Building A real-time Mirror/ Bilateral Symmetry Detector

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***Abstract*— Symmetry has always been an important concept in geometry. Mirror symmetry, as well as its subcase bilateral symmetry, are very common in the nature and generally been used in more and more fields, such as mathematics, physics, and biology. In computer vision field, researchers can utilize the symmetric property to help them recognize objects or detect the error in the production line. In this project, we proposed a robust method to detect the mirror symmetry and bilateral symmetry in a still image or real-time live stream using SIFT features. The experiments we performed prove that our detector has a high accuracy for both geometric objects and nature objects such as animals and architecture.**

The paper is broken down into several parts: (a) the main concepts of mirror symmetry and bilateral symmetry. (b) a review of related works in computer vision field on symmetry detection and the breakthrough and drawbacks. (c) describe our method in detail (d) the experimental results of our method and compare with previous works (e) Discussion and summary for our project, what we expect later for our project.

Keywords*— *Computer Vision, Mirror Symmetry, Bilateral Symmetry, SIFT

I. Introduction

Symmetry is an importance concept in nature and science and helps us in many ways. Mirror symmetry defines a phenomenon that a shape or region can be divided into two symmetrical parts along one straight line axis. As a special case of mirror symmetry, bilateral symmetry specifically defines that a nature object such as an animal or plant has a symmetrical structure. With the development of modern computers and image processing technologies, the concept of symmetry has gradually been applied in computer vision fields. For example, detecting the bilateral symmetry line of animals can be helpful for animal recognition or classification, detecting the mirror symmetry of a region can help researchers to do region segmentation. The symmetry also has some meaningfully application in medical imaging and gene detection.

Although symmetry is so important and have been used in many fields, researchers still realize that detection symmetry is a challenging task. There are lot of reasons affect people to detect symmetry in a highly accurate way:

(a) The symmetric axis of object is random; it is not always along the image axis, it can affect the accuracy of some feature extraction-based method, because the feature might be sensitive to the rotation.

(b) In real world, the illumination variable is hard to predict. the illumination can significantly impact the appearance (color, shadow) of objects.

(c) In an image or video, some object may be partially covered, this sets a higher requirement on symmetry detection.

(d) Non-rigid deformations, some animals' symmetric line is not straight, when detecting the symmetry for these objects, people should be careful.

To address these challenges, researchers have developed different methods in decades. The basic idea is to extract features from image and matching these features to find the symmetry. However, it's not easy to find such a feature because many features are sensitive to translations and rotations. To find a feature that are invariant to rotation and translations, scientists developed a lot of feature algorithm.

(1) SIFT

Scale-invariant feature transform (SIFT) is a feature that are invariant to scale, rotation, and translation. It utilizes image pyramid to generate image in different scale, and then apply the Difference of Gaussian (DOG) filters on these images. The SIFT feature take a circle region variable of feature points as its descriptor, it is a popular feature algorithm in pattern recognition and computer vision fields. This method in this project also applies SIFT feature [1].

(2) SURF

Speeded up robust features (SURF) is a variation on SIFT, it uses box filters to approximate the derivatives, it can utilize the integral image to speed up the feature extraction process. The SURF features are faster and more robust[5].

(3) HOG

Histogram of oriented gradient (HOG) feature algorithm divides the image into small cells and calculate the orientation histogram for each cell. So, HOG can capture the local distribution of gradient orientation, it is robust to illumination and environments changes.

In addition to the feature extraction-based methods discussed above. In recent years, scientist also try to apply machine learning and deep learning technology on object symmetry detection. A new way is to utilize a convolution neural network (CNN) to learn the hierarchical representation of image features and predict the symmetry line. Sebastian J. discovers symmetry Invariants and conserved quantities of image by introducing an interpretable Siamese Neural Networks (SNN) for similarity detection [2]. However, the deep learning-based method also has limitations. First, it requires a large, labeled dataset for training, it is hard to achieve because currently large public labeled dataset for symmetry training is lacked. Second, the learning features are difficult to predict, so it limits its application in some fields.

II. Related Work

Researchers and scientists have proposed different method for mirror/bilateral symmetry for a long time. In this project, we will pay more attention on the development of feature extraction-based approaches because it is more predictable and robust. Also, the feature extraction-based methods do not rely on large dataset, so it can be performed easily.

Sun, C developed a method which obtain direction of symmetry axis by gradient orientation histogram and center, then decide the position of symmetry by center of gravity and image projection along the symmetry direction. It was proved to be efficient on greyscale images. This paper utilizes a feature instead of SIFT to detect the symmetry line of an image, give us another sight into this area [3].

In 2004, Lowe presents the SIFT algorithm for extracting features from an image. The feature is invariant to image scale, rotation and provides a relatively robust matching in different images across illumination and viewpoints changes. Our project applies the SIFT algorithm proposed in this paper for extracting features in image, it shows a good performance in our work [1].

Loy, G and Eklundh, J create a novel method for grouping feature points based on their underlying symmetry and characterizing symmetries in an image. This approach is proved to be efficient when detect the mirror/bilateral symmetry in an image. It detects the potential pairs, evaluate the symmetry bonding of each pair, and applies distance matrices to vote the dominant symmetry line. Our method applies the same way of matching pairs and detecting symmetry talked in this paper and make some upgrade based on this article [4].

III. Methods

In this project, we first built a symmetry detector based on SIFT features and image processing techniques. Then we test our detector on a test set. After convincing its accuracy on detecting symmetry, we transfer this detector on a live camera, so it can display symmetry lines on a real-time base. Here are the steps of method in this project.

A. *Feature selection:*

This project selects the Scale-Invariant Feature Transform (SIFT) as potential feature, as it is invariant to scale, rotation, translation and stable for illumination and environment changes [1]. The SIFT feature best meets the requirement of this project.

B. *Features extraction from the image:*

Although the SIFT feature is invariant to rotation, translation, and scale. However, it is not invariant to inherently invariant to reflection or mirroring. To further find the matched pairs on the original image, we flip the original image horizontally (or vertically, depending on what we need) to create a mirror vision image. Then we extract SIFT key points and descriptors from both original and mirror image.

C. *Feature points matches*

This project utilized BFMatcher (Brute Force Matcher) with KNN (k nearest neighbors) algorithm to find matches between the key points between the original and mirror images. Fig. 1. shows the processing of extraction and matching of a pair of symmetric features [4].

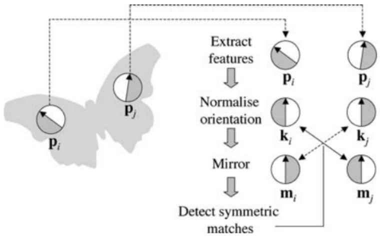

Fig. 1. Process on normalizing and matching a pair of features in image.

D. *Calculation of potential mirror symmetry lines polar coordinates*

Aftering finding the feature points matches, we got a set of pairs between original image and mirror image.

First, we need to find the corresponding position of the point in mirror image on original image. The feature point is represented by two parts: the coordinate and orientation. To get the corresponding orientation, we normalize the orientation of feature point and apply a flip operation on it. As we flip the original image by y axis, the y axis should be the same, calculate the x coordinate by (1).

$$x_o = width - x_m \quad (1)$$

In (1), x_o represents the x coordinate of feature points in original image, x_m represents the x coordinate of feature points in mirror image, width represents the width of image.

Second, we need to find the symmetry line which is perpendicularly through the midpoint of the line joining two feature points. We define the symmetry line by polar coordinate. As Fig. 2. describes, the θ can be calculated by (2) and radius can be calculated by (3) [4].

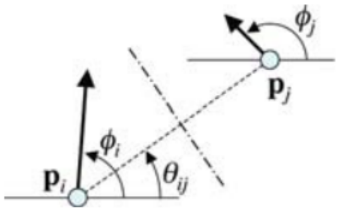

Fig. 2. Geometric analysis of a pair of matched position

$$\theta_{ij} = \arctan\left((y_j - y_i)/(x_j - x_i)\right) \quad (2)$$

$$r_{ij} = x_c cos\theta_{ij} - y_c sin\theta_{ij} \quad (3)$$

In (2), θ_{ij} represents the degree between the is the angle between the line connecting the two points and the x-axis. y_j represents the y coordinate of p_j, y_i represents the y coordinate of p_i, x_j represents the x coordinate of p_j, x_i represents the x coordinates of p_i. In (3), x_c and y_c are coordinates of the midpoint of the line joining two feature points. (θ_{ij}, r_{ij}) represents the polar coordinate of symmetry.

E. Draw a hexbin diagram:

Generate a hexbin plot using the polar coordinates of symmetry lines. Each hexagon in the plot represents a bin, and the number of votes in each bin is counted.

F. Choose the dominant symmetry lines:

The hexagon with most vote is selected, and the corresponding symmetry line is the dominant mirror symmetry line.

G. Test our detector

Detect the performance and accuracy of our detector in a test set. The test set consists of 67 images, including the following:

(1) 17 colored pictures of simple geometry or symbols. Fig. 3. shows some example of geometry images.

Fig. 3. Example of geometry images in test set

(2) 50 real photos in the nature, they are open-source test set from Laboratory for Perception, Action, and Cognition, the Pennsylvania State University. Fig. 4. shows some examples of photos.

Fig. 4. Example of photos in test set

H. Make our detector recognize real-time live stream:

To extend the function of the detector, we further applied this detector in a real-time live stream. The basic steps include capturing video frames, preprocessing frame, and apply the detector in the frame. By this way, our detector can detect mirror/bilateral symmetry in a real-time base.

IV. EXPERIMENTS AND RESULTS:

To test our work, we carry out a lot of experiments to demonstrate the effectiveness of our real-time mirror/ bilateral detector. The experiment is designed to test the accuracy and robustness of our method on an image dataset and a real-time live camera.

A. Feature extraction on original and mirror images

Our method extract SIFT features from original image and its mirror image. Fig. 5. is an example for this step, SIFT features are marked by green circles in the image.

Fig. 5. Extract SIFT features on original and mirror images

B. Matching feature pairs:

We match the pairs of symmetric features using k-Nearest Neighbors (KNN) algorithm. Fig. 6. shows Feature matching pair between original image and mirror image by lines.

Fig. 6. Process for matching SIFT features between original and mirror image.

C. Symmetry line calculation

For all matched pairs, we calculate the polar coordinates of the symmetry line.

D. Hexbin diagram

We create a hexbin diagram for all polar coordinates of the matched pairs to visualize the distribution of the potential symmetry lines. Fig. 7. is hexbin diagram of polar coordinates.

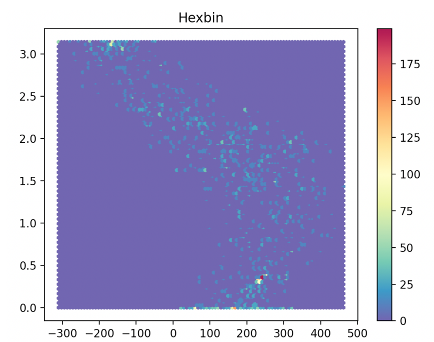

Fig. 7. Hexbin diagram analysis for the example image

E. Display symmetry line

We select the dominate symmetry by counting the votes in the hexbin diagram and draw the symmetry with white line on the image. Fig. 8. show the result on our example.

Fig. 8. Show symmetry line on the image

F. Testing on still images dataset

We test our symmetry detector on a dataset of 67 images containing various symmetric objects. We visually verify the success rate of our method by comparing the detected symmetry lines with the ground truth. Table. I is the result of test on dataset. Fig. 9. And Fig. 10. are the Sample images with detected symmetry lines.

TABLE I. TEST RESULT

Image type	**test condition**		
	Number of images	***pass***	***accuracy***
Geometry images	17	17	100%
Photos	50	45	90%
All images	67	62	92.5%

Fig. 9. Some examples of results on test set (part 1)

Fig. 10. Some examples of results on test set (part 2)

From the test result, we can find that our detector works perfectly with geometry images, achieve 100% accuracy when detect symmetry in geometry images. It also performs well when detects symmetry in photos, with an accuracy of 90%. Finally, we got an overall accuracy of 92.5%. We also notice that can not only detect bilateral symmetry in animals and architectures, but it also performs well on reflection phenomenon in nature, such as the second image in Fig. 9. shows.

However, we still got some error when detect some photos, Fig. 11. shows the photos our detector failed to draw the symmetries.

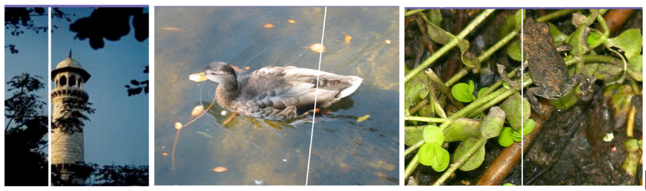

Fig. 11. Some examples of failed results on test set (part 2)

We then analyze the reason why our detector failed on these images.

1. In first image of Fig. 11., we find the tower in first image is partially obscured. Our detector still needs to be improved for this situation.
2. In second image of Fig. 11., we find the symmetry line is aligned with x axis. Because we flip our image horizontally, so the detector is weak to detect the symmetry which are perfectly aligned with the x axis.
3. In third image of Fig. 11., we find the color of frog is too similar with the environment.

This tells us our detector still need to improve for these situations in the future. However, our detector has shown very good results for most objects and images.

G. Real-time live stream

In the last step, we make our detector to detect symmetry line in a real-time video stream. Fig. 12. is Real-time detection of mirror symmetry in a live stream, we detect the symmetry line for a symmetrical tool set in different translation, rotation and scale. It shows an accurate result.

Fig. 12. Real-time symmetry detection with different translation, rotation and scale

Our experiments prove the robustness and accuracy of our proposed method in detecting mirror/bilateral symmetry for image and real-time video streams. While there is no standard benchmark for real-time mirror/bilateral symmetry detection, our results indicate that our method is highly effective for this task.

V. DISCUSSION AND SUMMARY

By theoretical analysis and performing experiments, our method of detecting mirror/bilateral symmetry demonstrates robust properties on both still image and real-time video streams. It works perfectly with simple geometry images and good with most environment in the nature. In our results, we also realize its limitations in some special cases. For example, In our method, we flip our original image by y-axis, so it might be some difficulty when we detect objects which are perfectly symmetric aligned with the x axis. The partial obscure and environment variables may also have possibility to increase the difficulty of detecting. To address these limitations and make our detector better, future work could explore alternative feature such as SURF. Additionally, investigating more advance matching algorithms or incorporating machine learning techniques may also lead to a better result in challenging scenarios.

In summary, our real-time mirror symmetry detector shows robust in detecting mirror/bilateral symmetry effectively. By addressing its current limitations and exploring potential improvements, the detector can be further enhanced to better serve a wide range of applications in computer vision and beyond.

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