Sumerianz Journal of Scientific Research, 2021, Vol. 4, No. 2, pp. 45-51
ISSN(e): 2617-6955, ISSN(p): 2617-765X
Website: https://www.sumerianz.com
DOI: https://doi.org/10.47752/sjsr.42.45.51

Original Article Open Access

Deep Learning in Satellite Imaging: A Survey

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Article History

Received: April 25, 2021

Revised: June 9, 2021

Accepted: June 13, 2021

Published: June 16, 2021

Abstract

In recent time deep learning has been extensively applied in satellite image analysis, the aim of this work was to conduct a thorough review on the application of deep learning in satellite imaging, moreover we have also provide a detail description regarding the principles of satellite image capturing, in addition to the mathematical models of image processing techniques used in satellite images such as image denoising, image filtering, image segmentation and histogram equalization. We have also discuss some of the aspect of deep learning but not in deep. Finally we have pave away for further research directions both in satellite imaging and deep learning.

Keywords: Satellite; Deep learning; Image processing; Histogram equalization; Segmentation; Filtering.

1. Introduction

Satellite image is an images of either the whole earth surface or some part of its (Lithosphere, Biosphere, and hydrosphere) or other planet captured by an artificial satellite from the space where electromagnetic radiation serves as a carrier of information [1-3]. These images collected have a variety of functions and applications such as military, intelligence security, space research agency, metrologies transportation system and so on.

Every object on the surface of the earth has different reflection strengths at different wavelength and spectrum Borra, *et al.* [4] Moreover, the quality of satellite images captured are primarily depends on the various energy sources active or passive and uniform or non-uniform, if it is sensor resolutions should be spatial or temporal and spectral or radiometric, and if it is atmospheric interference, real time energy should be reflectance or absorption. The satellite imaging sensor are basically classified into two optical sensor and microware sensors optical sensor uses light radiation which are reflected by the earthy object and are divided into two visible optical and infrared optical sensor which are used to understand the nature of objects such as forest, mountains, trees, water bodies and sea etc. microwave sensor use microwaves reflected by the earth object independent of the atmospheric conditions. It is also used to observe water bodies, mountains and condition of ice such as thickness and their temperature. However, image capturing by the satellite imaging sensor can either be done in two ways; active mode and passive mode. Kumar, *et al.* [5]. Satellite images are captured as a result of various sensor and scanners operate with variety electromagnet spectrum. Using many spectral bands provide a clear information of an objects. But it required more storage capability with much transmission complexity. In satellite imaging the higher the width of the spectral band the more the strength of the signal would be.

Satellite image resolution is a term used to described the ability to identity, classify detect, and distinguish object and their properties. Resolution of the image is directly proportional to the details information or clarity of the information provided by the image. Basically there are four types of image resolution in satellite images spatial, spectral, temporal and radiometric resolution. Kumar, *et al.* [5] Spatial resolution corresponds to the smallest area covered by a single sensor at any time the larger the spatial resolution the smaller the pixel the system captured and also provides higher clarity to distinguish object in an image. The object closer than resolution appears as a single object in 10 satellite imaging. The system with more than one kilometer (1km) spatial resolution is considered as a low resolution system while 100m to 1km is considered as a medium resolution and 250 and 500m is considered high resolution and also a satellite system with 5-100m spatial resolution is high resolution while less 5m is very high resolution. Spectral resolution is directly proportional to the width, sensitivity and position of the spectral band and their numbers. The higher the spectral band the higher the clarity of the satellite image and ability to classify object on it Example geographic information system satellite captured image in 3-8 spectral bands. Distortion in satellite imaging it mostly occur as a result of sensor characteristic, variation in aspect ratio, motion of the satellite, motion of and object under acquisition and viewing geometry. Moreover it also occurs due to the latitude and attitude change of the target and the satellite [6]. Temporal resolution of a remote sensing system is technically indicate how many time the system captured the image of a particular area. While radiometric resolution is refers to the actual sensitivity of remote sensing detector to differences in signal strength as it record the reflected, emitted or back scattered electromagnetic radiation with more precision that other sensing system.

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2. Satellite Imaging System

Satellite imaging system provide an effective means of collecting large amount of information about an objects or region of interest from far distance for a long period of time and making it possible to make analysis on the changes that occurs within the region of interest over a period of time. The system departed the strength of the electromagnetic spectrum to capture image of an object on the earth surface such as forest, trees, human, settlement, water bodies, route network etc. [4]. The electromagnetic spectrum is a fusions of many different wavelengths these includes; microwave, infrared visible light and ultraviolet light in which the major source is the solar system. The ray from the region of interest can be mathematically expressed either in terms of frequency or wavelength as;

$$E = hcf$$

$$E = \frac{he}{\lambda} \quad (1)$$

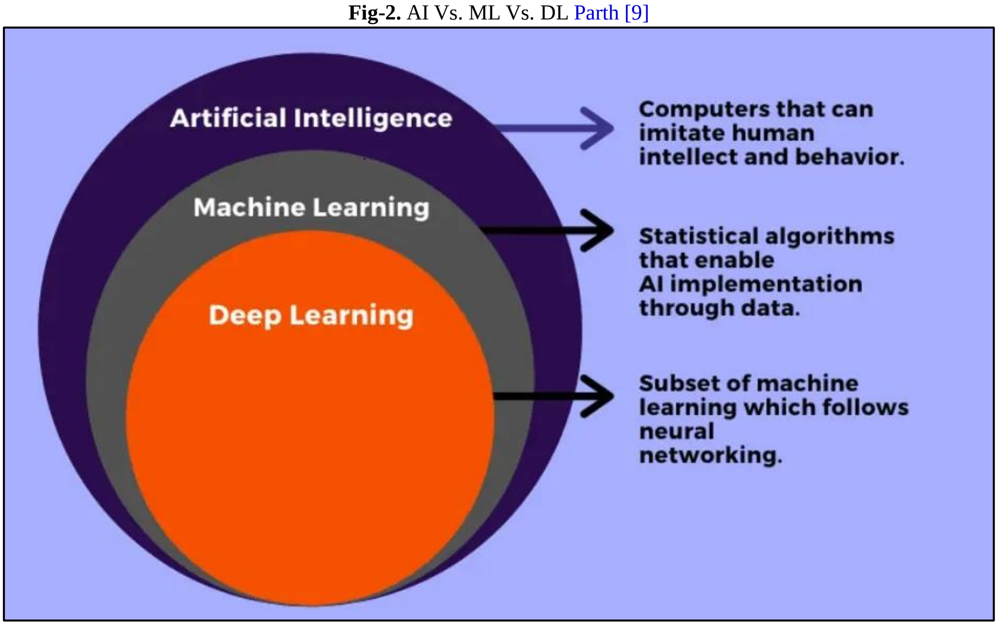
Where F is the frequency; C is the speed of light; L wavelength and h is the Planck's constant

Fig-1. Satellite [7]

2.1. Deep Learning

Deep learning was derived from artificial neural network (ANN) that is connectionist ANN is also derived it concept from working architecture of human brain. DL in trying to build multilayered architecture it also hired the concept of graph theory [8] in some perspective DL learning is considered as a subset of Machine learning (ML) and ML is considered as a subset of Artificial Intelligence (AI) as shown in the figure below;

Fig-2. AI Vs. ML Vs. DL Parth [9]



It is also noticed that DL not require any human intervention by creating rules that will be use for decision making as compare to ML rather it uses a large amount of datasets and provide different interpretation on this data [8] basically there are different deep learning networks applied in computer vision as summarized in the table below;

Networks	Focus	Approach
1. CNN	*Image classification*	*DSL*
	Image Recognition	
	Image Retrieval	
	Object detection	
	Computer vision	
	Natural Language Processing	
2. RNN	*Natural Language Processing*	*DSL*
3. DBN	*Image Classification*	*DUSL*
4. GAN	*Image classification*	*DUSL*
5. RVNN	*Natural language processing*	*DSL*
6. VAE	*Image processing*	*DSL*

2.2. Image Processing

An image can be expressed as two- dimensional function $f(x, y)$ where $x\ and\ y$ represent the spatial coordinate and the altitude of $f$at any pair of coordinate (x, y) is known as the intensity or gray level of the image at that point. If x, y and the altitude values of f are all finite and discrete quantities the image is called digital image. The term gray level is used to describe the intensity of monochrome images. However colored image are formed by three colors (Red, Green, and Blue (RGB) [10]. Digital image processing are mostly represented and store in a matrix form or in array of numbers every digit in the matrix is located at a specific row and column every digit is used to represent a pixel in a two- dimensional picture element that is non-divisible element of the digital image.

2.3. Image Processing Technique in Satellite Imaging

Digital image processing includes; image preprocessing which are radiometric and geometric correction. Image enhancement, photogrammetric image processing of stereoscopic imagery, parametric and non-parametric extraction, expert systems such as decision trees SVM and neural network image analysis (CNN, RCNN, DCNN etc.), hyper spectral data analysis and change detection of region of interest. In radiometric corrections normally digital and analog satellite images can contain noise or error that are accidentally introduced by the system sensor called electronic noise or due to atmospheric scattering of light into the sensor field of the view although advances has been made in trying to remove this errors and noise such as radiometric calibration to scale surface reflectance that is if the image are optical or through normalization technique [11]. Geometric correction is the process of converting satellite images into planimetrics (x, y) to enable their application in Geographic Information System (GIS) and spatial decision support system. Image enhancement is an important component of image preprocessing is the ability to contrast, stretch, cropped, filter, degrade image, cropped, filter, degrade image to enhance low and high frequency edges and texture of the images [12]. Moreover, satellite images can be linearly and non-linearly converted with the real world phenomena using statistical technique called principal component analysis [13]. Parametric information extraction refers to the process of extracting the region of interest in satellite images using object-based image analysis or segmentation algorithms, support vector machine, maximum likelihood classification, K-means nearest neighbor and many more classification algorithms. While non-parametric extraction refers to the process of extracting a region of interest on remote sense data through the use of heuristic techniques such as artificial neural networks and other deep learning techniques (CNN, DCNN, RCNN etc.) in detecting or classification of objects in satellite images.

2.4. Method of Satellite Image Analysis

Mathematically image are represented by a two dimensions function: $(x, y) \longrightarrow f(x, y)$ where the value of f at the spatial coordinator $(x, y)$are usually positive and mostly determined by the source of the image, hence $f(x, y) \neq 0$ and finite

$$0 < f(x, y) < \infty \quad (1)$$

Where the image function f has two major components

$$fi < (x, y) and r(x, y) hence$$

$$f(x, y) = 1(x, y)r\ (x, y) \quad (2)$$

where $0 < \ i\ (x, y) < \ \infty\ and\ 0\ < \ (x, y)\ < 1$

Such that $i(x, y)$ primarily relies on the illumination source and $r(x, y)$primarily depend on the texture of the image.

Moreover, if the image are formed via a transmission the same equation will be given as

$$L_{min} \leq 1\ =\ f(x, y) \leq\ L_{max} \quad (3)$$

Where $I\ =\ f(x, y)$ is the gray level at coordinates (x, y)

2.5. Image Denoising

From the degradation model $g(x, y) = f(x, y) = n(x, y)$ where $f(x, y)$ is the real image and $g(x, y)$ Degraded image and $n(x, y)$ is the noise. However there are different form of noise and are represented mathematically as:

i. Gaussian noise I relation to probability distribution function is define as

$$p(r) = \frac{1}{\sqrt{2\Omega\sigma}} e^{-(r-\mu)/2\sigma} \quad (4)$$

Where μ is the mean and σ is the standard deviation

ii. Uniform noise in relation to probability distribution function is given by

$$p(r) = f(x) = \begin{cases} \frac{1}{B-A} If\ A \le r \le B \\ O\ otherwise \end{cases} \quad (5)$$

iii. Impulse noise in relation to probability distribution function is given by

$$\begin{cases} PA\ if\ r = A \\ PB\ if\ r = B \\ O\ otherwise \end{cases} \quad (6)$$

2.6. Mean Filters of Random Noise Removal

Let g be the input noisy image and f be the output that is denoised image if also $S(x,y)$ is the neightborhood of the pixel $S(x,y)$defined as

$$S(x,y) = \{(x+s, y+t), -a \le s \le a, -b \le t \le b\} \quad (7)$$

of the image size $mn\ where\ m = 2a+1\ and\ n = 2b+t\ and\ are\ postive\ integer.$

Such that arithematic mean filter can be defined as

$$f(x,y) = \frac{1}{mn}\sum_{(s,t)\in S_{(x,y)}} g(s,t)(16) \quad (8)$$

wich is very good In denoising gaussian noise and uniform noise.

Geometric mean filter is also defined as

$$f(x,y) = \left(\prod_{(s,t)\in S_{(x,y)}} g(s,t)\right)^{1/min} \quad (9)$$

Contraharmonic mean filter is also defined as

$$f(x,y) = \frac{\sum_{(s,t)\in S_{(x,y)}} g(s,t)^{Q=1}}{\sum_{(s,t)\in S_{(x,y)}} g(s,t)^{Q}} \quad (10)$$

Modern filter is also called order statistics filter where $f(x,y)$ depend on the ordering of the pixel value of the image g in the window $s_{(x,y)}$ which is given as

$$f = (x,y) = modern\ \{g(s,t), (s,t) \in S(x,y)\} \quad (11)$$

Midpoint filter is seen to be a hybrid filter that combine statistical filter and averaging filter and which is good for denoising Gaussian noise and uniform noise as is given by

$$f(x,y) = \frac{1}{2}[\overset{max}{(s,t)es(x,y)}\{g(s,t)\} + \overset{min}{es(x,y)}\{g(s,t)\}] \quad (12)$$

2.7. Alpha-Trimoned Mean Filter

From the first order mn pixel value of an input image g in the window $S(x,y)$ and then we remove image g in the lowest $d/2$ and then largest $d/2$ and also we denote the remaining $mn - d$ value by grprovided that $d \le 0$ be an even integer such that $o \le d \le mn - 1$it is given by;

$$f(x,y) = \frac{1}{mn-d} = \sum_{(s,t)} \in S(x,y)\ gr \quad (13)$$

2.8. Image Restoration

Image restoration is the method of regaining the natural characteristic of the image that has been degraded. We already define the real image as $f(x,y)$ and the degraded image as $g(x,y)$the connected relationship between f to g is called degradation model represented as

$$g(x,y) = H[f](x,y) + n(x,y) \quad (14)$$

Where H is the degradation operator and n is the noise.

2.9. Image Segmentation

Segmented image is a proposed image without noise and sometime sharp which can be an input f and the output could be an image g 0r not even an image but would be an attribute set of point representing the edges of f boundaries of object but, segmentation is based on certain criteria such as similarity, color texture or region of interest or any set of predefined rules.

If we consider a differentiable function $(x,y) \to f(x,y)$ in two dimensions to let defined it gradient operator as being the vector of first order partial directives.

$$\Delta f(x,y) = \left(\frac{\partial f}{\partial x}(x,x) \frac{\partial f}{\partial y}(x,y)\right) \quad (15)$$

And the gradient magnitude as Euclidean norm of the vector Δf

$$|\Delta f|(x,y) = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2} \quad (16)$$

The central finite differences approximation of the gradient are assuming $\Delta fx = \Delta y = 1$

$$\frac{\partial f}{\partial x}(x,y) \approx \frac{f(x+1,y) - f(x-1,y)}{2}, \frac{\partial f}{\partial y}(x,y) \approx \frac{f(x,y+1) - f(x,y-1)}{2} \quad (17)$$

The gradient can be used to detect edges where the image f does not vary the gradient magnitude $|\Delta f|$ is close to zero while in the area where there are strong variation the gradient magnitude $|\Delta f|$ is larger. Since we have define the output image as $g(x, y) = |\Delta f|(x, y)$ which would show while edges or black background or a threshold version of $|\Delta f|$

If we are to represent the discrete version of the output it would become

$$g(x, y) = |\Delta f|(x, y) \tag{18}$$

Or the threshold gradient of the output can be represented as

$$g(x, y) = \begin{cases} 255|\ \nabla f|\ (x, y) \geq \text{toleranceT} \\ \ 0|\nabla f|(x, y) < \text{tolerance T} \end{cases} \tag{19}$$

Where the operation $f \to g|\nabla f|\ is\ non\ linear.$

2.10. Machine Learning Applied to Object Detection in Satellite Images

Machine learning algorithms are applied to object detection in satellite images such as support vector machine which is one of the popular machine learning techniques applied to object classification in remote sensing images which are earlier proposed in Bai, *et al.* [14] for detection in multi-class object (Cheng *et al.*, 2008) and [15] applied in change detection, more over another traditional object classification machine learning techniques are called K-Nearest-Neighbor (KNN) are serially applied to object classification in remote sensing images [16]. In addition to connectionist which is one of the most popular machine learning algorithms called Artificial Neural Network (ANN) are extensively applied in remote sensing application for object detection, classification and change detection as presented in Malek, *et al.* [17] and Tang, *et al.* [18] and Wang, *et al.* [19] and lately Ghosh, *et al.* [20].

Table-1. Deep learning techniques applied to object detection in satellite images

Authors and date	Focus
1. **Lei, *et al.* [21]**	Object Detection
2. **Liu and Shi [22]**	Detection of Invariant airplane
3. **Zhang, *et al.* [23]**	Object detection in high- resolution
4. **Zhang, *et al.* [24]**	Object detection in optical remote sense image
5. **Cheng, *et al.* [16]**	Automatic landslide detection from remote sensing
6. **Yao, *et al.* [25]**	Airport detection
7. **Ari and Aksoy [26]**	Detection compound structure using Gaussian
8. **Li, *et al.* [27]**	Robust Rooftop Extraction from Visible Band Images
9. **Benedek, *et al.* [28]**	Change detection
10. **DeMosrsier, *et al.* [15]**	Novel detection using SVM
11. **Cheng, *et al.* [16]**	Automatic landslide detection from remote Sensing
12. **Bai, *et al.* [14]**	Object Detection base on structural feature extraction
13. **Cheng, *et al.* [29]**	Object detection and geographic image classification
14. **Yokoya and Iwasaki [30]**	Detection of Object for optical remote sensing imagery
15. **Zhao, *et al.* [31]**	Hyper spectral image denoising via sparse representation
16. **Wang, *et al.* [19]**	Road network extraction
17. **Tang, *et al.* [18]**	Ship detection on space-born optical image
18. **Malek, *et al.* [17]**	Framework for palm tree detection in UAV image
19. **Sun, *et al.* [32]**	Texture based airport runway detection
20. **Toa, *et al.* [33]**	Airport detection from large IKONOS
21. **Lei, *et al.* [21]**	Object detection in forest using remote sense image
22. **Senaras, *et al.* [34]**	Building detection with decision fusion
23. **Wegner, *et al.* [35]**	Building Detection
24. **Wegner, *et al.* [35]**	Segment-Based Building detection with random field
25. **Bovolo, *et al.* [36]**	Novel approach to unsupervised change detection on SVM
26. **Lei, *et al.* [37]**	Texton forest for land cover transition detection
27. **Cheng, *et al.* [16]**	Landslide detection
28. **Cheng, *et al.* [16]**	Object detection on remote sensing imagery
29. **Das, *et al.* [38]**	Silent features for the design of multistage framework
30. **Mokhtarzade and Zoej [39]**	Road detection from high resolution satellite images
31. **Song and Civco [40]**	Road extraction using SVM and image segmentation
32. **Wang, *et al.* [19]**	A neural-dynamic framework road Network extraction
33. **Zhang and Couloigner [41]**	Separation of parking lots and roads on high resolution
34. **Bi, *et al.* [42]**	Visual models of ship detection in optical satellite images
35. **Zhu, *et al.* [43]**	Chain for ship detection using optical satellite imagery
36. **Pacific, *et al.* [44];**	Multi-scale textural metrics
37. **Zhong and Wang [45]**	urban area detection in remote sensing
38. **Zhao and Nevatia [46]**	Car detection

3. Conclusion

In this work we have systematically reviewed recent state-of-the-art in the application of deep learning in satellite imaging in addition to the operational architecture of satellite system in terms of remote sensing, we have briefly explored the concept of deep learning and its derivatives together with its networks such as CNN, RNN DBM and DBN etc. and finally discussed the mathematical models of image processing techniques that are recently utilized in satellite image analysis.

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