A 1-Dimensional Symmetry Operator for Image Feature Extraction in Robot Applications

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Abstract

For mobile robotics applications it would be beneficial to focus on visual sensory information only. In contrast to other types of sensory data, camera images offer additional information for range estimation, object classification, localization and navigation. Human vision proves that it is possible to realize these tasks without using laser scanners or ultrasonic sensors. In order to achieve good performance using visual data only, it is necessary to recognize, track and classify robust image features. Camera data representations of standard workspaces are usually simplified because the lighting conditions are constant at all times. In this type of environment, the use of color markings and maps is sufficient in order to achieve good results. In arbitrary environments, however, the lighting conditions vary. It is therefore necessary to extract additional information from the visual input data, such as natural and cognitive features. We propose a compact 1-dimensional qualitative symmetry operator which is capable of extracting horizontal and vertical symmetry from the image data. Throughout this article, the symmetry operator as well as different types of feature extraction are discussed. Additionally, a number of application fields is provided.

Keywords: Image Feature Extraction, Symmetry Detection, Robot Vision Applications

1 Introduction

Most objects in our world have a high degree of symmetry, possibly because symmetry creates a certain kind of beauty, simplicity and usefulness. Just like animals and plants are quite symmetrical in shape, humans are inclined to incorporate symmetry in art, architecture and artifacts. The effect of symmetry on humans has been tested in psychological experiments. It was examined how effectively human vision is able to explore symmetry in objects and scenes [4, 5].

As a result of these experiments, reflective symmetry and its orientation in particular seem of high importance for human vision. Eyetracking experiments prove that there are differences in quality and speed of detecting the various types of symmetry. For example, vertical symmetry (i.e. reflective symmetry with respect to the vertical axis) makes speedy and accurate feature detection possible in most cases. Assuming the presence of horizontal or vertical symmetry in a given scene, humans are able to immediately detect and thus take advantage of a symmetry axis for further visual exploration.

Locher and Nodine [4] exemplify their results on a symmetric and an asymmetric shape in Fig. 1.

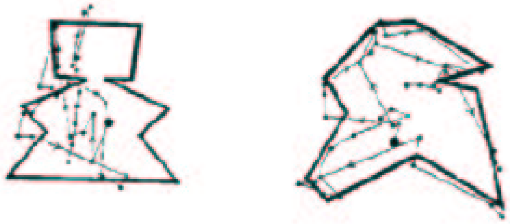


Figure 1: Eye fixations for symmetric shape (left) and asymmetric shape (right) [4].

In this example, dots display the points focused by the test person. The thin lines correspond to the eye movement between these points. On the symmetric object, eye fixations are confined to the left half of the object, omitting the right half. On the asymmetric object, however, the eyes are exploring the complete object due to the lack of symmetry. This example demonstrates the existence of human image pre-processing based on object symmetry and its effectiveness.

In addition to the efficiency achieved by detecting an object's symmetry, this symmetry is also important for all human interactions. The most significant symmetry type, vertical reflective symmetry (see Fig. 1), can help us to determine if an object or a person is directly facing us. Human interactions depend on this information. For example, people get a lot more of our attention when they are turned towards us, because this is how we notice that they could interact. Therefore, symmetry has a strong impact on getting attention from humans, affecting the way humans visually perceive their environment.

2 Related Work

Because of its relevance to human visual perception, the psychological aspects of symmetry have been widely studied. Palmer and Hemenway [5] studied the latency for detecting different types of reflective symmetries in a set of arbitrary oriented polygon shapes. The result of their experiments is that detection of vertical symmetry is the fastest, detection of horizontal symmetry the second fastest, detection of skewed symmetries being the slowest. Locher and Nodine [4] conducted experiments on visual detection of and attention to symmetry in composed pictures showing that the axis of symmetry is used by humans as a perceptual landmark for visual exploration. Ferguson [2] describes the detection of symmetry by using visual relations, by adjustment of an object's reference frame using its symmetry axes, and by the analysis of the effects of an object's orientation on perception.

Apart from the influence of symmetry on human perception, symmetry has also been used for various tasks in computer vision applications. Sun [7] proposes a fast symmetry detection algorithm for detecting the main symmetry axis of a given image. Reisfeld et al. [6] define a generalized symmetry transform which incorporates reflective symmetry for extracting regions of interest from arbitrary images and for determining symmetry values of objects. They use a square mask for detecting symmetry and gradient-based interest in order to establish a symmetry picture. Similar results are achieved by Kovesi [3], analyzing the frequency components of an image. His approach is based on the idea that if most components have their respective maxima / minima at a point of interest, this point will correspond to a point of high symmetry. Chetverikov [1] computes symmetry for finding facial orientations in portraits or for detecting structural defects in industrial applications. In order to achieve this, he defines a regularity value based on the symmetrical regularity of a pattern. Detection of faces in images is performed by Zabrodsky et al. [8] by utilizing symmetry. An explicitely defined rotational symmetry is used in order to reconstruct the information of partially occluded objects having a roughly rotational symmetry. For example, this is the case in an image containing partially occluded asymmetric flowers.

3 Symmetry Operator

Related approaches use symmetry in a global sense. Part of the algorithms use symmetry as a feature of the image itself [1, 7], or detect reflective symmetries in any direction [1, 3, 6, 7], or additionally incorporate rotational symmetries [8].

In our approach, which is mainly motivated by the demand from robot applications, we propose a simple, fast and compact operator to extract the regions of interest from images. The psychological experiments described in section 2 show that vertical and horizontal reflective symmetries are most important for human vision. Based on these results, only these two types are considered for our symmetry operator. This selection proves even more effective if we take into account that since images consist of horizontal and vertical arrays of pixels, it is not necessary to perform any interpolation or to use trigonometric functions. Therefore, only pixels in the same image row $R = [p_0, p_{w-1}]$ have to be used for the detection of vertical symmetry for a given pixel $p_i \in R$, where w is is the width of the image. The same holds for horizontal symmetry, considering only one column of the image. A further requirement of robot vision is the processing of real images. Because of the presence of distortion in real images, an operator that detects exact symmetry will fail and produce erroneous symmetry images. Therefore, we propose the following qualitative symmetry operator based on a normalized mean square error function:

$$S(p_i, m) = 1 - \frac{1}{C \cdot m} \sum_{j=1}^{m} \sigma(j, m) \cdot g(p_{i-j}, p_{i+j})^2 \quad (1)$$

where $m > 0$ is the size of the neighborhood of p_i along the direction perpendicular to the axis of symmetry. The symmetry value of p_i shall be detected with respect to this axis. The complete number of pixels considered is $2m$. C is a normalization constant which depends on the color space used and on $\sigma(j, m)$, which is a radial weighting function. The difference between two opposing points p_{i-j} and p_{i+j} is determined by a gradient function $g(p_{i-j}, p_{i+j})$, which typically is the Euclidian distance of the corresponding color vectors $\overline{p}_{i-j}$ and $\overline{p}_{i+j}$.

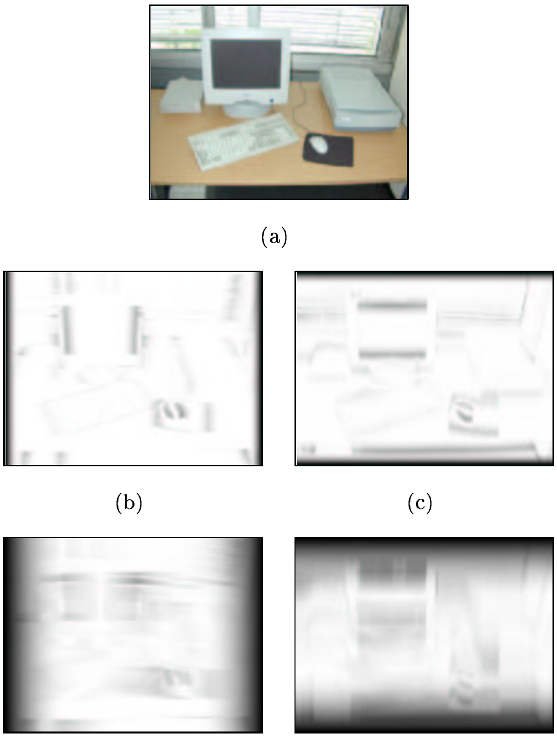
In all of our experiments, we used a 24-bit RGB color representation with

$$g(p_{i-j}, p_{i+j}) = \begin{cases} \|\overline{p}_{i-j} - \overline{p}_{i+j}\| & \text{if } p_{i-j} \in R \wedge p_{i+j} \in R \\ c & \text{otherwise} \end{cases} \quad (2)$$

where c is the maximum error possible (depending on the color space used), and a linear weighting function

$$\sigma(j, m) = 1 - \frac{|j|}{m+1} \quad (3)$$

A few example images are presented in Fig. 2, demonstrating that the choice of m is important for the performance of the algorithm. Setting m to a low value works out well for the symmetry axes of small objects, while it enlarges those of bigger objects. However, a large value m is better in detecting the symmetry axes of bigger objects.


(a)

(b) (c)

(d) (e)

Figure 2: Symmetries of a test image (221×166) (a): vertical and horizontal symmetry using $m = 10$ (b,c) and $m = 50$ (d,e).

Zhang and Huebner [9] conducted experiments using combinations of various mask sizes for symmetry extraction in panoramic images. Although this method provides better results for the extraction of symmetry axes, it is comparatively slow and inefficient.

Efficient detection of symmetry requires the application of a singular, low m. Further, this provides a better coverage of non-panoramic images, since the larger the value of m gets, the more the maximum error c affects the error function (see Eq. 2). In this case, the border regions of the images (left and right using vertical symmetry, see Fig. 2b and 2d; top and bottom using horizontal symmetry, see Fig. 2c and 2e) are influenced strongly by the effect of fading.

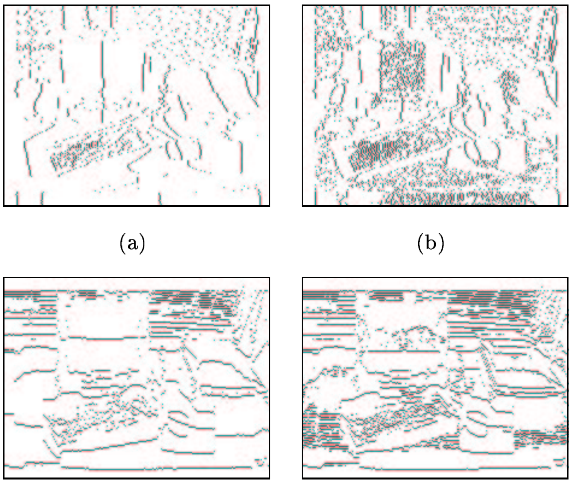
4 Feature Extraction

Whenever a resulting symmetry image is continuous, several types of feature extraction techniques can be applied to it. Without further processing steps, it is possible to apply density models to each of the symmetry images or to combinations of horizontal and vertical symmetry images.

Important symmetry axes can be found in places which do not necessarily have high symmetry values, but at which symmetric peaks can be detected. Although the extraction of maxima and minima of a symmetry image increases distortion in resulting binary images, it is more significant than using a threshold value. The threshold may vary from application to application or even from image to image. Additionally, an appropriate threshold is difficult to find for a normalized symmetry. A symmetry value of 0 corresponds to hard black-white transitions between each pair of opposing points p_{i-j} and p_{i+j}, while a value of 1 corresponds to exact parity. Therefore, higher symmetry values are more frequent and much more dense, which makes threshold setting very ineffective. Symmetry is more adapted for the application of local extrema, because it is a regional feature characterizing the local environment (in contrast to local features like edges). Since the calculation of a symmetry row is independent of any other row or column, maxima and minima can be detected line by line, or column by column for horizontal symmetry, respectively.

We use a simple maxima detection on two types of discrete symmetry images, that only differ in their degree of discretization. One type is an 8-bit representation providing 256 steps of resolution (equal to the gray-scale images in Fig. 2), the other type is a 24-bit representation. Higher resolution offers a more detailed detection of symmetry axes, but higher distortion (see Fig. 3).

Further, Symmetry Feature Points (SFPs) can be extracted as crossings of vertical and horizontal sym-



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

Figure 3: Symmetry maxima of image 2a: vertical 8-bit (a) and 24-bit (b) resolution and horizontal 8-bit (c) and 24-bit (d) resolution, using $m = 10$.

metry axes. Zhang and Huebner [9] used this feature type to track and classify points of interest with a mobile robot using an omnidirectional vision sensor. In the context of panoramic images, another application is the usage of histograms of vertical symmetry axes as a feature to recognize doors or the direction of the hallway in a closed building.

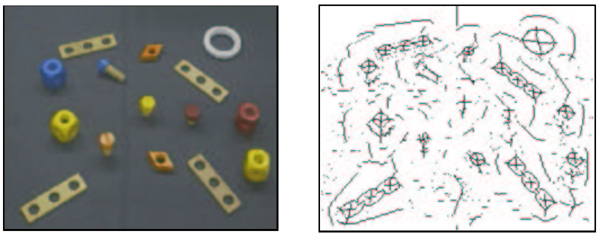
Choosing the best feature method mainly depends on the specific application. So we did not make use of continuous symmetry images. Vertical symmetry histograms and Symmetry Feature Points proved to be useful in panoramic images for mobile robot tasks like range estimation. In the following section, we will demonstrate some of our applications based on symmetry axes. To give a wider review of the performance of symmetry axis detection, further examples are presented in Fig. 4-6. Note that each result has been achieved by only using the symmetry operator and maximum or minimum detection, without any kind of pre- or post-processing like Gauss filtering, segmentation or related techniques.

5 Applications

In this section, some experiments are briefly presented to demonstrate some interesting applications using symmetry as a feature. Since this work concentrates on the topic of symmetry itself, experiments will not be illustrated in detail.

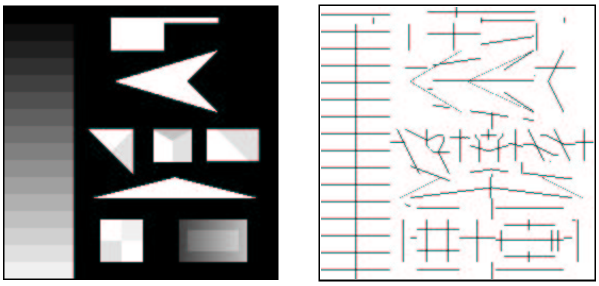
(a) (b)

Figure 4: Symmetry axis extraction of the colored "Lenna" image (256×256) (a), using 8-bit symmetry resolution and $m = 10$: horizontal and vertical symmetry maxima (b).



(a) (b)

Figure 5: Symmetry axis extraction of a colored assembly scene (242×199) (a) , using 8-bit symmetry resolution and $m = 5$: horizontal and vertical symmetry maxima (b).



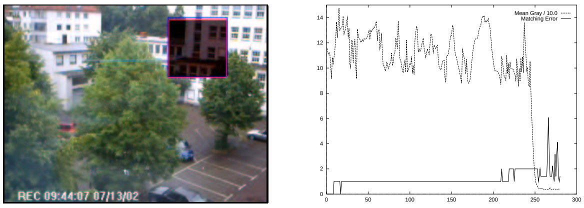
(a) (b)

Figure 6: Symmetry axis extraction of the gray scaled "SUSAN" edge detector image (256×256) (a), using 24-bit symmetry resolution and $m = 5$: horizontal and vertical symmetry maxima (b).

5.1 Pattern Matching with Significant Illumination Variances

One problem of computer vision is to recognize objects independently of actual light influences, whether they are natural or artificial. In this case, structural features like edges or symmetry are more effective than color.

We conducted an experiment based on a set of 280 images (320×240) of an outdoor scene taken between 9:45 in the morning and 11:45 in the evening. Recognition of a constant 70×70 part of each image in one reference image was based on vertical symmetry maxima and minima only. Parameters were $m = 10$ and resolution of 24-bit. Fig. 7 represents one example match and the development of the match error over the day. Even in darkness at night (image 250, 10:10 p.m.), the error did not exceed a matching distance of 6. This demonstrates that even in relatively dark images, the symmetry operator is able to detect the image structure. The almost continuous error of 1 is caused by a slight pitching of the camera.



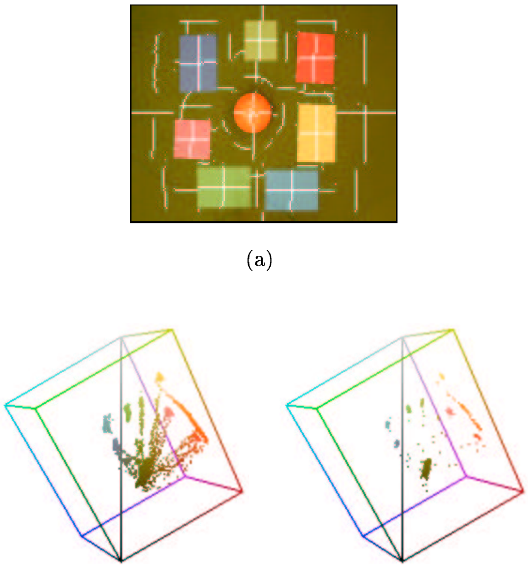
(a) (b)

Figure 7: (a) Sample match. (b) Matching error and mean gray value ($\frac{1}{10}$).

5.2 Data Reduction for Color Classification

Another common problem in computer vision is to classify colors independently of actual light influences for region segmentation. Therefore, image points have to be clustered in color space. In most cases, color clusters are blurred and thus hard to approximate by color thresholds or normal distributions.

The central idea within our application is to reduce image data by only using those points lying on symmetry axes. This does not only reduce the amount of data needed for further color classification, but also weakens the effect of blurring between color clusters, which is mainly caused by unclean color transitions on edges. Even the view onto a simple color calibration image (176×144) shows that the data points are usually widely spread in YUV color space (see Fig. 8).



(a)

(b) (c)

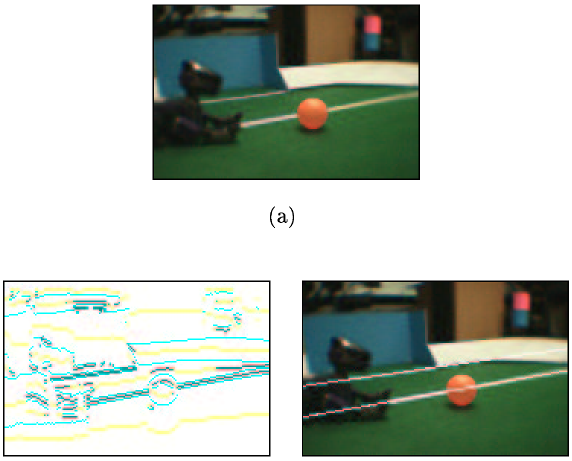
Figure 8: (a) Color calibration image (with marked symmetry axes). (b) Distribution of complete image data in YUV color space. (c) Distribution of symmetry axis data in YUV color space.

After applying symmetry axis extraction, 1160 points were found, which is about 1/20 of the complete image data. Resulting clusters in color space are concentrated on several locations which are assumed to correspond to significant image colors. By the loss of image data on edges, the distribution is also less influenced by cluster blurring.

5.3 Line Extraction

The task of line extraction was motivated by visual mobile robot localization in the RoboCup contest. In this field, the localization requires robust recognition of color markings which have to be explored all around the field. For robots with common cameras, searching those marks deters from concentrating on game objects like the ball. Thus, it is only possible to either localize or to capture the ball at a time. Accordingly, it would be more effective to concentrate on the field for localization at the same time. A possible and more intelligent solution could be achieved by the extraction of field lines.

Line extraction techniques usually need some preprocessing (e.g. edge detection, thresholding or thinning). Using symmetry, we can detect lines as a structure from arbitrary images. For example, a horizontal line is a structure of which we should continuously detect a given ASA-pattern (= Asymmetry(edge)→Symmetry→Asymmetry(edge)) in each small vertical neighborhood. An example for detection of this structure is shown in Fig. 9, where only horizontal symmetry extrema, using $m = 5$, were detected. If the specific ASA-pattern can be found in the same environment, we can assume that it is part of a line (see Fig. 9b).


(a)

(b) (c)

Figure 9: (a) RoboCup test image. (b) Line extraction based on symmetry extrema (light = S, dark = A, black = ASA). (c) Lines detected.

Though a horizontal operator is used, the technique also detects slightly skewed lines. A simple but adapted Hough transform was capable to extract the two field lines shown in Fig. 9c.

6 Conclusions and Future Work

We proposed a simple symmetry operator detecting horizontal and vertical reflective symmetry. Resulting symmetry images offer multiple feature extraction methods. In particular, binary images derived from symmetry axis detection are interesting for further image processing. The operator can be applied to arbitrary images without prior adaptation and without thresholds. The only parameters to specify are the size of the operator mask and the resolution of symmetry data.

Future work will include optimization of the algorithm, e.g. regarding mask size and the fading border effect. A main topic will be the implementation of the described robot vision experiments using symmetry as a feature. A special interest is the adaptation of the symmetry operator to omnidirectional or panoramic images, where coherences between the image borders can be found, eliminating the border effect.

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