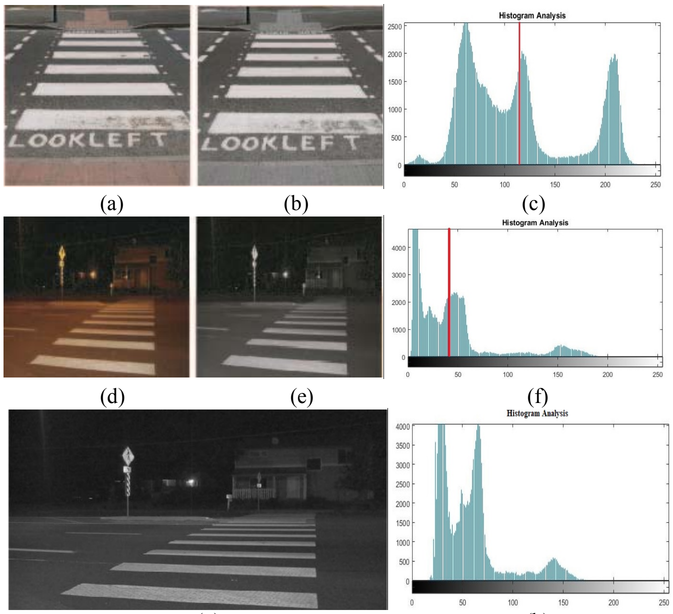
At first, the input zebra-crossing image is resized and converted to a grayscale image to reduce the computation cost. As the zebra-crossing regions are located in outdoor environments with different contrast and sharpness, to cope with these situations the input image's contrast and sharpness have to be improved. For that, the adaptive histogram equalization method is applied to the image which average intensity value is less than an empirical threshold value. The empirical threshold value is set to forty. This empirical threshold value (E) is estimated from the experimental analysis of the zebra-crossing samples. From the experimental analysis is revealed that at forty intensity values the zebra-crossing strip regions working better.

For applying the adaptive histogram equalization, the average intensity value of the input image is estimated at the different illumination conditions. If the average intensity value is less than the empirical threshold value E then the adaptive histogram equalization is used on that image to improve the contrast and sharpness. The average intensity value is used in this work because of low light images have less average intensity value and not sharp enough. In those cases, the zebra-crossing strip's regions are not sharp enough to extract the edges and increase the possibility to reduce the detection accuracy. By applying the adaptive histogram equalization increases the contrast and sharpness of a low light image. This robust pre-processing will ensure a high-intensity image.

The gray scale image of the input zebra-crossing image and the histogram equalization is shown in Fig. 2(b) and Fig. 2(c) respectively. The input image is shown in Fig. 4(a). Here, the average intensity value is 112.91. For that, in that image, the adaptive histogram equalization is not applied as the average intensity value is greater than the threshold value E. However, the average intensity value of the image Fig. 2(e) shown in Fig. 2(f) is 38.07. As the intensity value is less than the empirical threshold value E, so the adaptive histogram equalization is applied to this image. The image and histogram analysis after applying the adaptive histogram equalization is shown in Fig. 2(g) and Fig.2(h) respectively.

B. Converting to binary image and extracting the candidate region

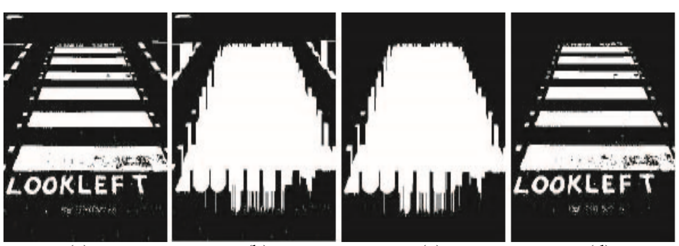
The pre-processed image is converted to the binary image through the Otsu method to extract the shape of the zebra-crossing candidate strip regions. The binary image is shown in Fig. 3(a). From the binary image, the candidate shape of the zebra-crossing strip regions will be extracted.



(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 2. Processing example of pre-processing and improving image contrast and sharpness: (a) input RGB image, (b) grayscale image, (c) histogram analysis, (d) input image which average intensity value is less than the threshold value E, (e) grayscale image of Fig. 2(d), (f) histogram analysis of the normal grayscale image, (g) grayscale image after applying adaptive histogram equalization, and (h) histogram analysis after applying the adaptive histogram equalization.

However, the zebra-crossing strip's regions have some gaps within and between the strip's regions for various regions. The morphological and flood fill operations are applied on the binary image to fill up the gaps. The morphological operation used in this section are filling and closing. For that, a structured element is defined here with the angle value of 90 degrees because all the zebra stripes are in a horizontal to each other from the viewpoint. The filled binary image is shown in Fig. 3(b). From the binary image, the largest bobs area is selected. The largest bob area is shown in Fig.3(c). This largest selected area is used as a zebra-crossing candidate region. The extracted largest candidate binary region and corresponding candidate zebra-crossing region is presented in Fig. 3(d).



(a) (b) (c) (d)

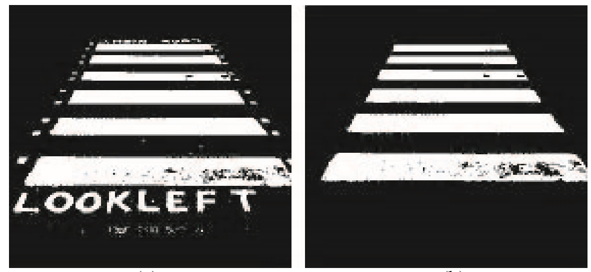
Fig. 3. Processing example of extracting candidate region: a) binary image of Fig. 2(b), b) The filled binary image, c) largest bob area, and d) extracted largest candidate binary region.

C. Eliminating Non-candidate Objects

From the extracted candidate region it is seen that in the candidate region exists many objects that are covered the small area. These non-candidate small objects are eliminated from the candidate region by using a proposed filtering process. According to the filtering process, the small objects are removed by utilizing a statistical threshold value. If any object exists in the region which edge length is less than the statistical threshold value will be eliminated from the candidate region. The threshold value is the first standard deviation of the edge length of the objects contains in the candidate region. The threshold value is defined as,

$$\sqrt{\frac{\sum_{i=1}^{N}(objectedge(i)-objectedge\_mean)^2}{N}}$$

where *objectedge(i)* is the edge length of object *i* and *N* is the total number of the objects in the candidate region. The outcome of the non-candidate object elimination process is shown in Fig. 4(b).



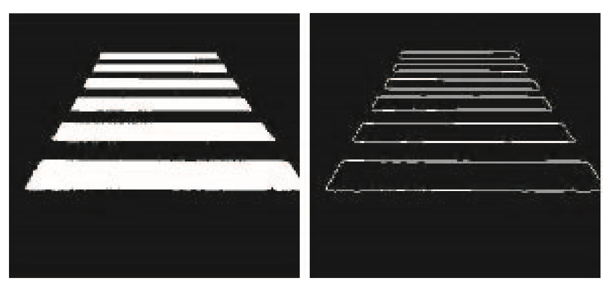
(a) (b)

Fig.4. Processing example of eliminating non-candidate objects: a) candidate binary region, and b) eliminating non-candidate objects.

D. Applying the Flood Fill method and Extracting Edge Information

In this section, the Flood fill method is applied to the candidate binary image to cover all the small holes inside the image. The zebra-crossing strip's regions may have some erosions and defects inside it. Those defects are covered by the Flood fill operation. The effect of the Flood Fill operation on the candidate binary image is shown in Fig. 5(a).

The flood fill candidate smooth image is used in this section to detect the potential zebra-crossing edges. For that, the canny operator is used in this work. This Laplacian operator is used because of its reliable performance. The advantage of this operator is to use the Gaussian filter to smooth the image and to use non-maximum suppression to get rid of the spurious response. This method also uses the double threshold to determine the potential edges. The edges are tracked by hysteresis and the detection is finalized by suppressing all weak edges which are not connected to the strong ones. The canny edge image is shown in Fig. 5(b).



(a) (b)

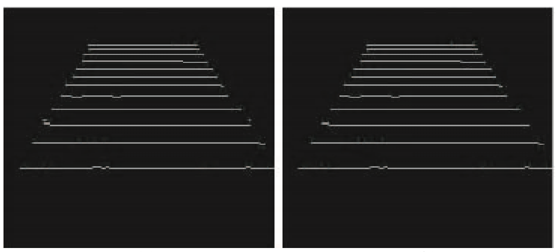
Fig. 5. Processing example of Flood fill operation and Canny edge detection: a) outcome of the Flood fill operation, and b) Canny edge image.

E. Eliminating Non-candidate Edges and Estimating Potential Horizontal Edge Lines

This section describes the process of estimating the potential horizontal edges from the canny edge image. These edges are used in the next section to justify the zebra-crossing image. For that, initially, the vertical edges are eliminated from the canny edge image. As a result, the edge image may contain the horizontal edges mostly. The horizontal edges are shown in Fig. 6(a).

From the Fig. 6(a), it is seen that in the edge image still presents many small edges. These small edges are eliminated from the edge image through a proposed filtering procedure. According to the filtering process, the small non-interest edges are eliminated by a statistical threshold value. Those edges are preserved whose edge length is greater than the statistical threshold value. The threshold value is defined as, $\frac{\sum|(edge(i) - edge_{mean})|}{N}$

The threshold value is the mean absolute deviation (MAD) of the edge length values presented in Fig. 6(a). Here, *N* is the number of horizontal edges. The outcome of small edge elimination process is shown in Fig. 6(b). Fig. 6(b) contains the potential horizontal edges from where the zebra-crossing region will be detected.



(a) (b)

Fig. 6. Processing example of extracting potential horizontal edges: a) eliminating vertical edges, and b) eliminating non-candidate small edges.

F. Justifying Potential Horizontal Edge Lines based on Hough Transform and Detecting ROI

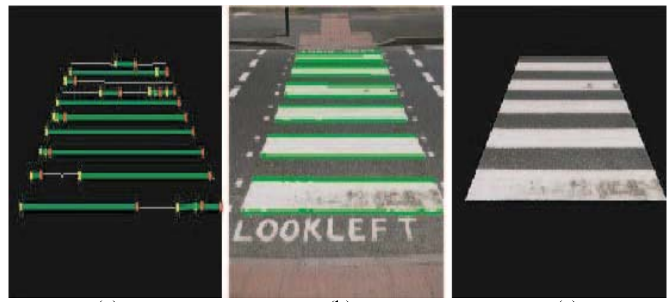
In this section, we applied the Hough transform to justify that the extracted potential horizontal edges are parallel to each other. Here, we use the Hough transform in the polar coordinates, which is denoted by the parameter r and ϴ for the edge lines in the Hough transform. The parameter r is denoted as the distance of the starting and ending point of the edge line and the ϴ is the angle of the parallel edge lines which have the similar angle (ϴ). So, the equation of the edge line can be demonstrated as (1).

$$r = y\ sin\theta + x\ cos\theta \quad (1)$$

The outcome of the Hough transformation is shown in Fig. 7(a). In the Hough lines shown in Fig. 7(a), the zebra-crossing parallel edge lines are shown as green, where, yellow and red dots denotes the starting and ending points of the straight edge lines respectively.

In the zebra-crossing edge lines, the parallel horizontal edges are not exactly horizontally straight edge line for different noises. Therefore, Hough lines are not presented from all the horizontal edge lines. Furthermore, the edge line contains gaps for different regions. For these regards, we consider a threshold value for gap length to group the edge segment as the same edge line. Moreover, the zebra-crossing parallel edges are in the different length. If any edge line is less than the threshold value (λ) then the edge line will not belong to the zebra-crossing edge segment. If the final detected Hough line number is less than the Φ then the extracted edge segment is considered as the negative edge segment. That means the edge segment is not extracted from the zebra-crossing image. In this work, we considered the value of λ as fifty and the value of Φ as five for the best performance of the proposed system. If the extracted edge segment satisfies the above conditions then the edge segment is considered as the zebra-crossing edge segment. The segment's area is considered as the zebra crossing region of interest (ROI).

The justified edge segment is reflecting in the RGB zebra-crossing image with the yellow horizontal edge. The outcome is presented in Fig. 7(b). The detected zebra-crossing ROI is shown in Fig. 7(c).



(a) (b) (c)

Fig. 7. Justifying zebra-crossing edge lines and detecting zebra-crossing ROI: a) outcome of the Hough transformation, b) justified edge segment is reflecting in the RGB zebra-crossing image with the yellow horizontal edge, and c) detected zebra-crossing ROI.

G. Feature Extraction and Classification

This section explains the process of extracting the features from the detected zebra-crossing ROI which is a vital issue for the object recognition. This is also an important part for the field of computer vision. For better feature estimation the zebra-crossing ROI is resized into 128x128 pixels. After that, from the resized zebra-crossing region the Uniform Local Binary pattern [12] features are extracted and sent to the Support Vector Machine [13] to recognize. The Uniform Local Binary pattern used in this work is moment invariant for eight neighboring pixels (R) and one radius (R). The feature size of the image for Uniform local binary pattern is 59 i.e., Px(P-1)+3.

III. Experimental Results and Discussion

The experimental results of different images containing zebra-crossing are explained in this section. All the experiments were accomplished in the Intel(R) Core(TM) i5 CPU@2.50GHZ processor with 4GB RAM. In this paper, the experiments were processed in MATLAB environment. A total of 140 zebra-crossing images were taken from different environment and illumination conditions. Some negative samples were also taken for analyzing the robustness of the proposed method.

This paper considered the zebra-crossing images that are captured from the zebra-crossing horizontal view only. So, for the experimental results all the zebra-crossing images were taken from the front side of the zebra-crossing. The height and angular displacement were different in every image to cope with various views from the pedestrian. Some positive and negative sample zebra-crossing images are shown in Fig. 8 and Fig. 9 respectively.

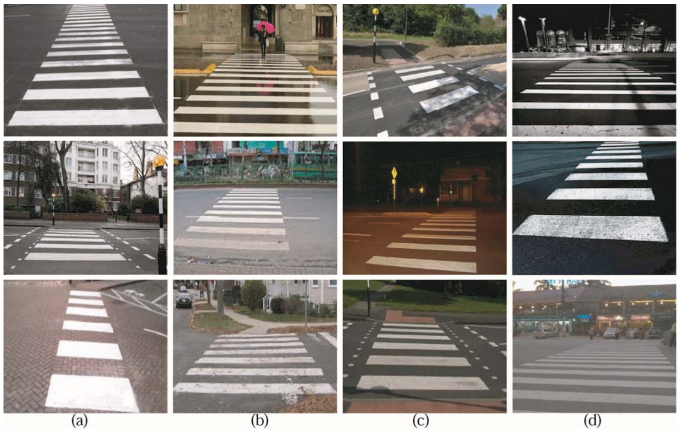
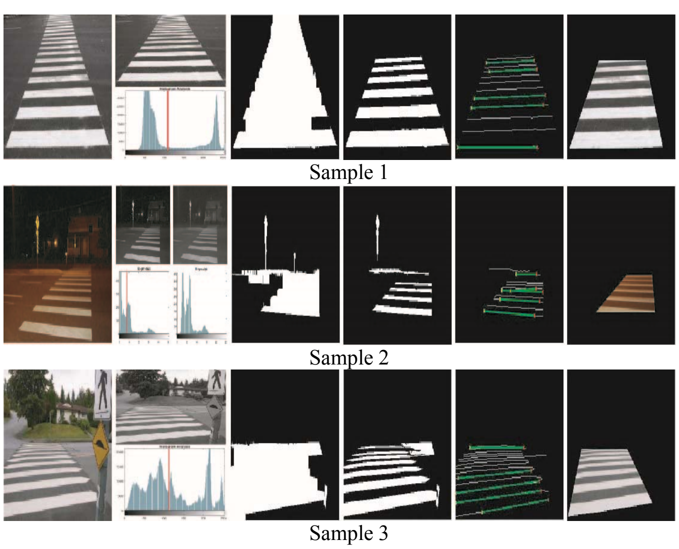


Fig. 8. Positive zebra-crossing sample images: a) normal environment, b) noisy environment, c) uneven illumination conditions, and d) noisy at night time.

Fig. 9. Negative zebra-crossing sample images.

The results of different processing samples are presented in Fig.10. In Fig. 10 shows the detection process of zebra-crossing region of interest. In this figure, the input zebra-crossing image, zebra-crossing grayscale image with histogram analysis, extracting candidate region, flood fill operation, justification of zebra-crossing horizontal edge lines with Hough transformation, and detected zebra-crossing region of interest are shown in Fig. 10(a), Fig. 10(b), Fig. 10(c), Fig. 10(e), Fig. 10(f), and Fig. 10(g) respectively.



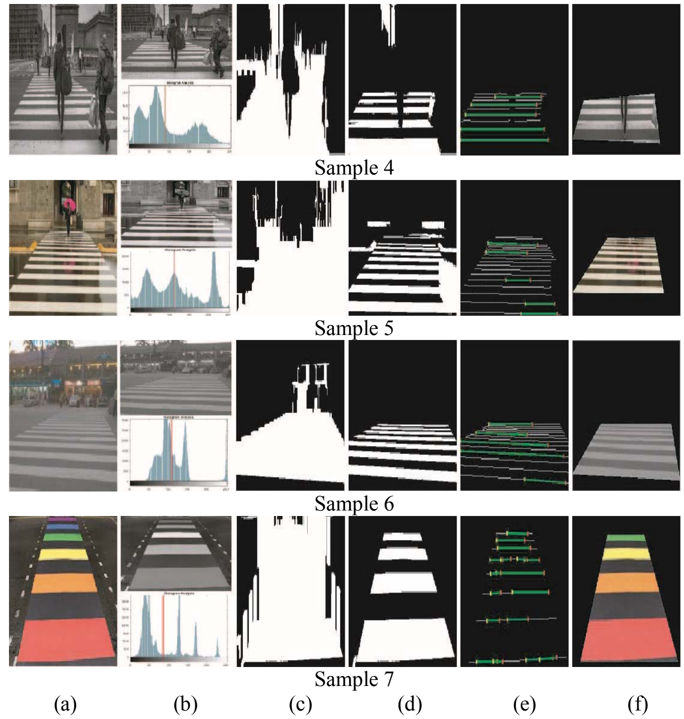


Fig. 10. Processing example of zebra-crossing region detection: (a) input image, (b) grayscale image with respective histogram analysis, (c) largest bob area in the binary image, (d) extracted candidate region, (e) justifying zebra-crossing edge lines with Hough lines, and (f) detected zebra-crossing ROI.

In Fig. 10, the sample images are taken from the different environment and illumination conditions. In it Sample 1, 3 and 4 are captured at the normal daylight with different orientations and focal angles. Where, Sample 1 is taken closely with short height. In Sample 1 shorter stripe regions are clear, however, the depth stripe regions do not resolute properly. Sample 2 is captured at the night time with uneven illumination conditions. In this image, the average intensity value is 38.07 which is less than the threshold value. For that, the adaptive histogram equalization is applied in this image for improving the contrast and sharpness of the image. The outcome of the adaptive histogram equalization is shown in Fig. 10(b) (ii). From Fig. 10(e) Sample 2, it is seen that sample contains one vertical object. This vertical object is broken in the vertical edge elimination process and the remaining horizontal edges are eliminated through the small edge elimination process. Sample 4 is captured from the normal illumination condition where some pedestrians are located in different portions of the zebra-crossing image. The portions of the zebra-crossing where the pedestrians are located are not detected by the morphological and flood fills operation. That's why, the pedestrian region's edges are not detected by the Canny edge image. However, the pedestrian portion's zebra-crossing region is detected by the proposed system as the Hough transform can detect the horizontal edges with the gap length of a threshold value.

Sample 5 is captured at the rainy day where the frontal portion of the zebra-crossing is clear. However, the further portion of the zebra-crossing does not resolute properly. Since the candidate object is selected through the morphological and flood fill operations so the low resolute stripe's areas are also detected by the proposed system. Sample 6 is captured from the low illumination noisy environment. It contains the other objects in the candidate region like Sample 2 and 4. The Non-candidate object regions are eliminated through the object and edge filtering process. Sample 7 is captured from the uneven illumination condition where the stripes are of different colors. From the experiment, it is seen that the proposed method can extract the candidate region effectively and justify the horizontal edges perfectly. Finally, the zebra-crossing region is extracted efficiently from this colored zebra-crossing image.

All the processing samples are shown in Fig. 10 demonstrate that the proposed system utilizes the adaptive histogram equalization method to the accurate images and detects the candidate region efficiently by utilizing small object elimination process. The system also perfectly extracts the potential horizontal edges by utilizing the vertical edge elimination process and small edge removing procedure, where, a statistical threshold value is used. Finally, the zebra-crossing edge lines are justified by Hough transformation and effectively detect the zebra-crossing region of interest. In the samples, some portions of the zebra-crossing regions are not detected by the proposed system due to the noise and different illumination conditions such as Sample 2 and 6, where some portion is not detected due to the pedestrian such as Sample 4. However, the proposed system can detect the zebra-crossing region effectively from the different environmental conditions.

TABLE I. THE DETECTION RESULT OF ZEBRA-CROSSING AT DIFFERENT ENVIRONMENTAL CONDITIONS

Conditions	Total Ima-ge	Detection error (%)		Recall (%)	Precision (%)	Detection accuracy (%)
		FN	FP			
Normal illumination	66	0.00	0.00	100	100	100.00
Uneven Illumination	42	4.12	1.55	95.88	98.45	97.17
Noisy background	32	4.86	1.76	95.14	98.24	96.69
Avg.	**140**	**2.99**	**0.97**	**97.00**	**98.89**	**97.95**

TABLE II. ZEBRA-CROSSING RECOGNITION ACCURACY IN DIFFERENT ILLUMINATION CONDITIONS

Conditions	Total images	Detected images	Accuracy
Normal illumination	66	66	100 %
Noisy background and lighting	32	31	96.88 %
Uneven illumination	42	41	97.62 %
Average	**140**	**138**	**98.17%**

TABLE III. COMPARISON OF THE PROPOSED AND SEVERAL METHODS IN TERMS OF RECOGNITION

Method	Accuracy
[1]	75.6%
[3]	96.2%
[6]	97.02%
Proposed system	**98.17%**

The performance of the proposed system based on the zebra-crossing detection is shown in Table I. The detection performance is presented with respect to the false positive (FP), false negative (FN), recall and precision. The FP denotes the detection of zebra region by the proposed system from images without zebra crossings. The FN denotes the zebra-crossing region that should be detected by the proposed system, however, the system has not detected. The recall defines the completeness of the proposed system, where, the precision defines the exactness of the proposed system. The recall and precision are defined in (2) and (3).

$$\text{Recall} = \frac{\text{TP}}{\text{TP+FP}} \quad (2)$$

$$\text{Precision} = \frac{\text{TP}}{\text{TP+FN}} \quad (3)$$

The zebra-crossing region recognition accuracy at the various environmental conditions is demonstrated in Table II. Form Table II, it is seen that the proposed method can successfully recognize all the zebra regions in normal conditions. The proposed zebra-crossing detection method is compared with [1], [3], and [6]. The result of the comparison is shown in Table III.

IV. CONCLUSIONS

In this paper, a zebra-crossing detection and recognition method has been proposed based on the image processing techniques. This zebra-crossing detection and recognition method is a key issue for the partially sighted and blind people to navigate the zebra-crossing automatically. The proposed system effectively detects the zebra-crossing region from the different environmental and illumination condition. And it does not require any initial information for the detection process. A various number of different environmental zebra-crossing images are utilized in this work to measure the efficiency and effectiveness of the proposed system. The proposed zebra-crossing detection method shows the acceptable detection accuracy of 97.95%, where, its recognition accuracy is 98.17%. This zebra-crossing detection method performs better for the traditional zebra-crossing images. It does not perform better for the unusual shapes of zebra-crossings such as rounding zebra-crossing image. In future, the proposed method will be updated for the unusual shapes zebra-crossing and make a mobile application for the blind and partially sighted people.

References

[1] S. Wang, H. Pan, C. Zhang, C. and Y. Tian, "RGB-D image-based detection of stairs, pedestrian crosswalks and traffic signs," In *Journal of Visual Communication and Image Representation*, Vol. 25, No. 2, pp. 263-272, 2014.

[2] S. Sichelschmidt, A. Haselhoff, A. Kummert, M.Roehder, B. Elias, and K. Berns, "Pedestrian crossing detecting as a part of an urban pedestrian safety system," *in proc. Intelligent Vehicles Symposium (IV)*, pp. 840-844, IEEE, 2010.

[3] C. Yuzhen, C. Lushi, and J. Shuo, "An image based detection of pedestrian crossing," *in proc. 2nd International Congress on Image and Signal Processing (CISP'09)*, pp. 1-5, IEEE, October, 2009.

[4] M. S. Uddin, T. Shioyama, "Detection of Pedestrian Crossing Using Bipolarity Feature- An Image-Based Technique", *IEEE Transactions on Intelligent Systems*, vol.6, No.4, pp. 439–445, December 2005.

[5] D. Ahmetovic, C. Bernareggi, A. Gerino, and S. Mascetti, "Zebra Recognizer: efficient andprecise localization of pedestrian crossings". In *22nd International Conference on Pattern Recognition*, Stockholm, Sweden, pp. 2566–2571 (2014)

[6] M. Khaliluzzaman and K. Deb, "Zebra-crossing detection based on geometric feature and vertical vanishing point" *in proc. 3rd International Conference on Electrical Engineering and Information & Communication Technology (iCEEiCT),* MIST, Dhaka, Bangladesh, September 2016.

[7] S. Se, "Zebra-crossing detection for the partially sighted." *in proc. IEEE Conference on Computer Vision and Pattern Recognition,* vol. 2, 2000.

[8] D. Herumurti , K. Uchimura , G. Koutaki , T. Uemura, "Urban Road Network Extraction Based on Zebra Crossing Detection from a Very High Resolution RGB Aerial Image and DSM Data" In *2013 International Conference on Signal-Image Technology & Internet-Based Systems,* Japan, December 2013.

[9] Z. S. Chen and D. F. Zhang, "An Effective Detection Algorithm of Zebra-Crossing" *in proc. of the 3rd International Conference on Electrical and Information Technologies for Rail Transportation (EITRT), Springer,* 2017.

[10] M. S. Uddin and T. Shioyama, "Robust Zebra-Crossing Detection using Bipolarity and Projective Invariant" *in proc. of the Eight Symposium on Signal Processing and Its Applications,* Vol.2, 2005.

[11] W. Czajewski, P. Dąbkowski and P. Olszewski, "Innovate solutions for improving safety at pedestrian crossings," *Arch. Transp. Syst. Telemat*, Vol. 6, No.2, pp.16–22, 2013.

[12] T. Ojala, M. Pietikainen, and T. Maenpaa, "Multiresolution gray-scale and rotation invariant texture classification with local binary patterns," *IEEE Transactions on pattern analysis and machine intelligence,* vol. 24, no. 7, pp.971-987, 2002.

[13] J. C. Burges, A tutorial on support vector machines for patten recognition, Data Mining and Knowledge Discovery, Vol. 2, pp.121-167, 1998.