Contour-based Object Segmentation Using Phase Congruency

Yong Li, Saeid Belkasim, Xiujuan Chen and Xuezheng Fu

***Abstract*— To segment an image using thresholding method, an optimal threshold is desired. In many practical cases, a fixed optimal threshold is not sufficient for the segmentation since objects have varying sizes, brightness, and noise. In this paper, we first use an edge detection method based on the phase congruency of the Fourier transform components to highlight the boundaries of image objects. We then use a contour based image segmentation method to separate object from its background. Since phase congruency is a dimensionless quantity that is invariant to image illuminations and contrasts, this method provides a way for image segmentation of objects within inhomogeneous background. To reduce the noises created from object boundaries highlighting process, we designed special noise removal filters. The experimental results show that our approach is robust for object segmentation of unevenly illuminated images.**

***Index Terms*— phase congruency, Fourier transform, edge detection, segmentation, adaptive thresholding.**

I. Introduction

IMAGE segmentation is widely used in the applications involving visual inspection. Given a nontrivial image, segmentation subdivides it into constituent regions or objects. One commonly used segmentation technique is optimal thresholding method which separates an object from its background based on the image intensity histogram. It has been shown, in many cases, segmented images from fixed global threshold either include unwanted noise or miss valuable information. This problem is more apparent when the objects are located in the uneven illumination background [1]. For example, due to the unbalanced illuminations, high pass threshold may filter out the objects which are located in the dark background areas. If we decrease the threshold, more noises may be included in the segmented images.

In this paper we introduce a new technique based on the phase congruency of the Fourier transform components. This method is based on the fact that high phase congruency corresponds to image features such as edges and corners. Since phase congruency is a dimensionless quantity that is invariant to changes in image brightness or contrast [2], it can be used to track the object boundaries in the images with uneven illumination. Given an image, we first generate its 2D phase congruency matrix which represents the phase congruency for all the pixels and then highlight the pixels which have high phase congruency. After that, we apply optimal thresholding to the enhanced image. In this way, a high-pass threshold filter will be able to detect the object boundaries which have been highlighted in the dim background. To remove the noise, we design two filters, one based on the length of the object contour and another based on comparing the intensity of the pixels in phase congruency image with its neighborhood pixels in the original image.

This paper is organized as follows: In Section II, we introduce image segmentation using contours. We also discuss the problems of this approach when the original images have unbalanced illumination. In Section III, we introduce image phase congruency and how to use it in the image feature detection. In Section IV, we present the algorithm for contour-based object segmentation using phase congruency. Experimental results and conclusions are outlined in Section V.

II. Image Segmentation Using Object Contour

Image segmentation methods are used to decompose an image into several parts or objects. These methods may be categorized into statistical classification, region growing and boundary methods.

In this paper, we automatically segment the object by its boundaries [3], [4]. The optimum automatic thresholding procedure is implemented using contour tracking to produce a continuously connected object border and leads to a fully segmented image. We obtained binary data from the image by using optimum automatic thresholding methods described in [4], [5] and then identified the object contour of the binary image with a border follower algorithm that uses an 8-connective path template to link contour pixels. The border tracking algorithm records coordinates of boundary pixels in a clockwise direction and terminates when it returns to the starting point. This method is capable of finding the main objects from background. However, in some cases, this approach fails to detect the detailed image features of the objects which are located in the inhomogeneous background.

The algorithm is applied to track the object boundaries of a crayfish neuron filled with a fluorescent tracer displayed in Fig. 1a. Segmented objects are represented as object boundary contours in Fig. 1b. Two questions arise when using this approach. 1). Can the optimal threshold separate

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objects efficiently: with all the objects selected and without noise included? 2). Are the object contours connected without broken points?

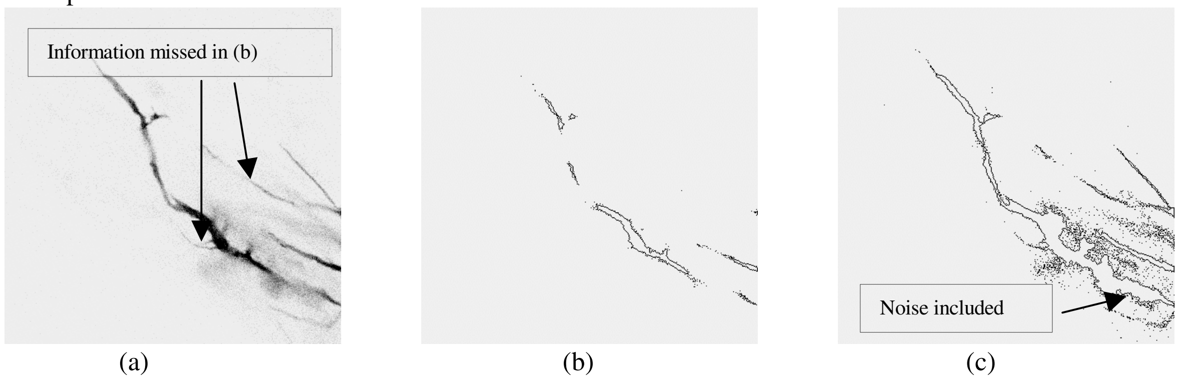


Fig. 1. (a) Confocal microscopic image slice of Crayfish neuron. (b) After applying optimal thresholding on the image (c) After applying thresholding on the image with the decreased threshold value.

We can see the objects and object details pointed in Fig. 1a have been filtered out because the overall brightness in that area is close to the background. To include the missed information, we have to decrease the threshold value. Fig. 1c shows the segmented image with a low threshold. It is clearly observed that much noise has been included in Fig. 1c when the threshold is adjusted to be able to detect the missed objects in Fig. 1b. This is inevitable when global threshold is applied and the absolute intensity of the missing object is close to the intensity of the noise or background. No matter what threshold value we choose, the binarized image will either miss out some valuable information or bring unnecessary noise.

Many approaches have been studied to deal with this situation. One approach is adaptive thresholding which divides the image into several sub images and applies different optimal thresholds for each sub area. But how to subdivide the image efficiently still remains a challenging problem.

In the segmentation process above, objects are traced along their boundaries, in which we are interested. This implies: for an image with uneven illumination, if we can distinguish an object's boundary from its local surrounding area, we will be able to first highlight all the boundaries of the objects which are located in various intensity backgrounds and then apply the optimal thresholding method for image segmentation. That is, if the object boundaries can be enhanced, our optimal thresholding program will not be sensitive to threshold value and the object contours will be connective with less broken points. Object edges are one of the main image features and can be detected by many image feature extraction methods [6]. Image segmentation using object contour provides us the opportunities of utilizing the well-studied image feature detection methods for segmentation. In the next section, we will introduce phase congruency image feature detector. Instead of processing image spatially, phase congruency method is capable of extracting image features using the phase and amplitude of the individual frequency components in an image. We will discuss how to use phase congruency techniques to highlight the object boundaries and compare it with canny edge detector.

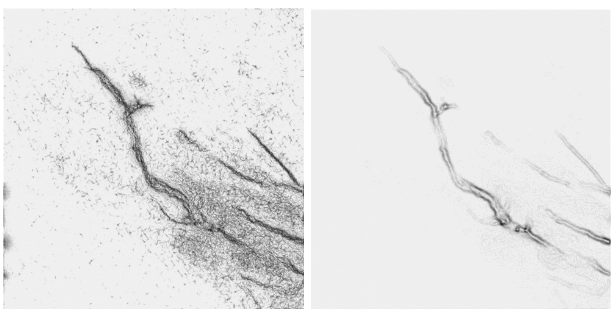
III. Phase Congruency for Edge Detection

Most of the edge detection techniques are based on gradient operators, such as Sobel and Canny kernel. These methods are sensitive to variations in image illumination, blurring, and magnification [2]. A local energy model for feature perception is introduced in [7] [8]. This frequency-based model is capable of performing calculations using the phase and amplitude of the individual frequency components in a signal. Based on this model, image features can be perceived by locating the points where the Fourier components of the image are maximally in phase. The phase congruency function for 1D signal is defined as follows:

$$PC(x) = \frac{\sum_n A_n(\cos(\phi(x) - \bar{\phi}(x))}{\sum_n A_n(x)} \quad (1)$$

where x represents the location of the signal, A_n represents the amplitude of the nth Fourier component, $\phi(x)$ represents the local phase of the Fourier component at x and $\bar{\phi}(x)$ is the angle which maximizes the function. When $PC(x)$ is equal to 1, the phase terms are all equal and the highest phase congruency occurs. A high phase congruency at x implies a significant feature at x, $PC(x)$ takes on a value between 0 and 1.

Phase congruency can be calculated via log Gabor wavelets. For a 2D image, by applying one dimensional analysis over several orientations and combining the results, a phase congruency image is derived [2]. Component value in the new phase congruency image represents the feature significance of corresponding pixels in original image. Fig. 2b is the phase congruency image obtained from Fig. 1a. It is easy to see that the boundaries of the neuron branches are all displayed prominently regardless of the variation of object intensities in the original image. Fig. 2b is the result of applying Canny edge detention method on the Fig. 2a. Both phase congruency and Canny methods successfully outline the object edges. Notice that the vague parts pointed in Fig. 1a can be detected on Fig. 2a and Fig. 2b. Comparing Fig. 2a with Fig. 2b, even though phase congruency method creates more additional noises, the pointed area in Fig. 1(a) is more apparent and distinguishable from the background. These object edges can be used to enhance the objects in the homogenous background.



(a) (b)

Fig. 2. (a) Phase congruency image. (b) Canny edge detection image.

IV. OBJECT SEGMENTATION USING PHASE CONGRUENCY

Since phase congruency is a dimensionless quantity that is invariant to image illuminations, we can use the phase congruency image to compensate object contours in the uneven illumination background which cannot be detected by the fixed threshold. The main idea is to overlap the phase congruency image with the original image and then apply optimal thresholding on the created image. We modify the optimal threshold algorithms as follows:

1. Remove noise using contour length filter.
2. Smooth image by the average filter.
3. Obtain the phase congruency image.
4. Apply the edge filter on the phase congruency image.
5. Smooth the phase congruency image and apply the contour length filter.
6. Combine the phase congruency image with the original image.
7. Apply the optimal thresholding on the combined image.

Since the filters used in this algorithm depend on the object intensity of the processed image, to simplify our discussion, we assume that segmented objects have higher intensity than those of its local surrounding area. Segmentation for images with dark objects and bright backgrounds can be easily adjusted using the similar approach.

Like gradient operator, phase congruency function is sensitive to noise, especially for isolated noise with small size. To remove those noises, in step 1 of the algorithm, we first binarize the image with a low threshold and then extract all the objects by tracing their boundaries. We apply a contour length filter (LF) to remove the noise. That is, we remove the object which has a very small contour length from the image. In step 2, the average filter is also helpful to remove the noise. In step 3, phase congruency image is obtained by applying log Gabor wavelets on the de-noised image.

Pixels which have a high value in the phase congruency image correspond to high significance of the image features. In this segmentation process, we only focus on image futures that represent the edges of image objects. Because the image objects are brighter than their surrounding background as we assumed, in most cases, we can conclude that a pixel on the object boundary has a higher intensity than the average intensity of its 8-neighthood. Based on this assumption, in step 4, we design an edge filter to generate the true/false table to check whether the pixel in the phase congruency image represents the object boundary feature. TABLE I is the edge filter mask.

TABLE I
EDGE FILTER MASK FOR OBJECT BOUNDARY FEATURE

F(-1,-1)= -1/8	F(-1,0)= -1/8	F(-1,1)= -1/8
F(0,-1)= -1/8	F(0,0)= 1	F(0,1)= -1/8
F(1,-1)= -1/8	F(1,0)= -1/8	F(1,1)= -1/8

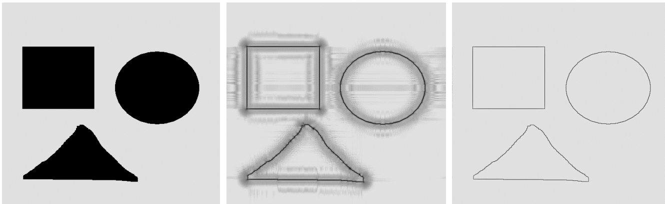
The edge filter works as follows. For an image g and its phase congruency image p, we first obtain the boundary true/false image b as:

$$b(x, y) = \sum_{a=-1}^{1}\sum_{b=-1}^{1} g(x+a, y+b) f(a,b) \qquad (2)$$

where $f(a,b)$ is from TABLE I. We then use image b to remove the components in phase congruency image p which are unrelated to object boundary feature by applying:

$$p(x, y) = 0 \quad \text{if} \quad b(x, y) <= 0 \qquad (3)$$

Using edge filter on phase congruency image enforces that only the candidate object boundary feature will be considered in the later steps. Fig. 3 shows how this filter works.



(a) (b) (c)

Fig. 3. (a). Original image. (b) Phase congruency image (c) After apply edge filter

We can see that Fig. 3b blurs around the object boundaries. This is because the phase congruency image highlights not only the pixels which are significant for the object edges but also others. Using edge filter, non-edge related features can be remove efficiently.

In step 6, we combine the phase congruency image and original image by averaging their intensities:

$$p(x,y) = k * p(x,y) + (1-k) * g(x,y) \tag{4}$$

where $k \in [0,1]$. We use a higher value of k when images are highly inhomogeneous.

Finally, we apply the optimal thresholding method to the combined image. Fig. 4 is the block diagram of the whole process.

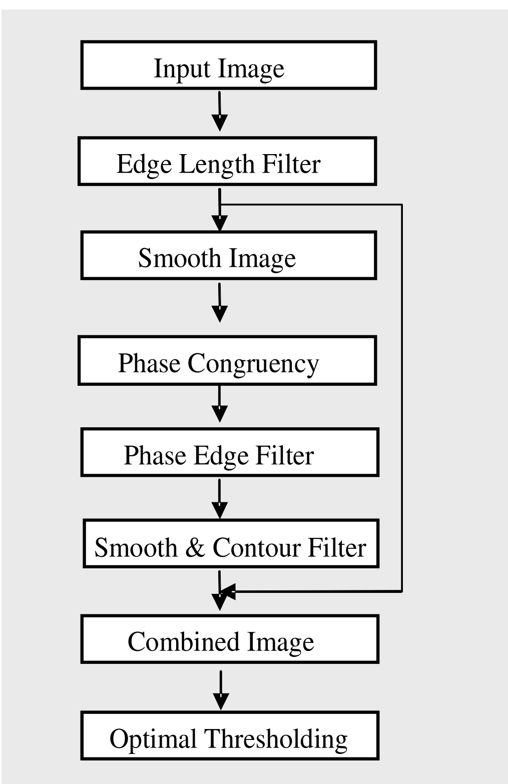


Fig. 4. Block diagram of the proposed algorithm.

V. EXPERIMENTAL RESULT AND CONCLUSION

We apply the algorithm on a confocal microscope crayfish neuron image slice which is displayed in Fig. 1a. Fig. 5a is the segmented image extracted from this progress. The value of contour length filter is set to 50 and the factor for overlapping the phase congruency image and original image is set to 0.5. Instead of using phase congruency method, we also repeat the process using Canny edge detection. The result is displayed in Fig. 5a. Comparing the circled area in Fig. 5a and Fig. 5a, we can see that more detailed information is extracted by using phase congruency method other than Canny detector.

In this paper, we introduce a new segmentation method by using edge detector operator to highlight object edges. As an edge detector candidate, phase congruency method is proved to be suitable from our experience. In the future work, more edge detectors or their combination should be tested.

(a) *LF=50, k=0.5* (b)

Fig.5 (a) Contour based image segmentation using phase congruency for edge detection. (b) Contour based image segmentation using Canny method for edge detection.

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