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# A Gravitational Edge Detection for Multispectral Images

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***Abstract***

*Gravitational edge detection is one of the new edge detection algorithms that is based on the law of gravity. This algorithm assumes that each image pixel is a celestial body with a mass represented by its grayscale intensity and their interactions are based on the Newtonian laws of gravity. In this article, a multispectral version of the algorithm is introduced. The method uses gravitational techniques in combination with metric tensor to detect edges of multispectral images including colour images. To evaluate the performances of the proposed algorithm, several experiments are performed. The experimental results confirm the efficiency of the multispectral gravitational edge detection.*

***Keywords****: edge detection, image processing, gravity, segmentation*

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## 1. Introduction

Edge detection is the process of localizing pixel intensity transitions. The success of edge detection provides a good basis for the performance of higher level image processing tasks, such as object recognition, target tracking, and segmentation. Over the years, the task of detecting edges in gray valued images is very well known, and has been thoroughly studied [1-3].

Nevertheless, these methods have to extend to color, multispectral and hyperspectal images. In recently, the development of sensors makes multispectral images usual objects for analysis. One of the most important tools for working with multispectral images is edge detection [3-4]. However, as long as the task of detecting edges in gray valued images is very well known, the same problem for multispectral images is much less well defined [3]. Although some methods for multiband edge detection have been proposed, most of them are only valid under certain conditions, or are only used for three band colour images [5]. The popular method is applying the Laplace of Gaussian (LOG) filter to all channels, then the results are summed and thresholding takes place on this image [5]. While DiZenzo [6] shows that the ways of finding edges by combining the output of difference operators in each component does not actually cooperate with one another. He considered the multi-dimensions as a vector field and found the tensor gradient [7]. In ref [8], W.H. Baker consider the problem in feature space, he uses LOG filter in combination with distance measures, such as the Euclidean distance, to detect edges of hyperspectral images. The method is simply and effective, however it will misses some important edges. Similarly, Kang [9] defines an objective function to detect edges of gray-level images and extend it to color image. This algorithm can eliminate double edges, speckles to some extent, but it will get thicker edge for nature images. Cumani [4] suggests the extension of procedures based on the second-order derivatives of the images functions. This operator is one of the fundamental works in multispectral edge detection. The multi-dimensional gradient method is also extended by Sylvain Rousseau [10]. In recently, although there proposed some new edge detection for multispectral images [11-12], it is still a challenge for multispectral images edge detection.

Recently, we have proposed a new method for edge detection (GED) based on the law of universal gravity [13]. Even if the original version of GED was improved by C. Lopez [14] based on the triangular norms, it suffer the two problems as mentioned above. The goal of this paper is to find ways to overcome the problems associated with the gravitational method and extend it to multispectral images. The basic idea of the proposed method come from that, for each component the spatial information should be involved. In this way, we tune the parameters

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to achieve the best possible edge detector for every component, and then utilize the detector to get edge magnitude of each component. Then consider the multispectral images as a vector field to fuse the results combined with metric tensor [6, 10]. The improved method can offers different masks according to different components and overcome the large kernel problems. Experiments indicate that the approach is effective for multispectral images.

The rest of the paper is organized as the following: the law of universal gravity is briefly reviewed in Section 2. Then, the algorithm of the proposed edge detector is presented in section 3. Furthermore, applications of the presented algorithm are given in Section 4. The performance is illustrated using a number of real images. Both noise free and noisy contaminated images are used for the experiments. Finally, conclusions are presented in Section 5.

## 2. The Gravitational Edge Detection

In this section, we introduce a brief review of gravitational edge detection [14]. As stated by Newton in the Law of Universal Gravity [15], anybody attracts every other body by a force proportional to the product of their masses as illustrated in Figure 1:

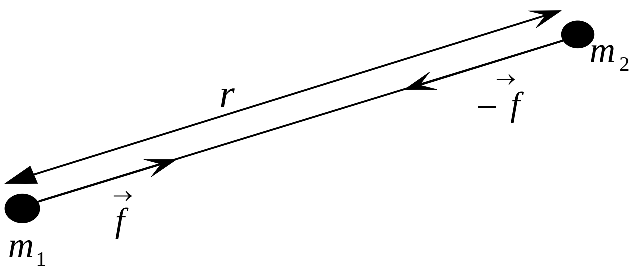



Figure 1. Newton's law of universal gravitation

More concretely, the force is given by:

$$\vec{f}_{12} = \frac{Gm_1 m_2 \hat{r}}{\left\|\vec{r}\right\|^2} = \frac{Gm_1 m_2 \vec{r}}{\left\|\vec{r}\right\|^3} \tag{1}$$

where $\vec{f}_{12}$ is the force on object 1 due to object 2, G is the gravitational constant, $m_1$ and $m_2$ are the masses of the objects 1 and 2, $\vec{r}$ is the vector connecting the positions of the mass.

To construct an edge detector, every pixel is assumed to be an object, which has some relationship with other pixels within its neighborhood through gravitational forces. For each pixel, the magnitude and the direction of the vector of the sum of all the gravitational forces the pixel exerts on its neighborhood, conveys the vitally important information about an edge structure. Now considering that the neighborhood of a pixel (i, j) will be restricted to a $\Omega$ window, the resulting force assigned to it will be:

$$\vec{f}_{i,j} = \sum \vec{f}_{i,j;k,l} = F^x \hat{x} + F^y \hat{y} \quad (k,l) \in \Omega \,\&\, (k,l) \neq (i,j) \tag{2}$$

where

$$\vec{f}_{i,j;k,l} = \frac{G m_{i,j} m_{k,l} \hat{r}}{\left\|\vec{r}\right\|^2} \quad (3)$$

$$\begin{aligned} F^x &= \sum f^x_{i,j;k,l} \quad (k,l) \in \Omega \,\&\, (k,l) \neq (i,j) \\ F^y &= \sum f^y_{i,j;k,l} \quad (k,l) \in \Omega \,\&\, (k,l) \neq (i,j) \end{aligned} \quad (4)$$

$$\begin{aligned} f^x_{i,j;k,l} &= \frac{G m_1 m_2 (k-i)}{\left\|\vec{r}\right\|^3} \\ f^x_{i,j;k,l} &= \frac{G m_1 m_2 (l-j)}{\left\|\vec{r}\right\|^3} \end{aligned} \quad (5)$$

Eq. (3-5) comprises the core of the method, in the sense that it provides the way of obtaining pixel (i, j) edge intensity, $F^x$ and $F^y$, with the direction of x and y respectively for every pixel in the image [13]. Finally, the edge magnitude can be computed as follows:

$$\begin{aligned} \|F\| &= \sqrt{(F^x)^2 + (F^y)^2} \\ \theta &= \arctan(F^x / F^y) \end{aligned} \quad (6)$$

The principle of gravitational method can be implemented as follows:

1) For each image point $g(i, j)$, we consider an m×n neighborhood $\Omega$ with pixels $(k,l) \in \Omega \,\&\, (k,l) \neq (i,j)$. For each point, the gravitational force of the point exerts on its neighboring pixels which is computed using Eq. (2);

2) Get the edge strength with Eq. (6).

Theoretically, gravitational method belongs to the class of soft computing algorithms [16]. Sun et al. [13] gave a comparative study between the method and a small number of well-known edge detection algorithms. The results suggest that this approach which is inspired by the law of gravity has merit in the field of edge detection

## 3. Multispectral Gravitational Method

Although traditional operators are very efficient, their efficiency is not well preserved once they are subjected to the analysis multispectral images. Early approaches to detecting discontinuities in multispectral images attempted to combine the response of edge detectors applied separately to each of the image component. While these methods suffered from some problems according to above analysis. In this paper, we would choose a metric tensor on the feature space computing the gradient as described by [6] and further used in [10] summarized as follows:

An m-band image is indeed be represented by function $f : R^2 \to R^m$ that maps a point $p = (x, y)$ in the image plane to an m-vector $f = (f^1(x, y), \ldots, f^m(x, y))$, obviously, for a color image, m=3. Let $f_1 = (\frac{\partial f^1}{\partial x},...,\frac{\partial f^m}{\partial x})$ and $f_2 = (\frac{\partial f^1}{\partial y},...,\frac{\partial f^m}{\partial y})$. A tensor T is then introduced:

$$T = \begin{pmatrix} \|f_1\|^2 & f_1 \bullet f_2 \\ f_1 \bullet f_2 & \|f_2\|^2 \end{pmatrix} = \begin{pmatrix} K & F \\ F & H \end{pmatrix} \quad (7)$$

The eigenvalues of T are given by:

$$\lambda_{\pm} = \frac{K+H}{2} \pm \sqrt{\frac{(K+H)^2}{4} + F^2} \quad (8)$$

and the eigenvectors are:

$$\eta = (\cos\theta_+, \sin\theta_-) \quad (9)$$

Where

$$\begin{cases} \theta_+ = \frac{1}{2}\arctan(\frac{2F}{K-H}) \\ \theta_- = \theta_+ + \frac{\pi}{2} \end{cases} \quad (10)$$

The eigenvectors of matrix T provide the direction of maximal and minimal changes at a given point P=(x, y) in the image, and the eigenvalues are the corresponding rates of change. $\theta_+$ is called the direction of maximal change and $\lambda_+$ the maximal rate of change. Similarly, $\theta_-$ and $\lambda_-$ are the direction of minimal change and the minimal rate of change, respectively. For monochromatic images, $\lambda_+$ is corresponding to the gradient. The eigenvalues $\lambda_+$ can be extended to locate edge point of color image. Based on the above equation, we proposed a multispectral image edge detection. The gradient is estimated as follows:

$$\left\| \nabla g = \sqrt{(\lambda_+ - \lambda_-)} \right\| \quad (11)$$

Where $\lambda_+$ is eigen values of matrix T in equation (3.6).

(1) According to what mentioned above, the entire algorithm for edge detection of multispectral images can be implemented as follows:

(2) For each image point $g(i, j)$, we consider an m×n neighborhood $\Omega$ with pixels $(k,l) \in \Omega \,\&\, (k,l) \neq (i, j)$.

(3) Use equation (2) to compute the gravitational force of the point $g(i, j)$ exerts on its neighboring pixels for each multispectral image component.

(4) Compute the magnitude of gradient using equation (11)

(5) Set an appropriate threshold to produce an edge map.

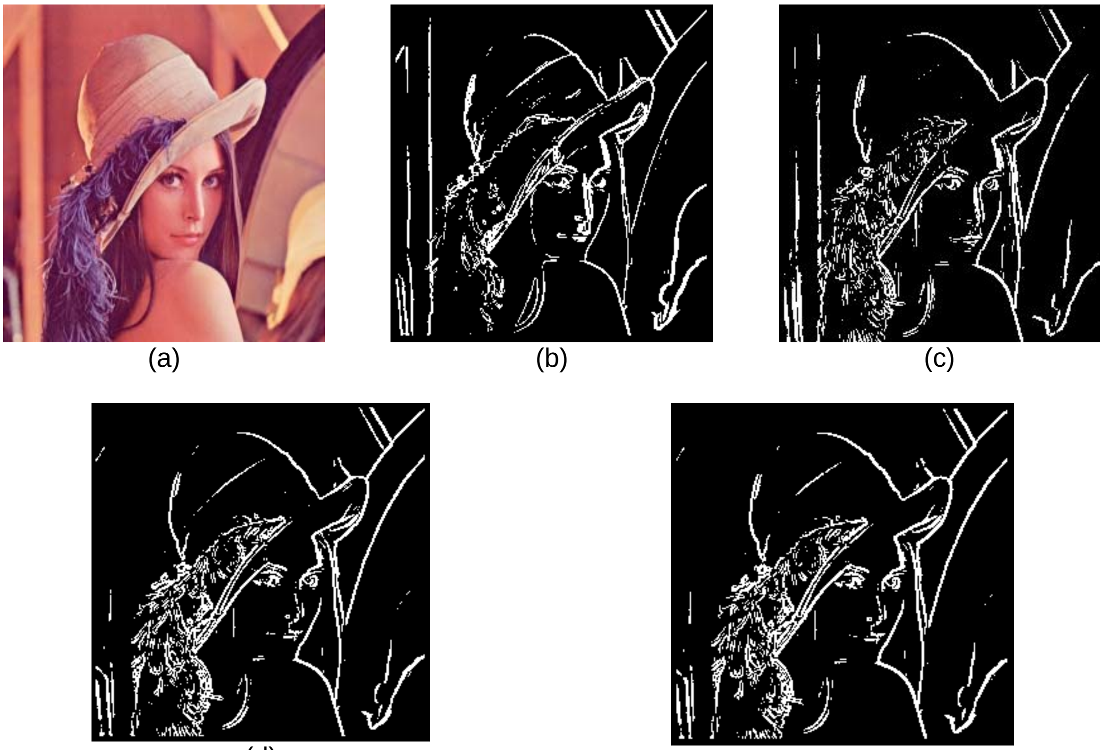
## 4. Results and Discussion

The primary goal of this paper is to extend the gravitational method to multispectral images. In this section we describe the results of our experiments. Both color images and remote sensing images are used. The color Lena image (Figure 2(a)) has some challenging features for edge detectors. For instance, shadows on the face and blurry background are difficult to process. The multispectral image (Figure 3(a)) is a complex scene which consists of 31 spectral bands [17].

We have selected the CVVEFM and Kang operators proposed in recently for comparisons with 3×3 kernel size since they produce better results [9, 18]. In order to show the superiority of the proposed method, a simple edge detection scheme is adopted, which is composed of gradient estimation and thresholding. Smoothing and postprocessing methods (e.g. nomaxima suppression, thinning) are not used in this section. For simplicity, this paper utilizes fixed threshold [19].

Figure 2. Shows color Lena image and gradient images with 3×3 kernel size. All gradient images are normalized with respect to their maximum values and thresholded at level 0.1. Figure 2(b) shows that the proposed method detects the edges correctly. However, the conventional method and CVVEFM method cannot extract smooth edges (e.g., vertical smooth line on the left side of the image) as shown in Figure 2(d) and (e), respectively. Figure 2. (c) shows that smooth edges at lower right corner seem to vanish and cannot detect the edge in the hat.

Next we will consider the multispectral image which is bigger than three bands (Figure 3(a)). Figure 3(c) is the result of CVVEFM method applied on the band 1, band 3 and band 4 since it is useful for three-band images only. Figure 3(d) and (b) shows the results of Kang and the proposed method, respectively. From the results, we see that, some edges could be detected in the multispectral image (Figure 3.2(b)) that was not determined in the three-band image (Figure 3(d)). In contrast, the edge image of Kang (Figure 3(d)) is poor.



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

Figure 2. Comparisons with different methods for “lena” image with 3×3 mask
(a) the original “lena” image; (b) the edge map by using the proposed method (c) the result of the Kang method (d) the result of CVVEFM method; (e) the result of conventional method. (Gradient images are thresholded at their 10% of their maximum value).


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

Figure 3. Comparisons with different methods for multispectral remote sensing image with 3×3 mask (a) the original multispcectral image; (b) the edge map by using the proposed method (c) the result of the CVVEFM method (d) the result of Kang method. (Gradient images are thresholded at their 10% of their maximum value).

## 5. Conclusion and Future Research

In recent years, various algorithms for edge detection have been developed. GED is a new algorithm where it is constructed based on the law of Gravity. To the best of our knowledge, GED algorithm has not yet been applied to multispectral image processing task up to date. In this article, a multispectral version of GED has been introduced. For each component of input image, the GED's output is determined and then, results are combined to compute gradients in vector image. The performance of the proposed algorithm is compared with many recently developed methods, including the Kang and CVVEFM detectors. It is evident from the obtained results that the algorithm is producing results containing most of the important edges for all images.

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