Improved Descriptor for Dynamic Line Matching in Omnidirectional Images

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***Abstract*—This paper proposes enhancement technique to introduce a robust descriptor for matching the vertical lines between the two moving images in the context of omnidirectional images. The first step is to propose a new descriptor by using signal entropy to determine the number of circular areas for extracted lines. Then, to enhance the orientation histogram, standard deviation over the entropy value and number of circles is used to determine the number of bins in each area. Evaluation results demonstrates the robustness of the proposed descriptor in dynamic line matching (DLM) in omnidirectional images.**

Keywords*— omnidirectional images; feature descriptors; vertical line matching; image matching

I. INTRODUCTION

Feature matching is one of the challenging areas in computer vision, since the matching is a basic instrument for many kinds of applications such as pattern recognition, motion estimation, robotics, buildings and environment constructions [1]. In many literature reviews, the majority of matching methods are based on the points or feature regions [2], in fact it is defective toward low texture scenes. On the other side, line features are abundant dealing with those matters because they provide rich information about the scene. However, line matching also has complexity of difficulties, such as deficiencies in extracting lines and their connectivity where the end points are not reliable. Moreover, the topological connections between line segments often lost during segmentation, and also they lack of disambiguating geometric constraints which are none for infinite lines [1]. A lot of studies have been conducted to improve the performance of vertical or perpendicular line matching by escalating the reliability of feature descriptors extraction. In previous related works [3-5], they presented a vision based on localization algorithm to estimate the position and orientation of the feature points. They implemented some invariant feature descriptors that used neighborhood distance for extraction and evaluated two or more lines or points with affine invariant. Their research is only applicable for standard perspective camera which is not sufficiently robust. Moreover, it cannot be applied directly to omnidirectional images due to non-linear distortions presented by large field of view structures of images [3].

Most of the omnidirectional images are formed by catadioptric systems that mean the combination of mirrors and lenses. The catadioptric consists of catoptrics discipline of reflecting surfaces which is called mirror and dioptric discipline of refracting elements called lenses. The images acquired by these cameras have shown different image geometry conditions [4]. In the reality, omnidirectional images are not easily interpreted and they are unpleasant views for human visualization. Therefore, it is a challenge to match some frames of sequences of omnidirectional images taken from robotic camera or other sources such as image sequences in transportation systems [6] or remote sensing images [7]. This issue is also held by Scaramuzza, et al. [5] who have notified the important problems in vision of robotic navigation or localization in order to search the correspondences in image with different viewpoints. They select vertical lines as features for matching between omnidirectional images which are robust against partial occlusion. Moreover, their method is computationally inexpensive and invariant to affine geometrical deformation. Based on Sagues, et al. [8], each line is described by a set of descriptors where the more invariant the descriptors are the less discriminant they are.

This paper proposes an improved descriptor for vertical line matching from a set of lines extracted from omnidirectional images. The images are from standard dataset [9] which are taken from a robotic camera. The camera is moving on the flat surfaces on the laboratory indoor environment where the robot camera is perpendicular to the object motion surrounding it.

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II. Related Works

A. The Growth of Feature Descriptors Extraction in Omnidirectional Images

The implementation of the line matching in omnidirectional images is conducted by several steps, starting from the descriptor of line features extraction then followed by matching and the evaluation of matching performances. In the earlier study of extraction, the descriptors in omnidirectional images [10],scale invariant features transform (SIFT) method that has been modified to speed up the time and reduced number of key-points. Moreover, Kernel shadow has been used to find mean-shift kernels for matching between omnidirectional images. Arican and Frossard [11] proposed a scale invariant method to be invariant toward rotation and translation based on Riemannian geometry to define differential operators on non-Euclidian. Then, they defined scale space analysis for which they build adapted to the geometry of omnidirectional images. Arican and Frossard [11] method enhanced Arican and Frossard [12] who have proposed new descriptor and feature matching for omnidirectional images. In their study, log-polar descriptor was built to adapt the specific geometry and non-uniform sampling density, whereas, it did not take into account the different number of samples for each spatial bin. And then, Ly, et al. [13] mapped original image on the sphere using projection model (orientation and magnitude) with scale invariant features and used affine invariant based on ratio of point and line distances. Their method is sensitive, because many incorrect lines were identified due to wrong point matches or similar ratios of point to line distances.

Some of those researches have been done to make the descriptors robust for matching omnidirectional images. However, they used points as the features to be extracted. Whereas this paper concerns with the line extraction feature descriptors.

B. Vertical Lines Matching in Omnidirectional Images

Line matching applications has been applied in robotic area since long time ago. It is familiar to measure robot localization, navigation and place recognition. Several studies in line with matching images have been practiced. Wang, et al. [14] have defined line support region and line descriptor matrix to be robust toward line matching. Their method was enhanced Fan, et al. [15] used line-point invariants, however, their methods depended on local geometric information of the neighboring points .Line-point ideas [16] have challenged a new method that was intersection context of coplanar line pairs and the result was able to deal with poor texture scenes while interest points were usually failed on this.

However, those all are mostly implemented on perspective or 2D images and quite seldom working on typical wide scene images, particularly 360 degree scene or well-known as omnidirectional images. Therefore, the following paragraphs will recount several studies which have been done regarding line matching on omnidirectional images.

Some researches such as [8] proposed method for robot localization used vertical lines with metric localization by building histograms and using descriptors of 1D radial trifocal tensor. They measured the similarity by using pyramidal matching algorithm. This research only achieved better performance with wide-baseline matches with which key-point was able to work with minimum database. Caron and Mouaddib [17] also worked on the similar study for robot self-localization with conducting detection, matching and triangulation of four radial lines of mirrors. ThenChong, et al. [18]improved vertical line detection and proposed descriptor scheme for integral image properties. The descriptor is constructed by partitioning sector centered on line features, then calculate 25 equispaced Haar wavelet for each partition in order to reduce the noise during detection edge. However in order to achieve higher performance, this experiment used optimum filter size with varying line threshold demonstrations, and detection line went to decline when the threshold increased.

This work proposes a new technique to improve the performance of feature descriptors extraction to achieve better result for vertical line matching in omnidirectional images. The proposed method is compared to Scaramuzza, et al. [5] method which presented a robust descriptors for tracking vertical lines in framework of mobile robotics.Scaramuzza, et al. [5] method is particularly combination with odometry application. The authors matched vertical lines between consecutive frames while robot is moving. They succeeded match features even the correspondent's features were not found in the previous frames. However, it has inadequacy in terms of determining the number of orientation bin and the number of circular area which effects the descriptors complexity as the beginning step to achieve better result for dynamic vertical line matching.

III. DLM Method

A. Enhancement Technique in Building the Descriptor

In this section, the previous study [5] has described that all lines are extracted with Sobel edge detection and Hough transform methods. Then, all candidate lines will be selected by building descriptors to be rotation invariance by computing the gradient information and dividing them into three equal circular areas for each radial line. The primary drawback of this technique, as we can see in Fig. 1, is that it is not sufficiently robust and identifies several outliers in matching results. In their method, each radial line has various pieces of information which are different from one another. In real world images, each circular area contains different information. One circular area might have less information compared to other circular areas which need to determine more features in terms of information density of illumination or patterns.

In order to overcome the drawback, we propose to extract the baseline based on the signal information for each line using signal entropy. The signal entropy determines how much information a signal carries [19], since the entropy is reliable to measure the randomness of signal that can be used to characterize the texture of the input image. The entropy is defined as Eq. (1)

$$E = -Sum\big(p.*\,log2(p)\big), \tag{1}$$

where p contains the histogram counts returned from the image signal. Therefore, the number of circular areas must be defined and divided based on the image signal information for each baseline not based on three equal non-overlapping circulars. In this condition, the number of circular areas are defined based on the signal entropy. The lines with higher signal entropy will have more circular areas and the lines with lower entropy will extract less information with lower number of circular areas. This is a fast and reliable approach to dynamically determine the number of features sections based on the image information. Fig. 1 shows a sample of circular area on each extracted line.

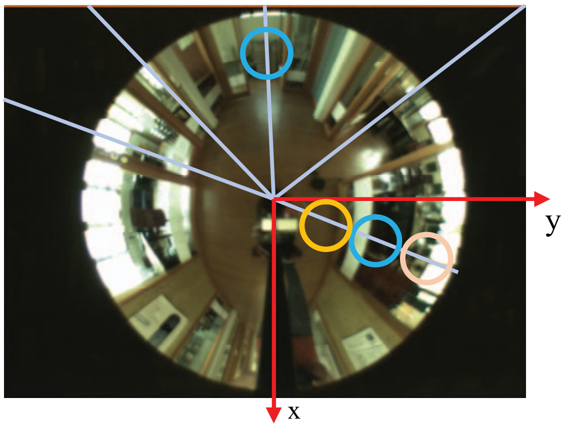


Fig. 1. Extraction of circular areas.

To extract the features of information in each circular area, gradient and orientation have been calculated. Eq. (2) and (3) defined the gradient information of the magnitude(M) and orientation(φ) to be computed for each circular area.

$$M = \sqrt{{I_x}^2 + {I_y}^2}, \quad (2)$$

$$\varphi = \tan^{-1}\left(\frac{I_y}{I_x}\right), \quad (3)$$

where I_x and I_y are the images of information in a circular area of a specific line in omnidirectional images. These features information extracted from the bins inside a circular area of the source image is compared to the features from the target image to determine the correspondence points.

B. *Enhancement of Orientation Histogram*

In order to reduce the false matches,Scaramuzza, et al. [5] each circular is divided into two parts, and each of which calculated the gradient orientation histogram. Each magnitude is weighted by factor$(1 - w)$, where φ is the gradient orientation in radians. Weight formula is defined as follows Eq. (4)

$$w = N_b \frac{\varphi - b}{2\pi}. \quad (4)$$

The number of orientation of bins (N_b) is divided equally to orientation space form $(-\pi \; to \; \pi)$ while in the reality, the area with lots of information needs more dynamic points and more bins.

To overcome this drawback, this study is proposed to determine the number of bins using standard deviation (σ). The standard deviation as defined in Eq. (6) measures the amount of variations or variability from the average among all of the available values. These properties help the method to determine the number of bins in each circular area. The standard deviation(σ) is divided by the number of circulars obtained from entropy value in the last section. Therefore, the line with higher signal information achieved higher number of circles will be multiplied with bins to achieve higher number of bins as well. Scaramuzza, et al. [5] used a static bins number which is not sufficiently efficient and fair. Whereas in proposing method, we use a dynamic bins number and circular area. The number of bins (N_b) proposed in this study is defined as Eq. (5)

$$N_b = \frac{\sigma}{N_c \; x \; bins}, \quad (5)$$

where σ is the standard deviation is defined as Eq. (6)

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}, \quad (6)$$

where N_c is the number of circles and bins are adjusted among 8, 16 or 32 bins, while (σ) is a standard deviation as a distribution normalization of a set of data.

From those emendations, the result of the weight sum has a strong influence upon the orientation histogram for being more robust toward noise of images.

C. *LINE FEATURES MATCHING*

Triple-wise dissimilarity of features extracted inside the circular area has been used in this study. It uses Euclidean distance to find the dissimilarity measures between descriptors. Scaramuzza, et al. [5] proposed a similarity measures computed between two bins of histograms. Their method is not sufficiently robust under different image effects and complicated natural imagery. In order to overcome this problem, the triple-wise similarity measure is conducted as a part of this study. In this technique, the similarity between two lines using triangle points which extract the closest and the most similar features from the triangle around the individual lines is measured. Fig. 2 presents a sample of extracting triple points to measure the dissimilarity.

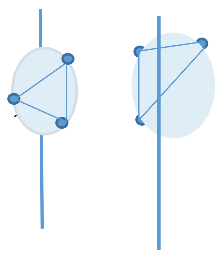
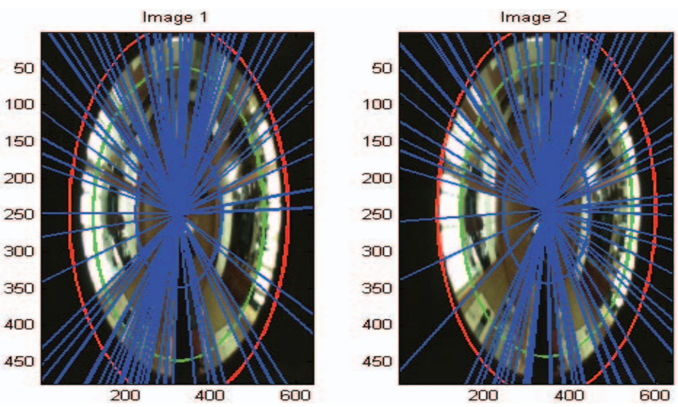


Fig. 2. Similarity from the features of triangle between two lines

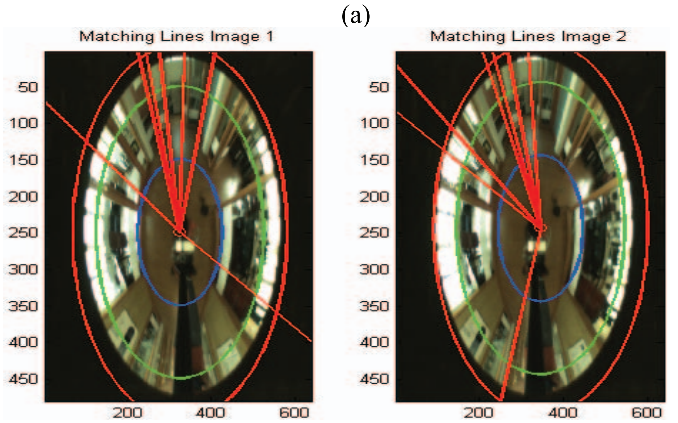
In this method, to extract the most similar circular areas in different images, after selecting the number of bins and circular areas, for each individual selected features, the similarity is calculated. The similarity of each selected points in source image which is compared to correspondence points in the target image. In case of finding multiple similar circular area in the source and target image, the similarity of the path between two features are compared. This additional similarity comparison confirms that the most similar circular area in both source and target images are detected. This can confirm the robustness of the technique to extract the most similar areas and eventually extract the correct lines in different images.

IV. Results

In this section, the result of the proposed method is compared to most relevant line matching techniques by Scaramuzza, et al. [5]. The relevant standard data set is called the Cosy localization database (COLD) [9] have been used to compare the results. The comparison results for the propose of study and Scaramuzza, et al. [5] method is shown in Fig. 3 and 4. It compares the result using the original technique [5] and the proposed technique by enhancing and making descriptor robust from rotation [20] and illumination changes. It uses entropy signal to determine the number of circular areas for each base line and number of bins by using standard deviation over number of circular area. Fig. 3 depicted the line matching results of Scaramuzza, et al. [5] method. Fig.3 (a) shows the initial line selection before matching in source and target images as shown at images 1 and 2 respectively. Fig. 3 (b) shows the results of line matching in omnidirectional images sourced from Cosy localization database (COLD) [9] dataset.



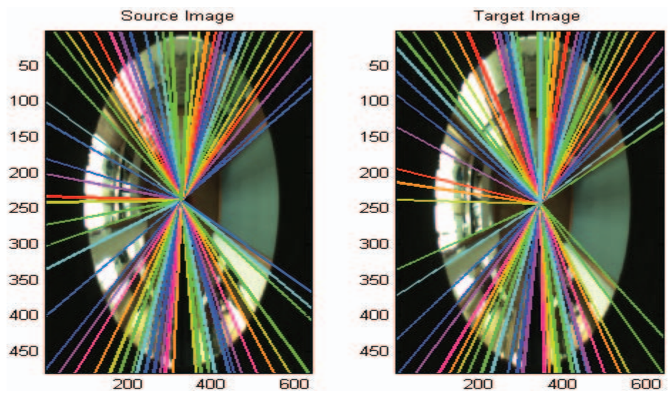
(a)



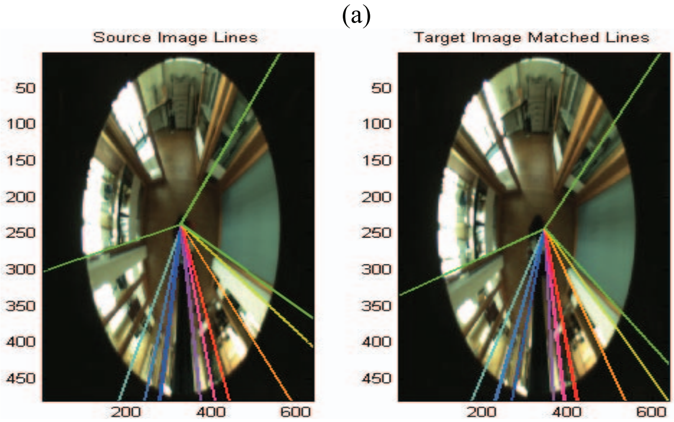
(b)

Fig. 3. Vertical line matching by using [5]. (a) Initial extracted lines. (b) Matching results.

As shown in Fig. 3, the result of Scaramuzza, et al. [5] method introduced some outliers in matching two different omnidirectional images. These outliers are achieved because of static technique in descriptors' circular area and line matching. As depicted in Fig. 3, the mentioned method, firstly extracts the center points and three different circular areas around the omnidirectional images shown in red, green and blue circles. The result of the DLM method is shown in Fig 4. In the first step, the lines with higher entropy are extracted in the source and target images. Then, using the proposed formulation to choose the circular area, bins and triple-wise similarity, the best correspondence features which leads to achieve the most accurate correspondence lines are achieved. In Fig. 4(a), all the initial lines in source and target images are identified with randomly selected colors, while in Fig. 4 (b), selecting the line colors are based on the matching results. This can help to visually determine the result of dynamic matching method proposed in this study.



(a)



(b)

Fig. 4. Vertical line matching using propose technique. (a) Initial extracted lines. (b) Matching results.

Fig. 4 (a) presents the initial lines extraction in the source and target images. Then, the result of dynamic line matching technique is presented in Fig. 4 (b). This result takes two consecutive frames of moving image to match. The result demonstrates the robustness of the technique compared to Scaramuzza, et al. [5] method.

V. Conclusion

In this paper, a new descriptor for line matching in omnidirectional images is proposed. Moreover, we proposed a new method to estimate the number of circles to extract the features based on signal entropy. The new method defines the number of bins in selected circular areas that have been conducted. The evaluation results indicate that the new technique overcomes related techniques in terms of accuracy. The results of dynamic line matching techniques can be used in different image processing applications such as image registration, movement extraction and aerial remote sensing studies.

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