A novel algorithm for linear feature detection in images

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Abstract— *We propose a novel algorithm for linear feature detection in images. Our algorithm is an extension to Beamlet Transform(BT). BT is a powerful transform for linear feature detection in images. It is based on the famous Radon transform. BT's weakness is that it can't detect lines with more than one pixel width. In this paper we propose an extension to BT that overcomes this problem in image processing applications. We compare the proposed algorithm with the original BT. The results show that the proposed algorithm has better results.*

Keywords- Beamlet transform, Radon transform, linear feature detection

1. Introduction

Linear feature detection is an important problem in computer vision and image processing. This issue goes back to the existence of lines in almost every image. Although we don't always observe true lines in images , but many elements of an image could be approximated by lines with different length and direction. Some of the examples are contours of objects, roads in aerial imaging and vessels in retinal images.

Linear feature detection is a well studied problem in computer vision and image processing. The algorithms could be categorized into two main classes which are local and global methods. In local methods the image is processed locally[7][8]. In these approaches the algorithm usually exploits a filter or feature template(for example Canny) which declares a pattern we are seeking in the image. The image is convolved with this filter to find the best matches for the pattern and the result image would have high response in regions that are similar to the feature template and low response otherwise. Local methods are usually followed by a thresholding step to extract the objects. The major drawback of these methods comes from the fact that local processing is highly sensitive to noise and not to the underlying smoothness of the line, which is a typical non-local property of linear features. The second category are global methods which process the image as a whole. These algorithms transform the image to another domain in which the lines are detected more effectively. The transformed domain is usually a line parameter domain and is generally accomplished by computing line integrals. For example Radon transform is a global line detection method. In this transformation, for an image f defined on a sub-space of $\mathbb{R}^2$, for every line parameter (ρ,θ) , Radon transform computes

$$\varphi(\rho,\theta)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x,y)\delta(\rho-x\cos(\theta)-y\sin(\theta))dxdy \quad (1)$$

The peaks in the line parameter domain represent potential lines of interest. This is a very reliable method for detecting lines in noisy images. However, there are several limitations. Firstly, Radon transform computes line integrals on lines that pass through the whole image and does not provide information on small line segments. In addition using Radon transform we can only detect peaks in the line parameter domain, and we can't detect line endpoints. To overcome these problems Beamlet Transform(BT) was proposed. BT is another global line detection method that doesn't have the shortcomings of Radon transform[1]. This algorithm could be assumed as a multi-scale Radon transform.

We propose a novel linear feature detection algorithm which is based on BT. In the proposed algorithm we aim to overcome one of the weaknesses of BT which is being unable to detect lines with more than one pixel width. To overcome this weakness we have proposed a simple algorithm which is applicable in images including lines with different widths. We have compared the proposed algorithm with the original Beamlet Transform.

The rest of the paper is organized as follows. Section 2 presents the original BT while section 3 presents the proposed algorithm. Finally, to validate the proposed algorithm in section 4, we present some experimental results and section 5 concludes the paper.

2. Beamlet transform

A line in an image could be specified with two points. An algorithm for line detection in an N*N discrete image that aims to detect all of the lines is of order $(O(n^4))$ which is a high time complexity. To reduce this complexity Beamlet Transform(BT) was proposed. The main idea of BT is to approximate linear objects in two dimensions by multi-scale line segments [1,2]. These line segments are called beamlets and a set of them, are a dictionary of beamlets. Every line in the image could be approximated using these line segments. Using these set of lines the order of complexity reduces to $(O(n^2))$.

2.1 Beamlet dictionary

The beamlet dictionary is a dyadically-organized library of line segments, which are at a range of scales and locations, and have different orientations and lengths [1,2]. This dictionary facilitates the approximation of line segments.

Formally, given a beamlet $b=(x,y,l,\theta)$ centered at position (x,y), with a length l and an orientation θ, the coefficient of b computed is given by

$$\Phi(f,b)=\int_{-l/2}^{l/2} f(x+\gamma\cos(\theta), y+\gamma\sin(\theta))d\gamma \qquad (2)$$

BT could be viewed as a multi-scale Radon transform therefore similar to Radon, Beamlet integrates image intensities along line segments, and Equation (2) is closely related to Equation (1).

As we tend to use BT for line detection in discrete images digital beamlet should be defined. A digital beamlet has been defined in the following three steps[2].

1) Recursive Dyadic Partitioning (RDP): Consider a unit square $[0,1]\times[0,1]$. We first divide the unit square into 2×2 smaller squares with equal dyadic side lengths. Each smaller square is further divided into 2×2 smaller squares, still having equal and dyadic side lengths. This process is repeated until the finest scale is reached.
2) Vertex Marking: On the boundary (four sides) of each square, starting from the northwest corner, vertices are marked clockwise at equal distance. The interdistance of the vertices is fixed in advance, and it does not vary with the side lengths of the squares.
3) Connecting: within each square, any pair of its boundary determines a line segment. This line segment is called a beamlet.

Fig.1 illustrates the key idea in defining beamlets. The set of all beamlets form a beamlet dictionary. Fig.2 shows that any line segment could be approximated by a chain of beamlets.

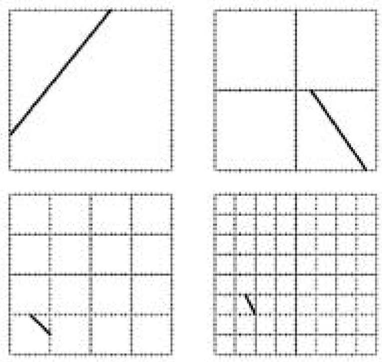

Figure 1. Dyadic squares marked with vertices and several beamlets

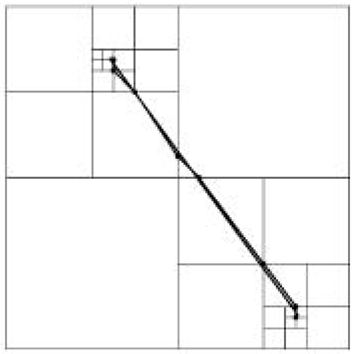

Figure 2. Approximating a line segment by a chain of beamlets

2.2 Digital beamlets for discrete images

Given two end pixels on the boundary of a dyadic square, a *digital beamlet* is determined by digitally interpolating between the two pixels [2]. There are two topological possibilities:

1) multiple pixels are allowed per column
2) only a single pixel is allowable per column

Assuming that (x_1,y_1) and (x_2,y_2) are two end pixels satisfying the following:

1) $0<x_1<x_2\le n, 0<y_1<y_2\le n$ Where the size of the image is $n\times n$

2) $|x_2-x_1|\ge|y_2-y_1|$.

In the first situation were multiple pixels are allowed per column we should enumerate all pixels whose interiors intersect the line that is from $(x_1-0.5, y_1-0.5)$ to $(x_2-0.5, y_2-0.5)$. In the second situation, in which there is

Identify applicable sponsor/s here. *(sponsors)* at most a single pixel per column, the set of pixels that are included in a digital beamlet can be derived as

$$\{(j, y(j)) : x_1 \le j \le x_2\} \quad (3)$$

Where

$$y(j) = \left\lceil y_1 + \frac{j - x_1}{x_2 - x_1}(y_2 - y_1) \right\rceil \quad (4)$$

This algorithm actually generates the same set of pixels as a well-adopted line drawing method: Bresemham's [3] line drawing algorithm.

2.3 Line approximation

After the beamlet dictionary is constructed, the image lines are approximated using the beamlets. In other words we seek to find the best and least set of beamlets needed to approximate the image lines. This is achieved in an optimization scheme(Figure 3).

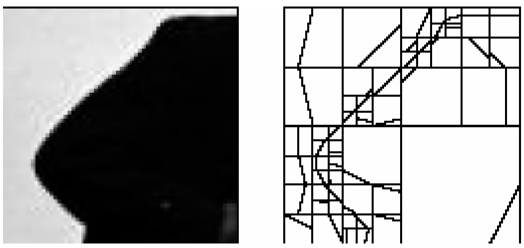

Figure 3. Approximating a image with bemalet transform

3. Proposed Algorithm

Our proposed algorithm is an extension to the original Beamlet Transform(BT). In previous literature a number of extensions have been proposed for BT [4,5,6]. Yang tends to reduce the complexity for computing the coordinates of pixels in building beamlets, and concentrates the BT on summation of the pixel grayscale values[4]. Berlemont unifies BT with a linear filtering technique in order to define feature adapted beamlet[5]. Ruiquing combines BT with wedgelet transform to detect linear features in grayscale images[6]. We propose a novel extension to BT, which is enabling it to detect lines with more than one pixel width. This property is important due to the existence of lines with different width in almost every images. In Figure 4 we see this issue in a retinal image.

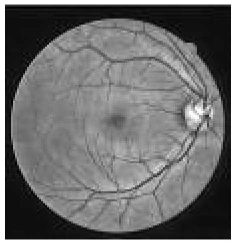

Figure 4. Lines with different width in a retinal image

3.1 Algorithm

In order to enable BT to detect lines with different widths, we change the beamlet dictionary. As we mentioned in section 2 the beamlet dictionary is composed of a set of line segments with different lengths and orientations. All of these line segments have one pixel width therefore we add another dimension to the beamlets which is the line segment width. Consequently the beamlet dictionary would be a set of lines with different length, orientation and width. Again mentioned in section 2 in an digital image beamlets are built by interpolating between two end pixels and there is a separate beamlet for every two end pixel. To accomplish beamlets with different widths we propose to add pixels next to the pixels of the existing beamlets. This could be done in two different ways which are locating pixels in the next rows or columns (Figure 5).

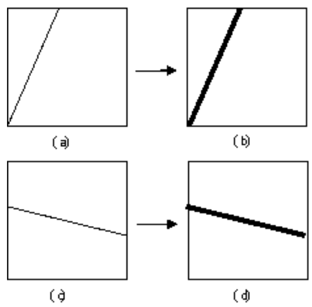

Figure 5. A view of two approaches to thicken beamlets, (a)main image,(b) pixels located in next columns and (c)main image,(d) pixels located in next rows

To build the proposed beamlet dictionary we assumed that lines with more than one pixel width have pixels located in the next columns. The only situation which is an exception are horizontal lines. In this situation we switch to pixels located in the next rows. The proposed algorithm is shown next

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Algorithm

- **BD = The beamlet dictionary;**
- **For each (*b* from BD)**
- **{**
  While (line-width< square side)
  {
  ***nb* = *b* with incremented line-width;**
  add *nb* to BD
  }//end while
- **}// end**
- **Compute the coefficients of beamlet dictionary**

As shown the proposed algorithm aims to change the beamlet dictionary. The width of lines in the beamlet dictionary are incremented and new beamlets are added to the dictionary. To increment the line widths we should consider both directions(Figure 6).

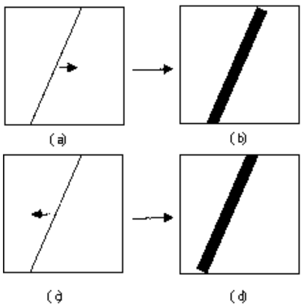
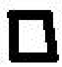
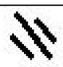
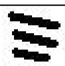
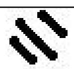


Figure 6. Adding pixels to next rows in both directions

4. Experimental results

The proposed algorithm and the original Beamlet transform were implemented using MATLAB 7. The algorithms were evaluated using a number of sample images. These images are chosen to have lines with different width. The images are shown in Table I.

TABLE I. SAMPLE IMAGES

1	
2	
3	
4	
5	

The detection rate was computed using the below relation. The results are shown in Table II.:

Detection_rate=Num of True detections/Num of all detections (5)

TABLE II. RESULTS OF BEAMLET TRANSFORMS

Image	B. transform	Proposed algorithm
1	*90.98%*	*93.23%*
2	*89.65%*	*95.45%*
3	*93.57%*	*94.74%*
4	*87.76%*	*92.66%*
5	*93.14%*	*93.86%*

As shown the proposed algorithm has better results compared to original Beamlet Transform.

5. Conclusion

We proposed a novel algorithm for linear feature detection in images. This algorithm is based on Beamlet Transform(BT). BT falls in the category of global methods for linear feature detection. Global methods process the image as a whole. The proposed algorithm overcomes a shortcoming in BT. The shortcoming is that BT is unable to detect lines with more than one pixel width. The proposed algorithms overcomes this weakness by changing the beamlet dictionary and adding a dimension which is line width to beamlets. The results show that the proposed algorithm improves the original BT.

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