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Comparative Analysis of Classical Edge Detector and Wavelet Based Techniques in Context of Object Extraction from Remote Sensing Satellite Imagery

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Abstract: *The automatic segmentation and extraction of objects is augmented by the availability of high resolution satellite images and improvements in the edge detection methodologies. Edges characterize boundaries and are therefore a problem of fundamental importance in image processing and particularly in feature extraction. In this paper a comparative study of the wavelet based edge detection techniques with the classical methods is conducted. Analysis results have shown that the multiscale wavelet based algorithm is best suitable for the object extraction in most contexts due to fact that it yields less number of false edges. Band wise analysis of these algorithms were also conducted to investigate the sensitivity of these with reference to the bands.*

Keywords: *Edge detection; Wavelets; Object extraction; Remote sensing.*

I. Introduction

The availability of high resolution satellite images has facilitated the automatic extraction and detection of objects and is a problem of fundamental importance. The detection and differentiation of edges is a core step in image processing and various attempts in this regard are available in the literature [1]. Various edge detection algorithms such as Sobel, Robert, Prewitt adopts gradient and zero crossing based strategies and are very sensitive to noise. These approaches lead to the misjudging of noises as the edge points or miss some real edge information. The Canny overcomes the problem of noise as it uses Gaussian filter for smoothing the image before finding the gradient [2] but this technique has also some practical limitation. Among the various classical edge detection techniques available over the literature, canny detector found to perform better for satellite images [3].

Various techniques and transforms were found in literature as being applied in the context of edge detection among which the wavelet based techniques found to yield better results especially in context of noisy images [4]. Wavelets are localized in frequency as well as space having an advantage over Fourier transform. As a result spatial-temporal information is retained during wavelet transform [15]. Multiscale wavelet method produces large wavelet coefficients at higher scale and small wavelet coefficients at lower scale [4]. The scale parameter used in wavelet analysis is like scale used in maps. As in case of map, large scale provides the non-detailed view (of a signal) where as small scale gives the detailed view. Similarly for wavelet, large scale corresponds to detailed view of a signal and small scale wavelet corresponds to compact view [6]. Increasing the scale of a wavelet implies enlarging the wavelet and decreasing the scale of the wavelet corresponds to compacting the wavelet.

Mallat [7] showed that location of the irregular structures can be detected using maxima of the wavelet transform modulus. Mallat's method not only finds edges, but classifies them into different types as well. Large scale wavelet filters are found to be very effective for noise removal and small scale filters conserves the exact location of the edges, but the former increase the uncertainty of the exact position of the edges and later fails in distinguishing between the real edge and noise [8]. Hwang et al. [9] has suggested a method of signal denoising based on wavelet maxima which adopts the Lipschitz regularity. The sharpness of an edge can be described with Lipschitz exponent which can be efficiently measured by wavelet transforms.

A method based on wavelet transform to solve edge detection problem is proposed by Niya and Aghagolzadeh [10]. Ordinary wavelet based edge detector has been used to extract edges and the edge pixels were classified using the primary knowledge about magnitude and direction. They found that proposed method was very helpful in improving the performance of the wavelet based edge detection. Jiang et.al [11] proposed an edge detection algorithm based on Gabor Wavelets (Simplified Gabor Wavelets) which outperformed Canny in the context of detection accuracy. Image edge detection method based on contourlet transform was proposed by Shun-feng Ma et al. [12] in which contourlets was used to obtain the modulus maxima of the transform. The contourlet approach was found to better capture the smooth contours and to suppress the noise such as Gaussian white

noise. Yi et al. [13] proposed a shearlet transform based approach that showed good results as compared to Sobel and other traditional wavelet methods. Niya et al. [14] have proposed the use of ordinary wavelet transform along with Gabor and Cauchy directional wavelets to detect edges accurately. They have concluded Gabor and Cauchy wavelet are better for edge detection as compared to ordinary wavelets and that Cauchy wavelet produced superior results than the Gabor wavelet. Noutsou et al. [15] suggested a feature extraction method based on biorthogonal and contourlets in which they concluded that biorthogonal wavelets were suitable for edge detection of urban features while contourlets accurately extracts linear features like roads. Kitanovski et al. [16] presented multi scale edge detection using Haar wavelet transform and reasoned out that the proposed method also gave equally good results to the classical edge detection methods.

In this paper a comparative study of the efficient wavelet based edge detection techniques and band wise analysis of these algorithms in the context of object extraction with regard to remote sensing satellite images from the Indian Remote Sensing Satellite (IRS) sensors LISS-III, LISS-IV, LANDSAT-5 TM, Cartosat-I and Google Earth is presented. The comparison has been done using commonly used edge detection algorithms like Sobel, Canny with Wavelet based methodologies. After going through the literature ([17], [18], [19]) it is obvious that the Sobel & Canny are the established & best available edge detectors hence these have been taken for the comparison using wavelet techniques. These are the basic classical edge detectors and so far not any significant improvement have been found over these techniques with reference to remote sensing imagery. The bandwise analysis of the algorithms has also been done to find the suitability of band for the extraction of various features.

II. Data Resources, Instrumentation and Study Area

The investigations of present research work have been carried out for the satellite images of different spatial resolution sensors for the Bhopal city and Chandrapur district in India and details are as given in the table-2. The study areas are new market area of Bhopal city and Chandrapur having area central point coordinates $23^{\circ} 55' N$ Latitude and $76^{\circ} 57' E$ Longitude and $19^{\circ} 51' N$ Latitude and $79^{\circ} 19' E$ Longitude respectively. Various edge detection algorithms have been implemented in the MATLAB software environment. The ERDAS-Imagine version 2011 was also used for the pre-processing of images and other image analysis tasks.

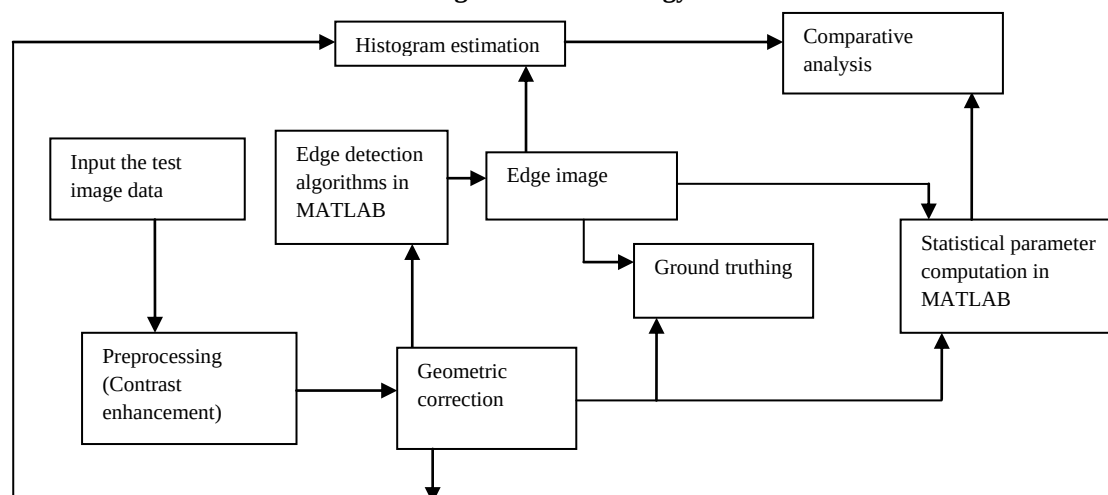
Table 1 Details of Satellite Images Used for Analysis

S.No.	Imaging sensor	Spatial resolution(m)	Satellite	Area	Date of Acquisition
1	PAN	2.5	IRS-P5(Cartosat-1)	Bhopal(India)	5 th April 2009
2	LISS-III	24	IRS P6	Bhopal(India)	5 th April 2009
3	LISS-IV	5.8	IRS-P6	Bhopal(India)	16 th March 2010
4	Google Earth	NA	NA	Bhopal(India)	16 th March 2010
5	LANDSAT-5TM	32.6	LANDSAT	Chandrapur(India)	26 th DEC 1990

III. Methodology

The satellite images of study area have been selected in such a way that they cover some known different land use ground features with well defined and arbitrary geometry as mentioned in the investigation result tables. The various edge detection techniques were analyzed using different sample images with regard to the context of object extraction and methodology is summarised in Figure 1. It is found that for certain images certain features can be better extracted using certain algorithms.

Figure 1. Methodology



The accuracy of the various edge detection methods are estimated using correlation coefficient as a statistical parameter. Correlation coefficient (r) for each edge image with reference to original image has been calculated using following formula (Alnihou, 2008).

$$r = \frac{\sum_m \sum_n (O_{mn} - \bar{O})(E_{mn} - \bar{E})}{\sqrt{\{\sum_m \sum_n (O_{mn} - \bar{O})^2\} \{\sum_m \sum_n (E_{mn} - \bar{E})^2\}}}$$

$\bar{O}$ = Average of the values in original image (O), and $\bar{E}$ = Average of the values in edge image (E)

IV. Mathematical Formulation

The comparative mathematical analysis of the various edge detection algorithms were conducted to justify the experimental results. Let $L^2(R^2)$ denotes the Hilbert space of measurable and square-integrable 2-D functions $f(x,y)$ which is an image (Mallat and Zhong, 1992).

The norm of the $f(x,y) \in L^2(R^2)$ is given by

$$\|f\|^2 = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} |f(x,y)|^2 dx dy \quad (1)$$

First or second-order derivative of the signal is used to detect the sharp variation of points and proper scale is adopted for smoothing of the signal by most of the multiscale edge detectors. Multiscale edge detection is related to wavelet transform as follows.

Considering any function $\theta(x,y)$ as smoothing function whose integral is 1 and converges to 0 at ∞ . Gaussian can be chosen as a smoothing function assuming that it is twice differentiable and defined.

A wavelet transform is computed by convolving a signal with dilated wavelet. Dilation of any 2-D function $q(x,y)$ by a scaling factor s is represented as

$$q_s(x,y) = \frac{1}{s^2} q\left(\frac{x}{s}, \frac{y}{s}\right) \quad (2)$$

The two wavelet function $\psi^1(x,y)$ and $\psi^2(x,y)$ can be defined as

$$\psi^1(x,y) = \frac{\partial \theta(x,y)}{\partial x} \quad \text{and} \quad \psi^2(x,y) = \frac{\partial^2 \theta(x,y)}{\partial x^2} \quad (3)$$

$$\text{Let } \psi_s^1 f(x,y) = \frac{1}{s^2} \psi_s^1\left(\frac{x}{s}, \frac{y}{s}\right) \text{ and } \psi_s^2 f(x,y) = \frac{1}{s^2} \psi_s^2\left(\frac{x}{s}, \frac{y}{s}\right) \quad (4)$$

The wavelet transform of the function $f(x,y)$ at scale s contains two component which can be defined as

$$W_s^1 f(x,y) = f * \psi_s^1(x,y) \quad \text{and} \quad W_s^2 f(x,y) = f * \psi_s^2(x,y) \quad (5)$$

following equation can be derived using equations (3) and equation (5)

$$\begin{pmatrix} W_s^1 f(x,y) \\ W_s^2 f(x,y) \end{pmatrix} = s \begin{pmatrix} \frac{\partial}{\partial x} (f * \theta_s)(x,y) \\ \frac{\partial}{\partial y} (f * \theta_s)(x,y) \end{pmatrix} = s \vec{\nabla} (f * \theta_s)(x,y) \quad (6)$$

The two components $W_s^1 f(x,y)$ and $W_s^2 f(x,y)$ of the wavelet transform mentioned in equation (6) are responsible for capturing the location of edge points. Magnitude and direction of the each edge points are obtained using equation (7) and equation (8) respectively.

$$M_s f(x,y) = \sqrt{|W_s^1 f(x,y)|^2 + |W_s^2 f(x,y)|^2} \quad (7)$$

$$A_s f(x,y) = \arctan \left(\frac{W_s^2 f(x,y)}{W_s^1 f(x,y)} \right) \quad (8)$$

General classical edge detection methods like Sobel, Canny adopts the following procedure.

If I be the image and K be the kernel are functions of two discrete variables n_1, n_2 then the formula for the two-dimensional convolution [5] of I and K can be written as

$$c(n_1, n_2) = \sum_{i=-\infty}^{+\infty} \sum_{j=-\infty}^{+\infty} I(i,j) K(n_1 - i, n_2 - j) \quad (9)$$

Where

$$K_x = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \quad K_y = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

The gradient magnitudes can then be determined as an Euclidean distance measure to reduce the computational complexity

$$|G| = \sqrt{G_x^2 + G_y^2} \quad (10)$$

It is sometimes simplified by applying Manhattan distance which is defined as

$$|G| = |G_x| + |G_y| \quad (11)$$

Direction of the edges are determined as

$$\theta = \arctan\left(\frac{G_y}{G_x}\right) \quad (12)$$

Thus a comparative analysis of equations (6) and (7) reveals that the multiscale technique can adjust itself in accordance with the noise variations where as other general edge detectors lack the scale adjustment

V. Results and Discussion

A. Analysis of The Various Sensor Images

The parameters that we used for analysis were the number of detectable objects and the frequency of false edges. The advantages and disadvantages of above discussed edge detection methods were discussed by various researchers ([3], [4], [22]) and some of the main points of these are summarized in the Table 2.

Table 2 Advantages And Disadvantages Of Edge Detectors

Operator	Advantages	Disadvantages	Remarks
Classical	Simplicity, Detection of Edges and their orientation	Sensitivity to noise & inaccurate	Computational time is less
Zero Crossing (Laplacian, Second directional derivative)	Detection of edges and their orientations with fixed characteristics in all directions	Responding to some of the non-existing edges and sensitivity to Noise	Sensitive to noise
Laplacian of Gaussian (LoG) (Marr-Hildreth)	Finding the correct places of edges, testing wider area around the pixel	Malfunctioning at the corners, curves and where the gray level intensity function varies. Not finding the orientation of edge because of using the Laplacian filter	Sensitive to noise
Gaussian(Canny, Shen-Castan)	Using probability for finding error rate, Localization and response.	Complex Computations, False zero crossing, Time consuming	Ideal for object extraction
Multiscale wavelet based method	The effect of noise can be reduced by adjusting the scale.Linear and curved features can be extracted.	Performance is sensitive to scale variation	Ideal for object extraction in presence of noise
Biorthogonal wavelet method	Extracts linear features more accurately.	High computational time , false edges	Sensitive to noise

Correlation coefficient for each edge image with reference to original image has been calculated and shown in Table-3. The images are subjected to various edge detection methods and the visual comparison of the results is shown in Figure 2-6.

Figure 2. Edge detection of features on Cartosat-I image using various methods from (a) to (e).

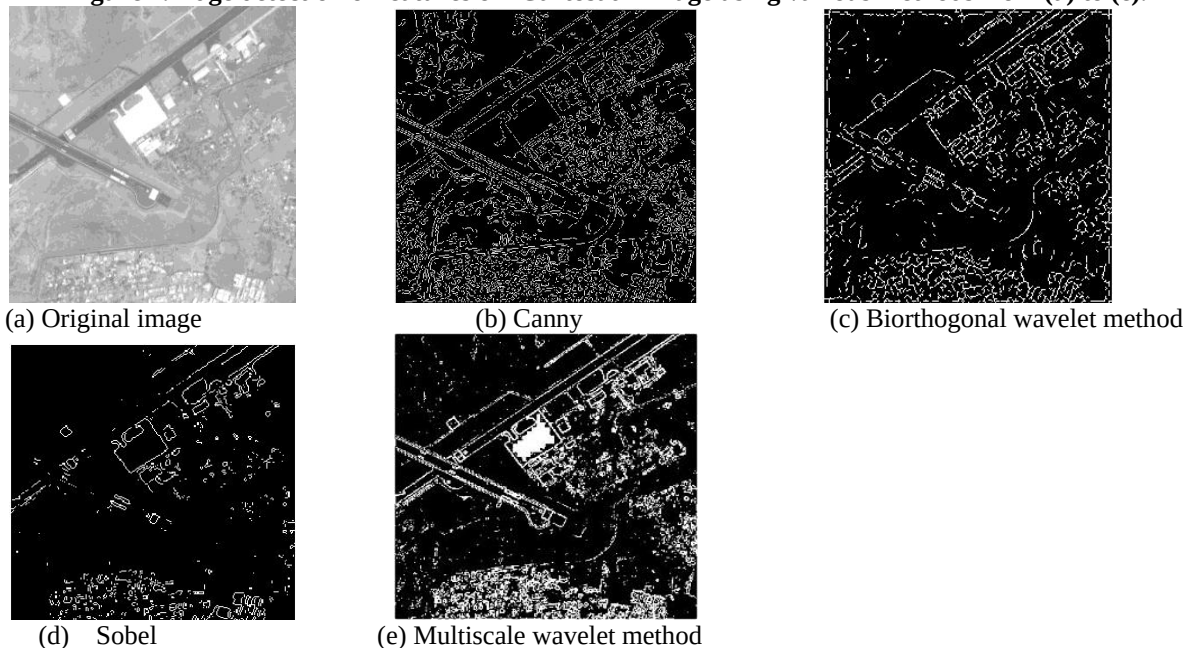


Figure 3. Edge detection of features on Google Earth image using various methods from (a) to (e).

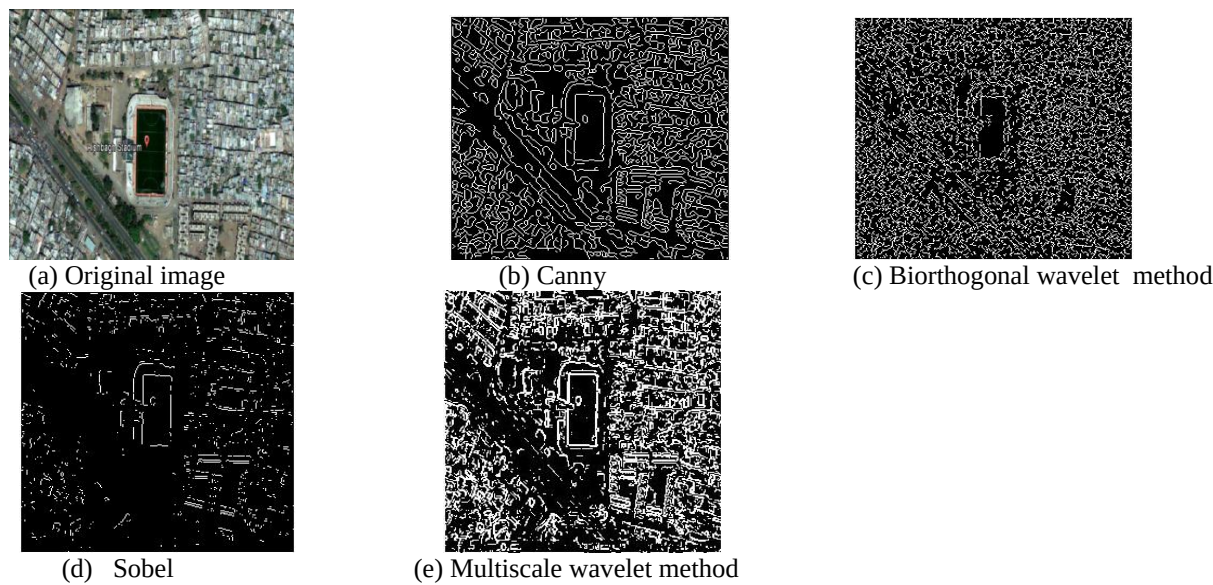


Figure 4. Edge detection of features on LISS-III image using various methods from (a) to (e).

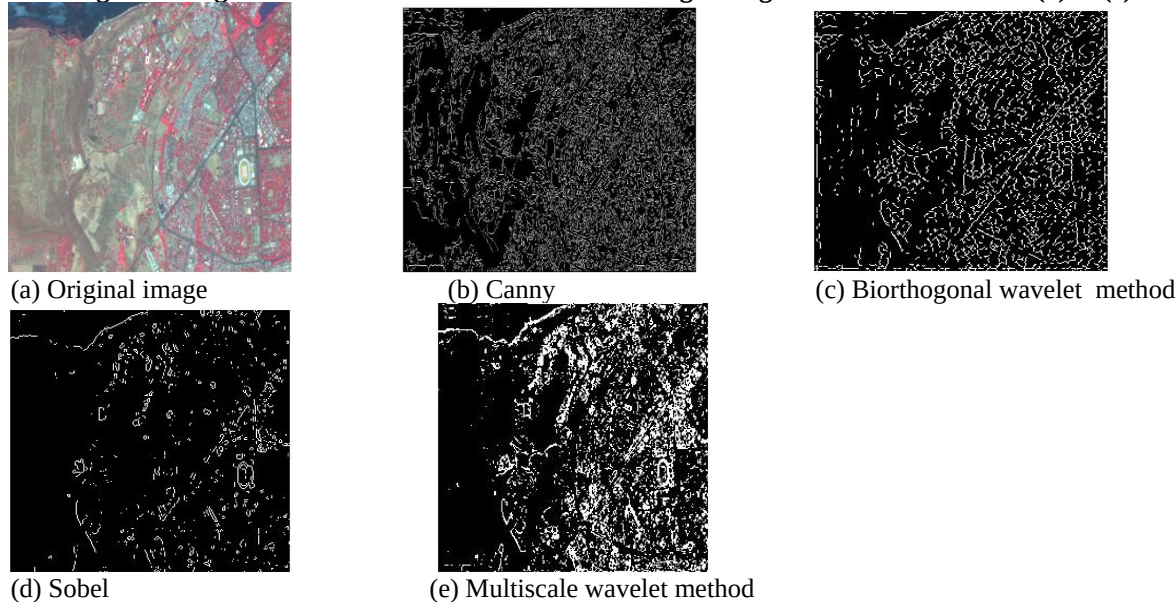


Figure 5. Edge detection of features on LISS-IV image using various methods from (a) to (e).

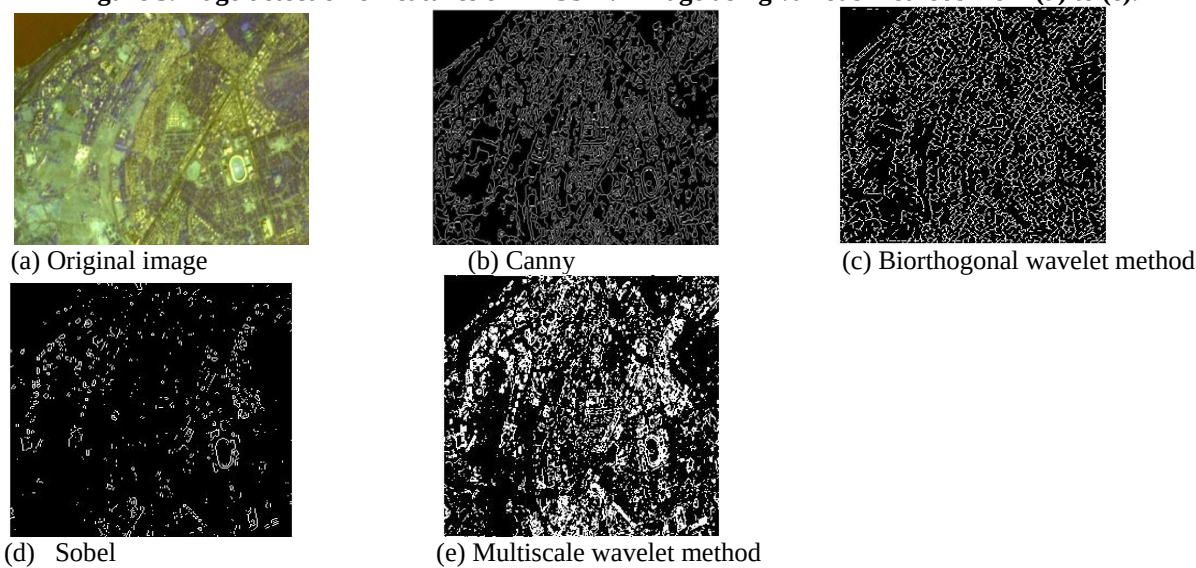
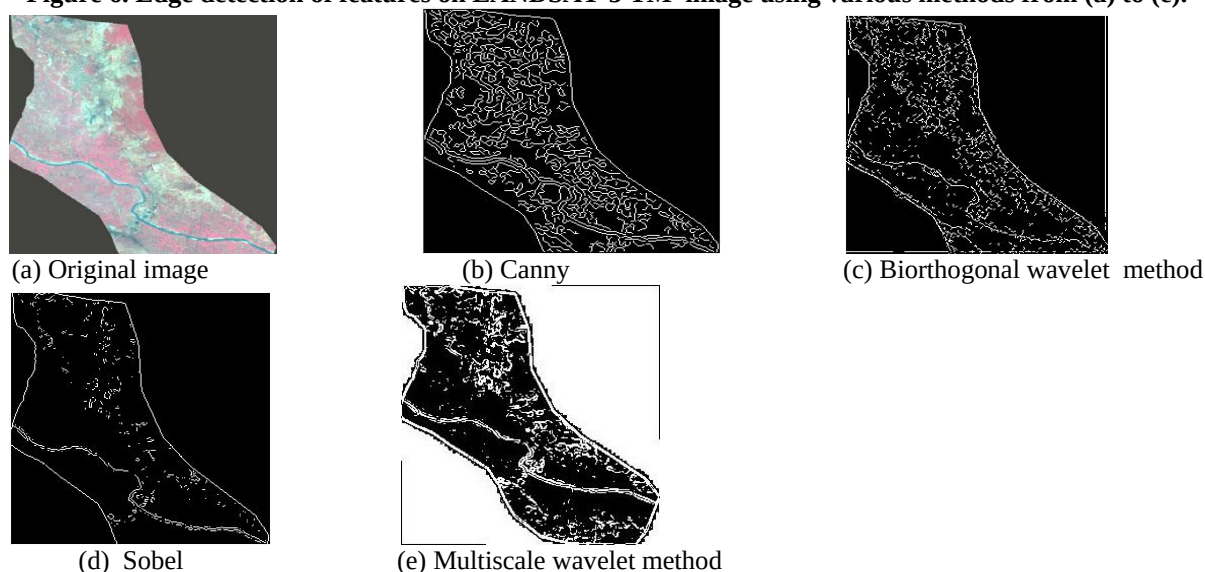


Figure 6. Edge detection of features on LANDSAT-5 TM image using various methods from (a) to (e).

The investigations of various spatial resolution images using different edge detection methods have shown that the gradient based methods are more sensitive to noise than their wavelet based counterparts. The comparison of each edge detection algorithm revealed that the various features can be efficiently extracted from the satellite images using multiscale wavelet technique and details of which are summarised in Table 3.

Table 3 Summary of the Results

S. No.	Image Sensor	Algorithm for edge detection	Correlation Coefficient(r)	Distinguished Features on the edge image
1	PAN (CARTOSAT-1)	Sobel	0.5365	Building
		Canny	0.4723	Air strip,Building
		Biorthogonal wavelet	0.3920	Buildings
		Multiscale wavelet	0.5829	Air strip and associated structures
2	LISS-III	Sobel	0.5568	Lake
		Canny	0.6855	Lake,Stadium
		Biorthogonal wavelet	0.0720	Lake,Roads
		Multiscale wavelet	0.7054	Lake,Stadium
3	LISS-IV	Sobel	0.5504	Stadium
		Canny	0.6003	Lake,Stadium,
		Biorthogonal wavelet	0.3552	Lake,Roads
		Multiscale wavelet	0.7126	Lake,Stadium,Buildings
4	LANDSAT-5TM	Sobel	0.2669	River
		Canny	0.5741	River
		Biorthogonal	0.4803	River
		Multiscale wavelet	0.7473	River
5	Google Earth	Sobel	0.3752	Stadium
		Canny	0.3542	Stadium,Roads,Trees
		Biorthogonal	0.3341	Stadium
		Multiscale wavelet	0.5532	Stadium,Buildings,Roads,Trees

B. Bandwise Analysis

The images were analysed band wise also to determine the sensitivity of various edge detection algorithms to image acquisition wavelength range. The visual results of the band wise analysis are as follows. The band wise analysis of LISS-III images also confirms that the algorithm gives better response for Band3 images and that IR-band is more suitable for the extraction of various natural features as vegetation and also for manmade features as roads, buildings etc.

Figure 7. Input image and detected features using various methods from (a) to (e).

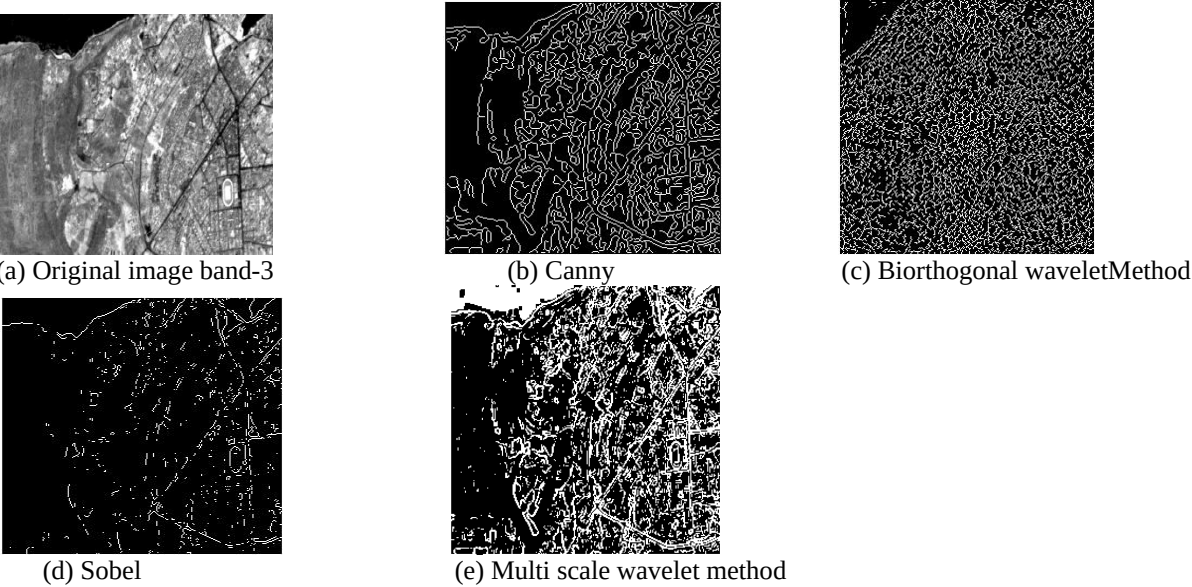


Figure 8. Input image and detected features using various methods from (a) to (e).

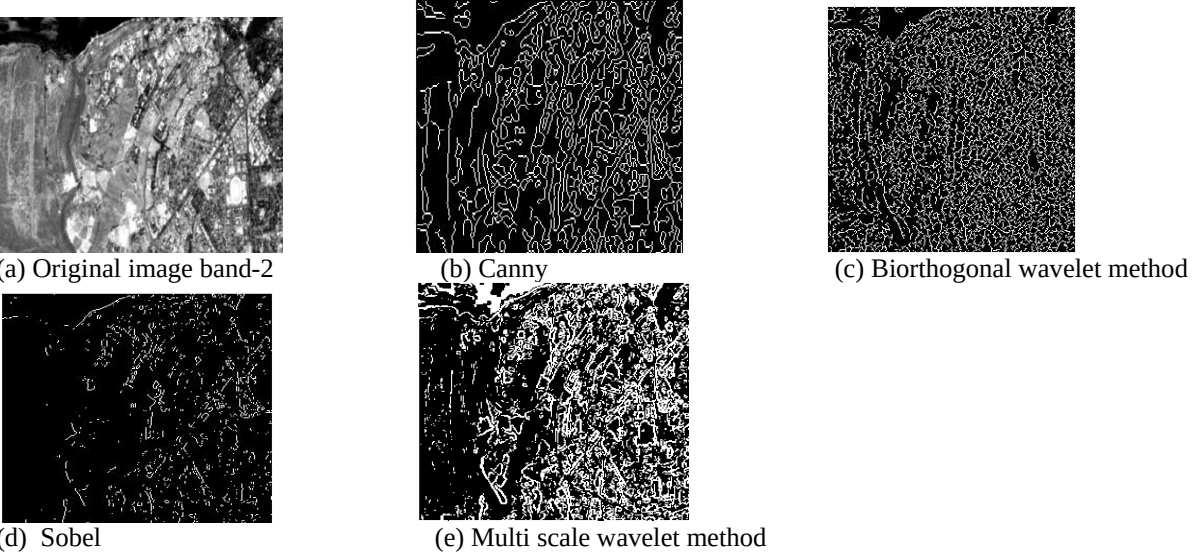
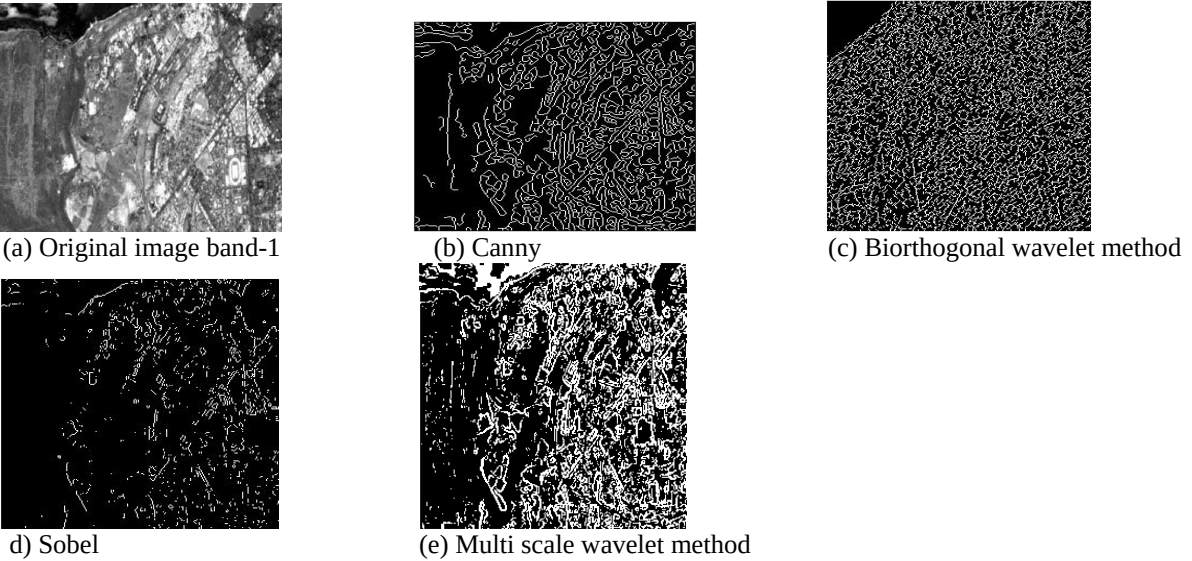


Figure 9. Input image and detected features using various methods from (a) to (e).



The comparison of each edge detection algorithm with reference to the bands revealed that the various features can be efficiently extracted from the satellite images using multiscale wavelet technique over NIR-band and details of which are summarised in Table 4.

Table 4 Summary of the Bandwise Analysis

S. No.	Band	Algorithm for edge detection	Correlation Coefficient (r)	Distinguished Features on the edge image
1	Band-1	Sobel	0.3590	Lake, Stadium
		Canny	0.3403	Lake, Roads
		Biorthogonal wavelet	0.2856	Stadium
		Multiscale wavelet	0.5493	Lake, Stadium, Roads
2	Band-2	Sobel	0.3018	Lake
		Canny	0.3431	Lake
		Biorthogonal wavelet	0.3285	Lake
		Multiscale wavelet	0.4989	Lake, Roads
3	Band-3	Sobel	0.4252	Lake
		Canny	0.3993	Lake
		Biorthogonal wavelet	0.3153	-
		Multiscale wavelet	0.5011	Lake, Roads

Ground truthing has been done with reference to Google earth and DGPS over the study area using Trimble R3 DGPS equipment. Area of the some ground features have been calculated in original and edge images obtained using Multiscale wavelet method and shown in Table 5. We have chosen those ground features which are having a fixed geometry as well as clear visibility in various images. The area observed in various edge images does not have much deviation from the actual area on ground. This indicates the accurate detection of the object edges by multi scale wavelet method.

Table 5 Area calculation of various ground features in edge image obtained using multi scale wavelet method

S.No.	Image sensor	Feature	Area (In original) (in km ²)	Area (Edge image using Multiscale wavelet) km ²
1	LISS 3	TT Nagar Stadium	0.021364	0.020776
2	LISS 4	TT Nagar Stadium	0.021364	0.020505
3	Cartosat-1	Big Building	0.025083	0.025033
4	Google Earth	Aishbagh_ Stadium	0.006018	0.005922
5	Landsat5 TM	River	2.4435	1.9875

VI. Conclusions

The investigations carried out in this research work revealed that the multi scale technique is suitable for the detection of linear edges and out performs Canny in the presence of noise. Analysis results have shown that the multiscale wavelet based algorithm is best suitable for the object extraction in most contexts due to fact that it yields less number of false edges. The investigation also revealed that the operator is less sensitive to band variations and that the NIR(band-1) band turned out to be best suitable for the extraction of features as road, drainages etc. The research work also concluded that the Canny, Sobel operators outperforms the bi-orthogonal wavelet based method while sensor based exceptions can be revealed from the analysis. The work reveals that the edge detection and object extraction works can be more improved by incorporating the wavelet based methods to the classical approaches.

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