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A Visually Assistive Guidance System for Visually Impaired Pedestrians Passing Crosswalks

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Abstract **-** Visually impaired people always experience inconvenience to manage many issues in their daily life. Crossing the road without tactile paving becomes a great challenge to the blind. Based on this motivation, this paper aims to develop a wearable assistive guiding system using techniques of machine vision to direct the visually impaired people walking on the central area of the crosswalks while crossing the road. Both safety and autonomy of visually impaired people can therefore be improved. This research incorporates image processing approaches to locate the central position of the crosswalks even affected by occlusion of pedestrians and interference of shadow. In addition, statistical approaches are also applied to reduce the influence of fault detection. A wearable device with vibration wristbands is then employed to provide information of guidance for the visually impaired people. Crossing-the-road experiments were conducted to examine performance of the proposed center-line detection algorithm and guidance of vibration strategy. In order to include all possible appearances of crosswalks in real world, four different conditions, head-on without occlusion, oblique without occlusion, head-on with occlusion, and oblique with occlusion, are studied. Finally, the presented assistive guiding system demonstrates promising performance to direct healthy human subjects with both eyes fully covered successfully walking on the crosswalk to pass through a road.

Keywords**:** image processing, machine vision, pedestrian crosswalks, visually impaired people, wearable device.

1. Introduction

Based on reports released by Department of Statistics in Ministry of Health and Welfare of Taiwan, the number of people with visual impairment reached 55,000 recently [1]. However, this number only covers persons with identification of disability. The total number of people with visual impairment in Taiwan should be more than three times of that. If moderate and severe amblyopia or low vision are included, the total number of people with visual impairment and difficulty will be up to 350,000.

Although accessible facilities, such as ramps, elevators, tactile paving, etc., are specially designed for walking of persons with disabilities, the task of crossing roads is still a challenge to visually impaired persons nowadays. Even though some roads are equipped with different sounds to provide signals of passing or stopping for pedestrians. Nevertheless, this design lacks of information of heading and cannot offer sufficient guidance for visually impaired persons to safely pass the road.

Due to rapid development of fabrication of electronics and sensors, technologies of machine vision have been extended from industrial applications to many fields, especially on self-driving automobiles including lane detection [2][3], and recognition of crosswalks and traffic lights [4][5]. Recently, visually impaired persons have gained assistance from novel machine vision technologies to reduce living inconveniences by sensing their environment with cameras [6][7]. For visually impaired persons, transportation probably is the most difficult part compared to other basic living demands such as food, clothing, and housing, in their daily life. Simply walking becomes a tough task because of limited accessible facilities. Visually impaired pedestrians may experience difficulties including finding a desired target [8], acquiring information from traffic signs [9], and keeping themselves away from obstacles [10] while walking. More and more research articles focused on applying the state-of-art technologies to provide assistances for visually impaired people so that they are getting better and better to manage their living style by themselves.

When visually impaired persons need to pass across the road, the crosswalks become a crucial role to lead them safely accomplishing the task. Therefore, some researches emphasized on crosswalks detection [11][12]. However, most studies were limited to locating the relative position of the crosswalks and provided guidance approaching to the starting end of the crosswalks. Furthermore, the shadow from pedestrians on the road and nearby objects such buildings and trees may greatly affect performance of crosswalks extraction. A number of investigations concentrated on shadow removal and compensation to conserve completeness and integrity of image information [13][14]. Therefore, this research aims at guidance development for visually impaired pedestrians at one end of the crosswalks to traverse across the road. In order to keep pedestrians away from dangerous situations, the goal of the guidance is to maintain pedestrians walking in the middle area of crosswalks. The major challenge in this research will be obtaining the middle points of crosswalks when only partial crosswalks can be acquired due to obstructed by other pedestrians on the crosswalks.

2. Extraction of Crosswalks

A crosswalk always consists of dozens of equally spaced white stripes depending on the width of the road. Theoretically, crosswalk extraction can be achieved by two important image features, the white color and parallel lines [15][16]. Although the white color should be easily extracted from the image, the light intensity from the sun on the crosswalks may not be always constant and is strongly affected by the weather and cloud conditions. As a result, separation of those white stripes of crosswalks should be able to be achieved by giving ranges of parameters in either RGB or HSV color space. Three parameters are required to be defined in RGB domain. However, different gray levels in white color only needs two parameters, i.e., saturation and value, in HSV color space. Consequently, the HSV color space is chosen for extraction of white stripes of crosswalks because of advantages of easy adjustment and faster computation speed. Through extensive tests, satisfactory results were reached using S less than 30% and V greater than 80%.

2.1. Shadow Detection and Compensation

Extraction of crosswalks will be greatly influenced by the shadow from pedestrians and objects in the surroundings such as buildings and trees, which partially hides white stripes of crosswalks and may bring about incorrect guidance due to incomplete detection. Therefore, shadow on the crosswalks needs to be carefully managed before extraction of white stripes of crosswalks.

Unfortunately, the shadow on the crosswalks does not appear as a simply gray level color. Through comparison between a regular RGB image and its corresponding HSV image, it can be found both the blue sky and the shaded crosswalks display similar HSV values. In other words, under the HSV color space, the shadow on the crosswalks exhibits the content of blue. This property can therefore be applied for shadow detection. Through appropriate choice of HSV values, the shadow on the crosswalks can be successfully extracted. Fig. 1(a) is the original image and Fig. 1(b) shows the image of extracted shadow using H between 180 and 235 degrees, S less than 30%, and V above 45%. In order to accomplish extraction of full crosswalks, the region with shadow needs to be restored to its original tone. It can be achieved by image compensation using intensity amplification. The final result after image compensation is displayed in Fig. 1(c).

(a) (b) (c)

Fig. 1: Shadow detection and compensation for the crosswalk: (a) The original image, (b) shadow detection, and (c) the result after shadow compensation.

After the shadow detection and compensation on the crosswalks is performed, the white stripes of crosswalks should be able to be successfully extracted. Nevertheless, in order to maintain reasonably computational efficiency to allow real-time application to be possible, a region of interest (ROI) is defined to restrict the searching and working area. In addition, a size filter is also employed to remove small particles caused by noises.

2.2. Line Detection and Extension for Crosswalks

Crosswalks with white stripes own features of the color of white and parallel lines. Previous section takes care of the feature of white color. In order to determine the middle line of crosswalks to guide visually impaired people to traverse the road, parallel lines need to be carefully detected. First of all, the Canny edge detection algorithm, a popular method for edge detection, is employed to extract stripe edges of crosswalks [17]. There are four major procedures, including image smoothing, gradient calculation, non-maxima suppression, and hysteresis thresholding, involved in the Canny's algorithm. After extraction of edge contours is completed, the Hough transform is chosen to locate groups of parallel lines in white stripes of crosswalks [18]. The Hough transform determines the line equation using the voting mechanism by converting points of a line defined in Cartesian reference system to a group of lines in a parameter space with polar coordinates. According to practical tests in real world, it appears that edge contours of stripes in crosswalks cannot be fully formulated by the Hough transform and most line segments are separated and incomplete. For the purpose of obtaining correct image information of crosswalks, broken segments on a line need to be extended and combined to form a complete contour.

2.3. Line Merging

In general, line segments lying on the same line can be combined with a single line using the proposed method for line detection and extension. However, due to stripes with unclear boundaries or blocked by other objects such as pedestrians, the technique of line extension may fail and extra work on line merging needs to be performed. A typical example is that line extension cannot cover the white stripes between two legs of a pedestrian. Therefore, the right and left line segments on two sides of the pedestrian are required to be linked together. By judging the intercepts and slopes of those two line segments are close to one another, whether they belong to the same line can therefore be concluded.

2.4. Slope Filtering

Although the ROI restricts the working area on the ground in the image and excludes unrelated regions, it is still possible to have some other line segments that are not on the edges of white stripes of the crosswalks. In order to maintain satisfactory detection performance of crosswalks for forthcoming determination of the center line, those irrelevant line segments have to be filtered out. Basically, line segments with different slopes can be easily rejected by the quartile approach, which divides the number of all data points into four equal-sized parts, i.e., quarters. The outliers can therefore be removed by choosing an appropriate multiplier λ and considering only data in the range of Q1-λ(IQR) and Q3+λ(IQR) for further investigation, where IQR (interquartile range) is defined as the difference between the first and third quartiles, i.e., Q1 and Q3. Nevertheless, this method only works for parallel lines, which happens to be the condition of facing the crosswalks in normal direction. If a visually impaired pedestrian faces the crosswalks with an angle, the long edges of white stripes will not be parallel to one another and the quartile approach may fail.

If the optical axis of the camera is not in normal direction of the crosswalks, long parallel edges of white stripes will intersect at a vanishing point as shown in Fig. 2(a). According to similar idea of Hough transform, a line equation $y = mx + b$ representing a long edge with a slope m and an intercept b can be projected as a point on the plane of b versus m. Since those lines will intersect at a common vanishing point, their corresponding points on the b-m plane need to be collinear as illustrated in Fig. 2(b). Assume this line is formulated as $y_v = mx_v + b$ and the location of the vanishing point (x_v, y_v) can be solved using the line's slope and the intercept on b axis, i.e.,

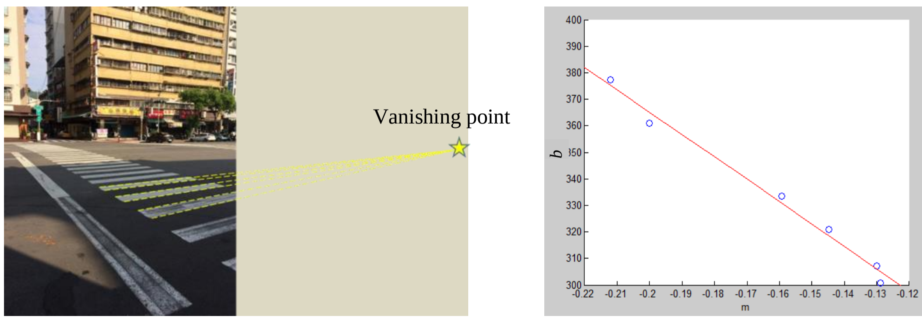
$$\text{slope} = -x_v \tag{1}$$

$$\text{intercept on } b \text{ axis} = y_v \tag{2}$$

However, irrelevant lines in the image may exist to deviate the position of the vanishing point. Consequently, outliers are removed by the method of Cook's distance [19], which employs an evaluation index D_i to judge the influence to the regression line before and after removing the *i*-th data point and has the following expression:

$$D_i = \frac{\sum_{j=1}^{n}(y_j - y'_{j(i)})^2}{P \cdot MSE} \tag{3}$$

where P is the number of parameters in the regression model and MSE stands for the mean square error of all data points. A common criterion for judgment is to discard the data point if its corresponding evaluation index is larger than 0.5.



(a) (b)

Fig. 2: (a) Extension of long edges of white stripes and the vanishing point, (b) collinear property of all the points representing intercepts and slopes of those long edges.

3. Direction Guidance

3.1. Searching for the Center Line

Theoretically, after the complete edges of white stripes are located, the center line can be easily determined by connecting all middle points of long edges. Unfortunately, possible errors due to inevitable noises and limited image resolution may exist. As a result, the standard least square approach is therefore applied to overcome this difficulty.

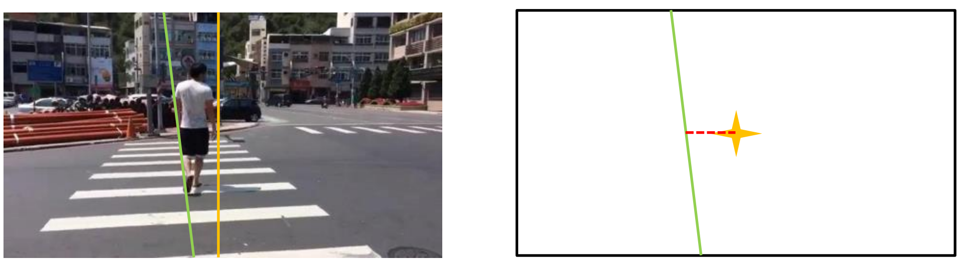
Although careful considerations have been managed for extraction of crosswalks, two common situations still occur to jeopardize correct guidance directions for visually impaired pedestrians. Conditions that may bring about false center line include incomplete shadow compensation, deficient line extension and line merging, and disturbance from other line segments. Another possible situation is that when the pedestrian is close to the end of a crosswalk and the resulting center line may be deviated by limited number of edges of white stripes of the crosswalk.

Considering that walking speed of a visual impaired pedestrian is relative slower than a healthy person, the correctness of guidance information is much more important than the time efficiency for image processing. Three to five outputs per second for guidance signal to direct the pedestrian passing the road should be a reasonable value. Consequently, based on this design guideline, the next and past three samples, and the current one are used to determine the final center line for direction guidance. In other words, the current sample will not be immediately applied and will be included by collecting with the next three coming samples to resolve the candidate for the center line. Again, for the purpose of eliminating undesired outliers, the quartile technique will be also applied to acquire the center line with the most statistical confidence.

Basically, while a pedestrian is walking on a crosswalk, the center line should have similar direction along the way. Therefore, if two consecutive center lines own limited difference within a given range, an average of these two lines will be presented for the direction. Nevertheless, significant difference between two consecutive center lines may indicate wrong detection. At this condition, the new center line will not be taken into consideration and the previous one will be still applied for direction guidance. This mechanism is able to maintain stable and smooth direction guidance that is very helpful for visually impaired pedestrians to follow while walking on the crosswalks to pass through the road.

3.2. Guidance Strategies

After localization of the center line is resolved, signals for direction guidance need to be transported to visually impaired pedestrians. A wearable device with vibration wristbands attached to both hands, which holds advantages with lightweight and easy maintenance, will be applied. When the angle between the detected center line and the pedestrian's heading direction is beyond a given range, e.g., 15 degrees in this research, a vibration wristband on one side will be activated to remind the pedestrian modifying walking orientation due to off course. However, although the angle between the center line and the walking direction is within an acceptable region, the pedestrian cannot be guaranteed walking in the middle area of a crosswalk. Consequently, the distance between the center line and the heading direction also needs to be taken into account. Fig. 3(a) demonstrates the view of the camera attached on a pedestrian. The vertical orange line indicates the person's heading direction and the green line represents the detected center line of the crosswalk. It appears that the pedestrian is walking too close to the right even though the angle between those two lines is within a reasonable range. Therefore, it's necessary to examine the horizontal distance between the detected center line and the image center as depicted in Fig. 3(b). Under this circumstance, if the distance is larger than a given threshold value, the vibration device will be activated to lead the pedestrian moving to the left in order to maintain walking in the middle of the crosswalk for safety reason.



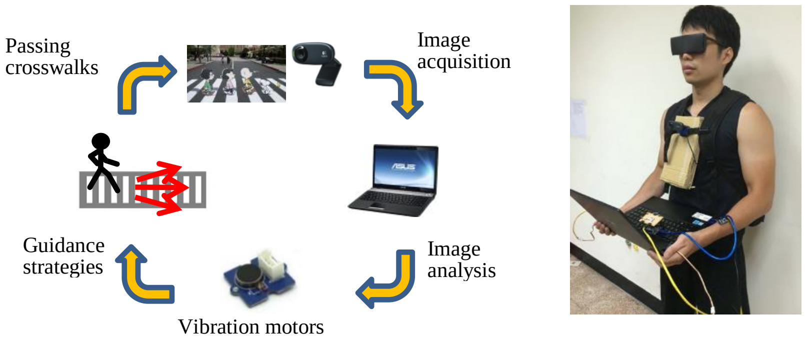
(a) (b)

Fig. 3: (a) The pedestrian's heading direction (yellow) and the detected center line of the crosswalk (green), (b) the horizontal distance between the image center and the detected center line.

As a pedestrian moves forward, the number of white stripes of a crosswalk becomes less and less. When the pedestrian is close to the end of the crosswalk, limited number of white stripes may not be sufficient to provide correct directional information for navigation. Therefore, at this situation, the vibration device on both sides will oscillate altogether to notify the pedestrian that the end of the crosswalks is near and maintain current walking direction.

4. Experiments

In order to verify the applicability and performance of the proposed visually assistive guidance system to help visually impaired people passing pedestrian crosswalks, actual experiments were conducted. The experimental framework is depicted as in Fig. 4(a). The image acquisition is achieved by a Logitech HD C310 webcam, which can provide image resolution up to 1280x720 pixels. A vibration motor was chosen as the vibration device because of its advantage of small volume as 2 cmx2 cm, low energy consumption, and high reliability. Besides, in order to send control signals to vibration motors, an Arduino Uno control board was applied. A healthy person with their eyes fully covered by a black mask was selected as a subject of the visually impaired pedestrian. Fig. 4(b) demonstrates the prototype of the proposed wearable assistive system.



(a) (b)

Fig. 4: (a) Experimental framework, (b) the prototype of the proposed wearable device.

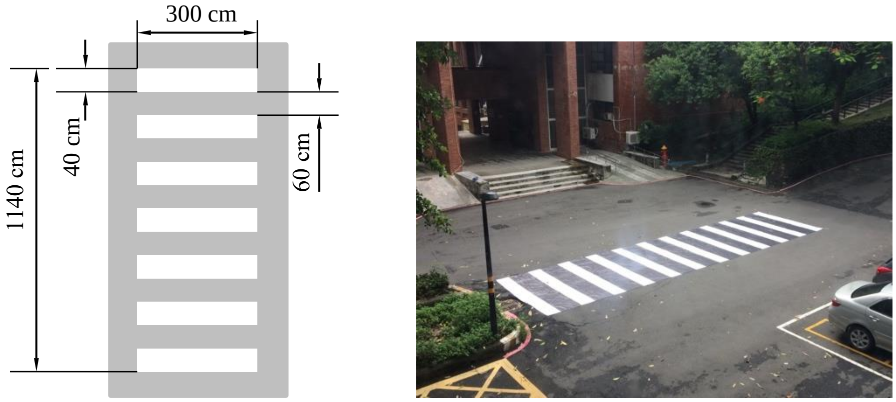
Detection of the center line of a crosswalk plays a crucial role to make the whole wearable guidance device successful. Therefore, the first part of the experiments aims at verification of the correctness of the detected center line. Eight different scenes with four different situations, including head-on or oblique, and with or without occlusion. As a result, there are 32 sets of data in total. The detection performance of the center line is justified according to two evaluation indexes, i.e., angle difference $\Delta\theta$ and offset of intersections Δd. Table I lists means and standard deviations of absolute values of $\Delta\theta$ and Δd in terms of degree and pixel, respectively, in four categories, i.e., head-on without and with occlusion as well as oblique without and with occlusion. Apparently, occlusion always brings about higher errors for the center line and the head-on direction generates better results than the oblique direction. Nevertheless, most angular and offset errors are within 10 degrees and 20 pixels and present satisfactory detection performance.

Table 1: Statistical analysis of the detected center line for four different conditions.

Conditions	$\mu_{\|\Delta\theta\|}$ (deg)	$\sigma_{\|\Delta\theta\|}$ (deg)	$\mu_{\|\Delta d\|}$ (pixel)	$\sigma_{\|\Delta d\|}$ (pixel)
Head-on without Occlusion	3.356	5.582	11.265	19.116
Oblique without Occlusion	6.813	7.277	18.609	20.651
Head-on with Occlusion	6.565	8.281	15.282	23.619
Oblique with Occlusion	11.629	8.588	28.031	19.706

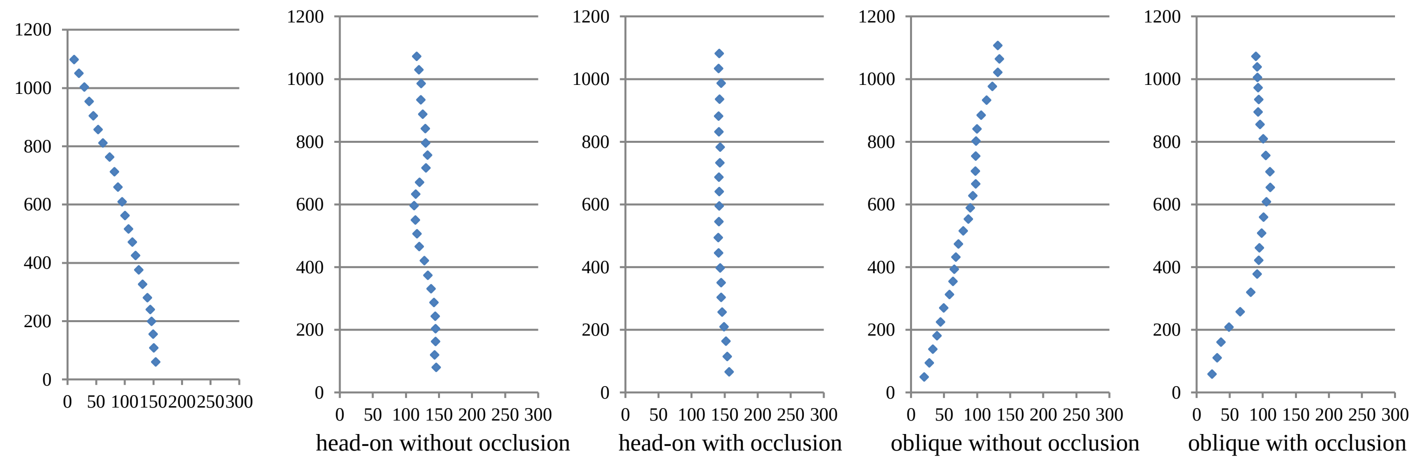
The second part of the experiments was designed to examine the actual performance of the proposed wearable guidance system assisting a visually impaired pedestrian walking on a crosswalk to traverse the road. In order to simulate the actual scene on the street by keeping pedestrians away from dangerous traffic situations as well as easy for data measurement and collection, an artificial scene in the campus was created using a crosswalk made of plastic material as shown in Fig. 5. Similar as previous experiments, four different conditions including head-on without/with occlusion and oblique without/with occlusion, are considered. For the purpose of capturing the route of the pedestrian subject on the crosswalk, four subjects were required to walk slowly so that their footprints could be carefully marked manually.

Fig. 6(a) shows routes of subject #3 on the crosswalk with their eyes fully covered. Apparently, people do not get used to walk without visual information and it's difficult to make their moving trajectories straight along the crosswalk. Experimental results indicate consistently significant improvement for visually impaired people passing the pedestrian crosswalk with the assistance of the proposed visually assistive guidance system. These results also verify that the image processing techniques developed in this research produce positive influence on directing correct guidance. Without surprisingly, the least smooth routes happened to the case for oblique with occlusion. This phenomenon implies that occlusion indeed affects estimation of the center line of the crosswalk. Nevertheless, the wearable guidance system still provides satisfactory directional information to successfully lead the subject passing the crosswalk. Trajectories of subject #3 across the crosswalk for four different scenarios, i.e., head-on without/with occlusion and oblique without/with occlusion are also illustrated in Fig. 6(b).



(a) (b)

Fig. 5: (a) Specifications of the artificial crosswalk, (b) the simulation scene in the campus.



(a) (b)

Fig. 6: Routes of subject #3 on the crosswalk (a) without any visual assistance, (b) with the proposed wearable guidance system.

5. Conclusion

Follow the traffic light to pass the road is a simple daily job for ordinary people. Nevertheless, the same task becomes an almost impossible mission filled with danger for visually impaired persons without assistance. Therefore, this paper presents a wearable device with a camera and vibration wristbands to guide visually impaired pedestrians walking along the center line of crosswalks. In order to acquire white stripes of crosswalks as complete as possible even with occlusion from other pedestrians, extraction of crosswalks is achieved by a series of algorithms for image processing including shadow detection and compensation, line detection and extension, line merging, and slope filtering. Guidance strategies are developed by incorporating both the angle and the distance between the detected center line of the crosswalk and the pedestrian's heading direction. For the purpose of examining the performance of the proposed visually assistive guidance system to help visually impaired people passing pedestrian crosswalks, experiments were conducted for an artificial crosswalk in the campus. Experimental results demonstrate promising performance on leading human subjects with eyes fully covered successfully walking in the middle region of the crosswalk in four different scenarios such as head-on without/with occlusion and oblique without/with occlusion.

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