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AN EXPLORATION OF CHANGE DETECTION TECHNIQUES FOR IMAGES

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ABSTRACT

Change detection refers to recognizing dissimilarities arising in the characteristics of an object, over a period of time. Widespread application of change detection in areas like remote sensing, machine vision, video compression, military reconnaissance, etc. has made it demanding area of research. In image processing, detecting changes is an essential and crucial component. Several techniques like image differencing, principal component analysis, object based methods, visual analysis, etc. have been applied successfully and some new techniques like clustering, probabilistic change detection, hyperspectral detection, etc. are currently under active research. This paper analyses various traditional and emerging techniques that efficiently detect changes in different kinds of images and explores the suitability of each method for respective areas.

Keywords: *3D Images, Change Detection, Hyperspectral Images, Image Processing, Multispectral Images, Object-Based Change Detection, SAR Images*

1. INTRODUCTION

Identifying changed regions in temporal images of the same scene comprises a basic aspect of different application areas like geographical monitoring, medical science, infrastructural development, military operations, etc. [1] [2]. Due to involvement of large areas in analysis, it is necessary to develop automated techniques so as to reduce manual effort in image analysis [3]. Emergence of newer high resolution sensors has increased the complexity of images and has opened up more possibilities for development of advanced techniques [4]. Active research has led to proposals of a large number of techniques, most of which have been analyzed and compared. These studies show different authors arriving at varied views about the best techniques, owing to the impact of a number of affecting factors. This leads to the conclusion that selecting a suitable technique for a particular instance is not a simple task. The nature of study area and type of input data affects the results produced by the selected technique. Hence review of available techniques is useful to identify the applicability of these methods to specific problem areas [5].

Existing literature broadly defines unsupervised and supervised approaches towards change detection. Unsupervised approach considers only the raw multispectral images to generate further image. It performs preprocessing to make the input images compatible, which are then compared according to individual pixels or features. This leads to generation of the resultant image which is analyzed to detect changes. Different approaches in this category include change vector analysis (CVA), image rationing, expectation maximization, etc.

Supervised approaches make use of training sets for learning purpose. This allows easier statistical estimation of the types of changes occurred. This approach is advantageous since it is robust and can process images from multiple sources. But the difficulty arises in availability and generation of suitable training sets required [3] [4] [6].

Besides traditional techniques the advent of high-end processing systems and better algorithms has led to development of newer change detection approaches. Ease of extracting features and identification of spectral similarities has facilitated implementation of an object based change detection (OBCD) approach [7]. With the development of Synthetic aperture radar (SAR) imaging, multi-temporal data has been made available and techniques have been developed to exclusively process SAR images [8]. A new technology known as hyperspectral remote sensing is able to perform

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automated target detection and hence, is a potential area for researching change detection [9]. Also change detection techniques have been developed for 3-D images [10].

This paper deals with the various existing techniques that have been implemented for these categories. Due to the availability of numerous techniques, the aim of this work is to provide details about those techniques and their characteristics alongwith their pros and cons, so as to throw light on which technique to select for which purpose. Although many papers have dealt with this issue previously, but the emergence of different types of images and their increasing complexity, besides development of new algorithmic approaches has provided more areas to be researched in recent times, which form the crux of this review in its attempt to provide details of recent work that has been done till date, in various categories of this domain.

2. BASICS OF CHANGE DETECTION

Change detection is a technique to determine changes in particular features of an object over specific interval of time. Its main aim is to provide quantitative and qualitative information of deviations and their spatial distribution including category, amount and areas of changes occurred [11]. Discovering abnormalities in medical diagnosis, detecting land use and land cover changes, target reorganization and surveillance for military purposes, urban planning, environmental conservation etc. are some of the relevant areas which make use of detecting changes in images of a scene at varying time intervals [12]. In mathematical terms general change detection algorithm analysis an input image sequence $\{IM_1, IM_2, \ldots IM_n\}$ where n is the number of images, and generates a difference image D, where:

$$D(i) = \begin{cases} 1, & \textit{if } I^{th} \textit{ pixel is changed in } IM_n \\ 0, & \textit{otherwise} \end{cases}$$

Here each pixel I has an intensity $I(i) \in \mathbb{R}^j$, where j depends on type of image, e.g. 1 for grayscale images, 3 for RGB images or more for hyperspectral or SAR images [1].

The effect of a wide range of factors on the results of change detection often leads to difficulties in selecting the most suitable technique for a specific problem. These factors includes geometric registration, normalization, good quality of input data, cost and time limits, algorithms used, complexities and familiarity of study area and classification techniques [5] [13].

3. OUTLINE OF CHANGE DETECTION METHODS

Conventional images used for change detection, mostly remotely sensed images, were multispectral images that captured data at different wavelengths from the electromagnetic spectrum. Hence, initial techniques were developed accordingly, that processed such multiband remote sensing images [3]. However, technological advancement and increasing application areas has led to availability of high resolution and more detailed images for which such traditional techniques are not adequate. Thus resent research has focused more on finding new techniques that are able to process these kinds of images [14]. Here the authors have described traditional as well as modern techniques successfully applied for change detection. The various image change detection techniques can be classified as shown in fig 1.

3.1 Multispectral Change Detection

This category includes traditional techniques used to process images acquired from remotely sensed data. These techniques consider spectral, spatial, temporal and thematic constraints. The following seven sub-categories fall under this category, more details of which are provided in Table 1.

3.1.1 Algebra

This sub category employs threshold selection mechanism in order to determine the areas of change. This makes such methods simple to implement but it is necessary to properly select appropriate threshold. Image differencing, change vector analysis, image regression, background subtraction techniques and vegetation index differencing fall under this category.

3.1.2 Transformation

This mechanism uses determination of components which represent change by making use of skills of the analyst. Reduction of data redundancy and emphasis on difference in information are achieved. But detailed change matrices are not achieved. Tasselled cap (KT), Gramm–Schmidt (GS), Principal component analysis (PCA) and Chi-square transformations are some of the methods used.

3.1.3 Classification

These techniques use training data to generate classified images of historical data. Its benefit

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includes generation of change matrices and reduction of outside factors. It is necessary to select sufficient good quality sample data set. spectral–temporal combined analysis, expectation, ANN, post-classification comparison, unsupervised change detection, hybrid change detection, and maximization algorithm (EM) change detection are fall under this sub category.

3.1.4 Advanced model

These techniques convert image reflectance values to physical parameters through models, which are more suitable to extract information then spectral signatures, but are more time consuming and difficult. Spectral mixture models, biophysical parameter estimation models and the Li–Strahler reflectance model belong to this category.

3.1.5 GIS

GIS methods use overlaying of GIS layers on images and masking. It incorporates data from multiple sources. So it is necessary to normalize data formats and accuracies. Remote sensing method and the integrated GIS and the pure GIS method are techniques in this category.

3.1.6 Visual analysis

Visual analysis is performed using the experience of an analyst to identify changes in patterns, size, texture and shape. Such methods are not suitable for large areas. Digitization of changed areas on-screen and visual multi-temporal image composite interpretation are the methods included [5] [15].

3.2 Change Detection in SAR Images

Synthetic aperture radar (SAR) is a microwave imaging radar that can be used for remote sensing in all weather conditions. Due to high penetrability it is useful for civil and military applications. It can integrate multiplatform, multi-polarization resources and multi-band resources for detecting changes [16] [17] [18]. The following techniques have been developed to detect changes in SAR images.

(1). Detail-Preserving Scale-Driven Approach *(Bovolo and Bruzzone 2005)* [19]

(2). Unsupervised Change Detection on SAR Images Using Fuzzy Hidden Markov Chains *(Carincotte, Derrode, and Bourennane 2006)* [20]

(3).The Multi-scale Change Profile: a Statistical Similarity Measure *(Inglada and Mercier 2006)* [14]

(4). Change Detection in Multisensor SAR Images Using Bivariate Gamma Distributions *(Chatelain, Tourneret and Inglada 2008)* [21]

(5). SAR Image Integration Change Detection *(Huang 2008)* [22]

(6). Texture Features Fusion Voting (TFFV) algorithm *(Huang, Li and Cai 2009)* [23]

(7). PCA technique involving Singular Value Decomposition Method (SVD) *(Kumar and Garg 2013)* [24]

These techniques are detailed in Table 2.

3.3 Object Based Change Detection

Developments in performance of computing systems and algorithms have brought about a new approach known as object based change detection. This technique is more suitable for high resolution images in which it processes a set of pixels as a single unit or object. This helps in removing redundancy and reduced spectral variations. Here the basic feature is the extraction of image-objects through segmentation and processing them as homogeneous units [7] [25]. Recent research includes the following object based methods.

(1). Rectangular building extraction *(Tanathong, Rudahl and Goldin 2009)* [26]

(2). Objects Based Change Detection in a Pair of Gray-Level Images *(Miller, Pikaz, Averbuch 2009)* [27]

(3). Genetic Algorithm based object-oriented method for High-Resolution Images *(Tang, Huang, Muramatsu and Zhang 2010)* [7]

(4). Object-Oriented Change Detection from Multi-Temporal Remotely Sensed Images *(Liu and Du 2010)* [28]

(5). Object-based detection mechanisms *(Chen, Hay, Carvalho and Wulder 2012)*

a) Image-object mechanism
b) Class-object mechanism
c) Multitemporal-object mechanism
d) Hybrid mechanism [25]

These techniques are detailed in Table 3.

3.4 Change Detection in 3D Images

Real world images, mostly of urban scenarios, can benefit a wide range of services hence precise 3D images need to be acquired. Due to dynamic nature of cities these models need to be updated regularly. So it is required to capture high quality images and rebuilt 3D models, which helps in areas like city planning, damage assessment etc. Change detection of 3D images need to be flexible enough to

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process images available from general camera settings. Following techniques come under this category [10].

1. 3-D image change detection by a 3-D voxel-based model (Pollard and Mundy 2007) [29]
2. Detecting geometrical changes in urban locations (Taneja, Ballan and Pollefeys 2012) [30]
3. City-Scale Change Detection in Cadastral 3D Models (Taneja, Ballan and Pollefeys 2013) [10]

These techniques are detailed in Table 4.

3.5 Change Detection in Hyperspectral Images

Hyperspectral remote sensing is a new technology that automatically searches for definite targets. It makes use of differences in surface properties between object and background in real time. However it exhibits higher falls alarms rates in case of unstructured backgrounds. Following are methods used to detect changes in hyperspectral images [9].

1. Hyperspectral Change Detection in the Presence of Diurnal and Seasonal Variations (Eismann, Meola and Hardie 2008) [9]
2. A Model-Based Approach To Hyperspectral Change Detection (Meola 2010) [31]
3. A Subspace-Based Change Detection Method for Hyperspectral Images (Wu, Du and Zhang 2013) [32]

These techniques are detailed in Table 5.

3.6 Other Techniques

Certain methodological concerns like misregistration faults, choice of threshold etc. persist in most of the techniques. As a result certain researchers have focused on developing different techniques that address such issues and explore new mechanism for detecting changes. Some of the methods which do not fall into any of the above categories are as follows [2].

1. Patch-Based Markov Models for Change Detection *(P´ecot and Kervrann 2007)* [33]
2. An a-contrario approach for sub-pixel change detection *(Robin, Moisan and H´egarat-Mascle 2009)* [2]
3. Building Extraction and Change Detection in a Joint Stochastic Approach *(Benedek, Descombes and Zerubia 2009)* [34]
4. Similarity Measures of Remotely Sensed Multi-Sensor Images for Change Detection *(Alberga 2009)* [35]
5. Fuzzy clustering algorithms *(Ghosh, Mishra and Ghosh 2010)* [36]
   a). Hard c-means (HCM) clustering
   b). Fuzzy clustering
      i).Fuzzy c-means clustering (FCM)
      ii).Gustafson–Kessel clustering (GKC)
6. A Split-Based Approach to Change Detection in Large-Size Images *(Bovolo and Bruzzone 2010)* [19]
7. A change detection method with radiometric normalization and shadows removal *(Mena and Malpica 2011)* [37]
8. Change detection in VHR images using contextual information and support vector machines *(Volpi, Tuia, Bovolo, Kanevski, Bruzzone 2011)* [38]
9. Probabilistic Change Detection for Analyzing Settlement Dynamics *(Vatsavai and Graesser 2012)* [15]
10. Sequential Statistical Change Detection *(Lingg 2012)* [39]
11. Comprehensive Change Detection Method (CCDM) *(Jin, Yang, Danielson, Homer and Fry 2013)* [40]
   a). Multi-Index Integrated Change Analysis (MIICA)
   b). Zone

These techniques are detailed in Table 6.

4. SOFT COMPUTING APPROACHES TOWARDS CHANGE DETECTION

Soft computing is a practice that tolerates uncertainty and imprecision in the process of decision making and computing, which are principal components in real life situations. This maps the working of human brain more suitably to the problem in hand [41]. The basic methodologies of soft computing incorporate fuzzy logic, evolutionary computing and neural networks. These techniques are not isolated but mutually cooperative [42].

Soft computing techniques have been applied to many areas but are still to be deeply explored in the processing of remotely sensed images and data. Here the authors summarize existing work on image change detection performed using soft computing approaches.

4.1 Fuzzy Logic Approach

In soft computing a fuzzy logic scheme integrates numeric as well as linguistic data. It maps crisp vector input to a crisp scalar output. By the usage of fuzzy logic and fuzzy sets, various engineering and mathematical problems can be approximated closer to actual solutions [43]. Here

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some of the change detection methods using fuzzy logic are given.

1. Fuzzy-based logic and mathematical morphology for detection spatial changes in urban areas (Maupin, Quere, Desjardins, Mouchot, St-Onge and Solaiman 1997) [44]
2. An interactive fuzzy fusion system applied to change detection in SAR images (Bujor, Valet, Trouve, Mauris and Bolon 2002) [45]
3. Fuzzy image classification for advanced change detection (Colditz, Schmidt and Dech 2008) [46]
4. Change detection based on fuzzy Bayes decision rules (Ke, Bao-ming and Ming-xia 2009) [47]
5. Unsupervised image change detection based on 2D fuzzy entropy (Sun, Chen, Tang and Wu 2010) [48]
6. Algorithms based on fuzzy clustering (Ghosh, Mishra and Ghosh 2010) [36]
    a). Hard c-means (HCM) clustering
    b). Fuzzy clustering
        i).Fuzzy c-means clustering (FCM)
        ii).Gustafson–Kessel clustering (GKC)
7. Fuzzy clustering and image fusion for change detection in SAR images (Gong, Zhou and Ma 2012) [49]

These techniques are detailed in Table 7.

4.2 Neural Network Approach

A neural network refers to a set of identical processing units, each having some internal factors known as weights. Non linear controller problems can be efficiently solved using such systems. It mimics the working of human brain and nervous system [50]. Following are the methods that have applied to solve change detection problem using neural network.

1. An artificial neural network for detecting changes between images over highly variable regions (Feldberg, Netanyahu, Shoshany and Cohen 2001) [51]
2. A Hopfield neural network for change detection (Pajares 2006) [52]
3. Unsupervised change detection in images using one-dimensional self-organizing feature map neural network (Patra, Ghosh and Ghosh 2006) [53]
4. A neural network design for change detection from multi-spectral satellite images (Pacifici, Frate, Solimini and Emery 2007) [54]
5. Context sensitive unsupervised change detection based on Hopfield-type neural network (Ghosh, Bruzzone, Patra, Bovolo and Ghosh 2007) [55]
6. Context-sensitive change detection in images using modified self-organizing feature map neural network (Ghosh, Patra and Ghosh 2008) [56]
7. Pulse-coupled neural networks for high resolution change detection in urban regions (Pacifici, Frate, and Emery 2009) [57]
8. Aggregated Pulse Coupled and Hopfield networks for detecting changes in remotely sensed images (Santos, Castaneda and Yanez 2012) [58]
9. Automatic change detection in suburban areas from SAR images using multiple neural network models (Pratola, Frate, Schiavon and Solini 2013) [59]

These techniques are detailed in Table 8.

4.3 Evolutionary Computing Approach

Evolutionary computing uses principal of natural selection and evolution. It uses a population of individual elements that performs optimization using certain objective functions that help select the best individuals which are carried forward for the further computation. This mechanism helps search large and complex solution spaces which would otherwise be difficult to search using traditional algorithms [60]. The major techniques in this category include Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) and Bee Colony Optimization (BCO). Some of the evolutionary and swarm based approaches to change detection are given.

1. Swarm intelligent algorithm (hybrid ACO/PSO) based change detection of remotely sensed images (Dai, Liu and Liu 2010) [61]
2. Genetic Algorithm based Change Detection on High Resolution Images in an Object-Oriented approach (Tang, Huang, Muramatsu and Zhang 2010) [7]
3. Genetic Algorithm and Gaussian mixture model for detecting changes (Celik 2010) [62]
4. Genetic Algorithm for change detection in Satellite images (Celik 2010) [63]
5. Change detection using multi-objective cost function optimization by Genetic Algorithm (Celik and Yetgin 2011) [64]

These techniques are detailed in Table 9.

5. SCOPE FOR FUTURE RESEARCH

Detecting changes is an evolving field which has a wide range of applications in various areas. Hence it promises to be an exciting area for further research. With the advancement in technology, use of better and more powerful cameras and imaging techniques are in emergence, which leads to

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acquisition of more detailed and high resolution images. This requires development of new and more efficient techniques that can effectively detect changes with minimal errors and false alarms. This work has tried to provide an extensive and up-to-date reference about change detection and existing work on it. It has also tried to contribute towards providing a clear idea about the available techniques, which can help anyone going for change detection to select the best technique as per their aims and type of data available, among the widely available mechanisms. Future work can be done in the field of improving the existing techniques and devising new and more efficient techniques to detect changes in different kinds of input images. As new imaging techniques develop, it opens up the scope for developing fresh techniques applicable for such images as well.

6. CONCLUSION

In this paper the authors analyze the various traditional and modern techniques that have been proposed and implemented for change detection in images. Selecting the best technique for a particular project is always a challenging task owing to varying nature of images, environmental conditions, lighting and angle of image capturing, accuracy requirements, etc. Hence a good judgment is required to select a suitable method depending on the project in hand. This paper can prove handy for aiding in proper selection of technique to be used as per the specifications of problem in hand. On the other hand, due to vast domain of the field, this paper has been unable to deal in more detail with the individual methods or provide comparisons among them. Such points can be dealt with in more detail in future survey work.

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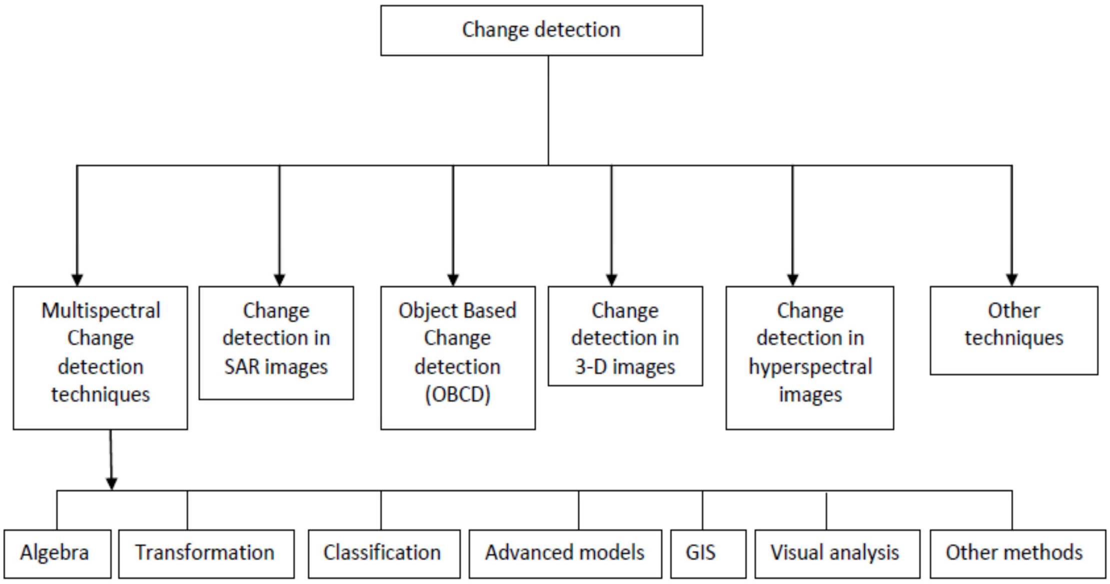

Figure 1:Classification of Change Detection Techniques

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Table 1: Multispectral Change Detection Methods

Category	Methods	Characteristics	Advantages	Disadvantages
Algebra	Image differencing, change vector analysis (CVA), image regression, background subtraction techniques and vegetation index differencing	Threshold selection for change determination	Simple, ease to implement and interpret, Detailed change information by CVA	Thresholds selection is difficult
Transformation	Principal Component Analysis (PCA), Chi-square transformations, Gramm–Schmidt (GS), Tasselled cap (KT)	Analyst's skill used for changed component identification	Reduction in data redundancy, emphasis on different information	Fails to provide detailed change matrices, problems in interpretation and managing the change information
Classification	Post-classification comparison, spectral–temporal combined analysis, unsupervised change detection, ANN, hybrid change detection, expectation–maximization algorithm (EM) change detection	Classification of images based on available sample data	Change information matrix, reduction of external impact	Selection of sufficient quality training sample sets is difficult
Advanced models	Li–Strahler reflectance model, biophysical parameter estimation models, spectral mixture models	Conversion of image reflectance values to physical parameters through models	More easy to understand and better to pull out vegetation information	Require more time and complexity to develop suitable models for conversion
GIS	Integrated GIS and remote sensing method, pure GIS method	Overlaying of images and binary masking, GIS layers directly on image data	Capability to integrate data from multiple source into change detection applications	Various source data linked with different data accuracies and formats affect the results
Visual Analysis	Visual interpretation of multi-temporal image composite, on-screen digitizing of changed areas	Uses human experience and knowledge, incorporates Visible features	Analysis of two or three dated images is possible at a time	Requires much time for applications like large-area change detection, difficult in results updation

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Table 2: Change Detection Methods for SAR Images

Authors	Techniques	Characteristics	Advantages
Bovolo and Bruzzone (2005)	Detail-Preserving Scale-Driven Approach	Wavelet-based multiscale decomposition of log-ratio image to achieve scales and change detection by scale-driven adaptive fusion algorithm	Better performance in spatial fidelity and increased accuracy
Carincotte, Derrode, and Bourennane (2006)	Unsupervised Change Detection on SAR Images Using Fuzzy Hidden Markov Chains	Simultaneous use of Dirac and Lebesque probability measures to allow coexistence of hard and fuzzy pixels in one image	Suitable for long term changes detection and allows modification of fuzzy classes characterization
Inglada and Mercier (2006)	The Multi-scale Change Profile: a Statistical Similarity Measure	Local statistics estimation using series expansion and measurement of degree of evolution	Computation of only 4 statistical moments, provides change information over many scales at small cost
Chatelain, Tourneret and Inglada (2008)	Change Detection in Multisensor SAR Images Using Bivariate Gamma Distributions	Uses maximum likelihood principal, inference function and method of moments for estimations	Ability to handle images with different number of looks
Huang (2008)	SAR Image Integration Change Detection	Considers gray difference, correlation coefficient and texture features comparison	Obtains precise detection results and detects whole change by fusing advantages of multiple techniques
Huang, Li and Cai (2009)	Texture features fusion voting (TFFV) algorithm	Analysis of image spatial texture & use of gray-level cooccurrence matrix (GLCM) method	Textural features are considered & influenced of image speckle noise is reduced
Kumar and Garg (2013)	PCA technique involving Singular Value Decomposition Method (SVD)	Uses Singular Value Decomposition (SVD) method & pixel-by-pixel comparison	Easy classification & use of less storage area by converting image into lower dimension

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Table 3: Object Based Change Detection Methods

Authors	Techniques	Characteristics	Advantages
Tanathong, Rudahl, Goldin (2009)	Rectangular building extraction	Knowledge-based intelligence agents & detection of size, structure, spectral & disappearance change	Detection of both small & large size buildings & flexible approach for different resolution images
Miller, Pikaz, Averbuch (2009)	Objects Based Change Detection in a Pair of Gray-Level Images	Connectivity analysis along gray-levels technique to extract blobs & their classification & matching	Extraction of objects appearing in only one two input objects in the presence of noise or illumination differences
Tang, Huang, Muramatsu, Zhang (2010)	Genetic Algorithm based object-oriented method for High-Resolution Images	Multi-resolution segmentation & use of GA to generate optimal binary change detection map	Uses information from high-resolution images exhaustively & avoids classification errors & variance
Liu, Du (2010)	Object-Oriented Change Detection from Multi-Temporal Remotely Sensed Images	Segmentation to create homogeneous objects & overlapping of polygon layers to determine thresholds	Effectively restrains salt & pepper effects
Chen, Hay, Carvalho, Wulder (2012)	(i). Image-object mechanism	Direct comparison of image-objects defined by a threshold	Easy & straighforward
	(ii). Class-object mechanism	Comparison of independently classified objects	Results in the form of change matrix
	(iii). Multitemporal-object mechanism	Temporally sequential images are combined & segmented, producing spatially corresponding change objects	Single segmentation step creates image-objects consistent in shape, size & location
	(iv). Hybrid mechanism	Algorithms involving both object & pixel paradigms	Successful reduction of noisy & spurious changes

Table 4: Change Detection Methods for 3D Images

Authors	Techniques	Characteristics	Advantages
Pollard and Mundy (2007)	3-D image change detection by a 3-D voxel-based model	Maintaining 3D voxel model that stores probability distribution & appearance of image	Quantitatively superior to planar-based model, exhibits good convergence
Taneja, Ballan and Pollefeys (2012)	Detecting geometrical changes in urban locations	Incremental updation of models & exploitation of existing geometry to find inconsistencies	Optimization of model updation process by restriction on acquiring data
Taneja, Ballan and Pollefeys (2013)	City-Scale Change Detection in Cadastral 3D Models	Based on re-projected images & relative alignment among neighbouring images	Deals with geometric inaccuracies & minimizes alignment error

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Table 5: Change Detection in Hyperspectral Images

Authors	Techniques	Characteristics	Advantages
Eismann, Meola and Hardie (2008)	Hyperspectral Change Detection in the Presence of Diurnal and Seasonal Variations	Spectrally segmented linear predictors to accommodate effects of spectral changes	Improvement in clutter suppression & subtle target change detection
Meola (2010)	A Model-Based Approach To Hyperspectral Change Detection	Pixel-based comparison & use of information over statistics for improved detection	Allows for differences in signal measures arising out of illumination changes
Wu, Du and Zhang (2013)	A Subspace-Based Change Detection Method for Hyperspectral Images	Measurement of spectral changes using neighbourhood spatial data & spectral data of undesired types	Reduction in false alarms & suppressing changes of undesired land-use types

Table 6: Other Change Detection Techniques

Authors	Techniques	Characteristics	Advantages
P´ecot and Kervrann (2007)	Patch-Based Markov Models for Change Detection	Regularization of difference image using Markov random fields framework	Robust to lower signal-to-noise ratio, lower false alarm rates
Robin, Moisan and H´egarat-Mascle (2009)	An a-contrario approach for sub-pixel change detection	Probabilistic criteria determining coherence level of images & stochastic algorithm selecting domains containing likely changes	Improves robustness & avoids inter-calibration problems
Benedek, Descombes and Zerubia (2009)	Building Extraction and Change Detection in a Joint Stochastic Approach	Inverse modelling approach & optimization merged in a probabilistic framework	Good convergence & high modularity, easily adapted to different applications
Alberga (2009)	Similarity Measures of Remotely Sensed Multi-Sensor Images for Change Detection	Alternative procedure using similarity measure & use of coregistration methods for change detection	Permits complementary data to be exploited & helps estimate dissimilarity between images
Ghosh, Mishra and Ghosh (2010)	Fuzzy clustering algorithms	Fuzzy clustering approach for spatial correlation between surrounding pixels & its optimization	Less time consuming, no need of prior knowledge of pixel distribution
Bovolo and Bruzzone (2010)	A Split-Based Approach to Change Detection in Large-Size Images	Splitting of large images, their adaptive analysis & automated threshold selection	Efficient small changed area detection, less computation time
Mena and Malpica (2011)	A change detection method with radiometric normalization and shadows removal	Normalization of multivariable distribution followed by PCA & shadows removal	Independent of image format, no need of thresholding, simpler than most other methods
Volpi, Tuia, Bovolo, Kanevski, Bruzzone (2011)	Change detection in VHR images using contextual information and support vector machines	Includes contextual & spatial information from morphology & local textures & non-linear classification	Ease of class separation, reduction in noise, improved spatial coherence

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Vatsavai and Graesser (2012)	Probabilistic Change Detection for Analyzing Settlement Dynamics	Grid-based probabilistic approach & clustering to represent degrees of change	Comprehensive information about change, minimal post-detection thresholding
Lingg (2012)	Sequential Statistical Change Detection	Two-pass process taking multiple images for each pass, statistical characterization of signal exploitation problems	Inclusion of registration uncertainty data, detection against common reference configurations simultaneously
Jin, Yang, Danielson, Homer and Fry (2013)	Comprehensive Change Detection Method (CCDM)	Integration of spectral algorithms & use of knowledge-based system to combine changes from these algorithms	Ease of operation, wide application & capability to capture various disturbances occurring in nature

Table 7: Fuzzy Logic Approaches to Change Detection

Authors	Techniques	Characteristics	Advantages
Maupin, Quere, Desjardins, Mouchot, St-Onge and Solaiman (1997)	Mathematical morphology and fuzzy logic to detect spatial change in urban area	Topology used to analyze grayscale images and use of morphology and fuzzy systems for spatial changes detection	Successful detection with good results providing a solid base for further research
Bujor, Valet, Trouve, Mauris and bolon (2002)	An interactive fuzzy fusion system applied to change detection in SAR images	Fuzzy based fusion of characteristics found from images with apriori map information and linguistic detailing of attributes	A generic approach providing an interface for linguistic parameter adjustment and internal numerical features handling
Colditz, Schmidt and Dech (2008)	Fuzzy image classification for advanced changed detection	Fuzzy classification through bagging and decision tree and presenting of map agreement from confidence of classification	Useful for large spatial changes and advanced change detection methods
Ke, Bao-ming and Ming-xia (2009)	Change detection based on fuzzy Bayes decision rules	Parameter updating dynamically and conversion of probability function to find unchanged pixels	Better precision of results and avoidance of hard plot
Sun, Chen, Tang and Wu (2010)	Unsupervised image change detection based on 2D fuzzy entropy	Fisher criteria employed to find average gray levels and use of best segmented 2-D histogram to generate fuzzy membership function	Dominant performance and good distinction between noises and edge pixels
Ghosh, Mishra and Ghosh (2010)	Algorithms based on fuzzy clustering	Fuzzy clustering approach for spatial correlation between surrounding pixels & its optimization	Less time consuming, no need of prior knowledge of pixel distribution
Gong, Zhou and Ma (2012)	Fuzzy clustering and image fusion for change detection in SAR images	Fusion method generated difference image that is clustered by fuzzy c-means	Low error rate and reduced speckle noise, better incorporation of local data than previous methods

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Table 8: Neural Network Approaches to Change Detection

Authors	Techniques	Characteristics	Advantages
Feldberg, Netanyahu, Shoshany and Cohen (2001)	An artificial neural network for detecting changes between images over highly variable regions	A flexible backpropagation neural network is used that divides study areas into four different identification classes	More accuracy over traditional methods and better performance than alternate classifier techniques in many cases
Pajares (2006)	A Hopfield neural network for change detection	Customised Hopfield network based relaxation of optimization and use of energy function for stable convergence	Allows for balance between own criteria and neighbouring pixels information, minimizes errors from inaccurate decisions
Patra, Ghosh and Ghosh (2006)	Unsupervised change detection in images using one-dimensional self-organizing feature map (SOFM) neural network	Clustering by SOFM used to distinguish changed and unchanged areas within the difference image	No need of assuming of distribution of classes explicitly, results as effective as previously existing techniques
Pacifici, Frate, Solimini and Emery (2007)	A neural network design for change detection from multi-spectral satellite images	Neural network based approach for parallel exploration of multi-temporal and multi-band data	Flexibility and higher accuracy factor, better filtering of false alarms
Ghosh, Bruzzone, Patra, Bovolo and Ghosh (2007)	Context sensitive unsupervised change detection based on Hopfield-type neural network	Hopfield network for spatial relation between adjoining pixels of difference image along with a heuristic process of thresholding	Free of distribution and doesn't require parameter setting, fast convergence
Ghosh, Patra and Ghosh (2008)	Context-sensitive change detection in images using modified self-organizing feature map neural network	Modified SOFM neural network whose output neurons give a change detection map on converging	Distribution free and automatic, better performance over existing technique in less time
Pacifici, Frate, and Emery (2009)	Pulse-coupled neural networks for high resolution change detection in urban regions	Generation of scene signatures from waves using pulse-coupled networks on images and their comparison for change detection	Faster, automated, doesn't require preprocessing or individual pixel comparing
Santos, Castaneda and Yanez (2012)	Aggregated Pulse Coupled and Hopfield networks for detecting changes in remotely sensed images	Hopfield network for reconstructing images and pulse-coupled network for change detection with high precision by detecting targets, segmenting and classifying	Developed reconstructing and diversity in change detection in an innovative manner
Pratola, Frate, Schiavon and Solini (2013)	Automatic change detection in suburban areas from SAR images using multiple neural network models	Combination of pulse-coupled and perceptron networks of multiple layers to detect changes automatically in SAR images	Robust towards coregistration faults, less false alarms, faster and completely automatic

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Table 9: Evolutionary Computing Approaches to Change Detection

Authors	Techniques	Characteristics	Advantages
Dai, Liu and Liu (2010)	Swarm intelligent algorithm based change detection of remotely sensed images	Use of swarm algorithms to construct rules of change that are used for data processing based on Bayesian model for networks	Good results and efficient mechanism having the merits of cooperation, intelligence, organization and communication
Tang, Huang, Muramatsu, Zhang (2010)	Genetic Algorithm based Change Detection on High Resolution Images in an Object-Oriented approach	Multi-resolution segmentation & use of GA to generate optimal binary change detection map	Uses information from high-resolution images exhaustively & avoids classification errors & variance
Celik (2010)	Genetic Algorithm and Gaussian mixture model for detecting changes	GMM with N components and GA-estimated parameters for difference image that is classified and Bayesian rules of inference applied further	Tuning of parameters not required, generic for different image types and completely automated
Celik (2010)	Genetic Algorithm for change detection in Satellite images	Difference image divided into regions whose mean square errors are used in fitness function calculation by GA to find change mask	Consistent over large variations, doesn't require prior assumptions
Celik and Yetgin (2011)	Change detection using multi-objective cost function optimization	Change detection masks generated by GA-based multi-objective cost function that divides image into changed and unchanged regions	No need of difference image computation or assumptions on distribution, hence can be used for optical as well as SAR images