Chapter 1

Introduction

1.1 Remote sensing

Remote sensing (RS) in Earth’s perspective is the process of obtaining information about the Earth’s surface features without being in direct contact with it, but using on-board sensors or camera systems from the satellite platform. The data collected by these sensors are in the form of electromagnetic energy (EM) which are emitted or reflected by the object at different wavelengths depending on its physical properties. In addition to this, objects emit radiation depending on their temperature and emissivity. Every pixel of the digital remote sensing data represents an average value of the EM energy and is recorded as a digital number (DN) ranging from 0 to 255 in 8 bit data format. The recorded energy at different wavelengths follows a pattern which is the characteristic of that object and is known as the spectral signature of the object or class. Proper interpretation of the spectral signature leads to the identification of the object and further extraction of information in RS.

During the past few decades, the majority of remote sensing work has been focused only on natural environments as the availability of data was restricted to low and medium resolution images. Today, the advent of high resolution imagery driven by technological advances and societal needs has made urban remote sensing a field of utmost interest among the RS community in the context of urban land use/land cover (LU/LC) classification and change detection. To be more precise, the new generation satellite-borne instruments provide higher spatial and spectral resolution with a synoptic view and repetitive global coverage to detect changes on the Earth’s surface. Consequently, the power of the computational machines and advancements in data analysis together have made remote sensing a better alternative to traditional methods of monitoring and management of natural resources and cultural processes by way of extracting thematic information [1]. The themes may be the type of vegetation, forest cover, water bodies, settlement, etc. which in general refers to various LU/LC classes. Further, the availability of accurate and up-to-date LU/LC information is central to many resource management and planning, and monitoring programmes. However, the classification of higher spatial resolution data, particularly of urban or semi-urban area, poses a challenge to the analysts...
due to certain limitations inherent to the classification algorithms and the methodologies which are traditionally being used. The low accuracy of LU/ LC classification in urban areas is largely attributed to the mixed pixel problem, where single pixel comprising of several types of LU/ LC information makes it difficult to classify a pixel as belonging to only one class. The mixed pixel problem is caused from the fact that the scale of observation (i.e., pixel resolution) fails to correspond to the spatial characteristics of the target [2]. One of the remedies to circumvent this problem is to go for higher spatial resolution data. On the other hand, when the spatial resolution of the satellite imagery is increased, the higher within-class variability reduces the statistical separability between the LU/ LC classes in spectral space and tends to continue diminishing classification accuracy of the traditional classifiers which are mostly per-pixel and parametric in nature. Paul Mather remarked that it is rare to have achieved the classification accuracy of greater than 80% over urban features using per-pixel classification algorithms [2], and it is also found to be true from the studies carried out by Maria Irene [43] and Dengsheng and Weng [70]. Another major drawback of the commonly employed parametric classifiers lies in the difficulty of integrating spectral data with ancillary data. In fact, the finer the spatial details provided by the high-resolution imagery, the larger the amount of information available thereof. This desperately forces the user to identify a large number of objects or classes that are present in the area ignoring their significance and requirement, which may also cast a negative impact on the performance of the classifier.

Besides, the selection of a proper image fusion technique is also crucial in classification. Literature on remote sensing discusses various types of parameter selection criteria and indices for feature extraction, feature selection, and techniques for evaluating image quality and performance of the classifier. Unless a critical study of the above mentioned criteria or indices is made in respect of reliability and relevancy to the context, their non-rational way of adoption would adversely affect the performance of even the best classifier. Hence, improving classification accuracy of the remote sensing data has always been an important concern to extract the real world situation in the form of thematic maps. A similar conclusion is also drawn in literature [3], [4], [5], [6], [7], [8], [9]. Consequently, today, the modalities and techniques of RS data acquisition, processing and interpretation are attracting a large group of research community and receiving extensive contributions from disciplines, viz. solid state electronics, optics and physics, pattern recognition, artificial intelligence, data mining, computer vision, image processing, statistical analysis and geographical information system (GIS).
1.2 Classification and related constraints

Digital image classification is one of the most often used quantitative data analysis and information extraction techniques in remote sensing. It can be primarily grouped into three categories: image rectification and restoration, enhancement, and information extraction which involves classification. The on-board remote sensor acquires a response which is based on many characteristics of the land surface including natural or artificial cover. Unless, the raw data is converted into a thematic data and analysed, the usefulness of the data is uncertain. The conversion of an image data into a thematic map is accomplished through a process called classification. In general, classification of RS image can be seen as an iterative process in which categorisation and classification of spectral measurements taken from satellite sensors into various LU/LC features on land surface are made by generating digital thematic map. Here, the concepts concerning LU/LC activity are closely related and in many cases they have been used interchangeably. Land cover describes ‘the vegetational and artificial constructions covering the land surface’ [10]; cited by [11], i.e., the features physically present on the Earth’s surface, such as grass, water, concrete, bare soil, etc. Land use, on the other hand, indicates the type of human socio-economic activity on a particular land area; the examples are: residential area, commercial area, industrial area, etc. Land use is more difficult to identify directly from the RS images; mostly it is derived indirectly from the land covers recognised in the RS data. It is inferred from the literature [11], [12] that using satellite data for classification of LU/LC has a long history of about 35 years. Since then various classification algorithms and methodologies have been evolved to make the classification of LU/LC features more reliable and accurate for the following reasons.

The classifiers are grouped into supervised and unsupervised classifiers based on the training process; parametric (statistical) and non-parametric (non-statistical) classifiers based on their theoretical modeling considering the type of distribution of data; soft and hard classifiers based on the degree of membership of a pixel belonging to the classes. The various classification algorithms evolved so far can be summarised as ISODATA, parallelepiped, minimum distance-to-means, maximum likelihood classifier, Bayesian classifier, decision tree, artificial neural network (ANN) based back-propagation (BP) learning algorithm, support vector machines, fuzzy and neuro-fuzzy classifiers, etc. It is appropriate to recall that the ultimate goal in classification techniques is to best exploit primarily the spectral, spatial and temporal resolutions of the data and other inherent characteristics, as observed in microwave data (E.g. SAR), like multi-polarisation, multi-frequency and multi-incident angle signature [1], [177], to make classification more
reliable and accurate. To achieve the above goal, the interpreter constantly uses patterns, tones, textures, shapes, size and, site and class associations to derive information about the land use activities and identify various objects present in the images. The extraction of textures and tones leads to texture-based approach in classification. The application of shape information into classification has developed segmentation and hierarchical classification techniques, whilst the association has introduced context-based classification techniques. Moreover, the class discrimination capability of the classifier can also be enhanced by introducing ancillary data, texture features, segmentation and contextual information. Hence, the whole of the digital image classification process is constantly trying to exploit the potentials of advanced classification algorithms and techniques of digital image processing to make classification more reliable.

A good number of literature mentions that attempts of classifying high-resolution satellite data with traditional computer classification techniques (also called hard classification) show limited success since the existing traditional hard classification algorithms are parametric in nature and examine only the spectral variance ignoring the spatial distribution of the pixels corresponding to LU/ LC classes. Since, ISODATA is an unsupervised algorithm; parallelepiped is order dependent; minimum distance-to-means, maximum likelihood classifier and Bayesian classifier are parametric in nature, they show limited success on spectrally overlapping features. Another major concern in classification is the learning and classification speed of the algorithm. Nonetheless, the support vector machines and artificial neural networks exhibit relatively higher learning accuracy; their practical employability is not encouraging since both are very slow in training and learning phase. In the above circumstances, the decision tree classification algorithm is found to be very attractive on account of its shorter learning and classification time. The other factors which make the decision tree classifiers so popular are that the construction of the classifier does not require any domain knowledge or parameter setting. Moreover, they have no assumptions about the distribution of data and hence called non-parametric classifiers. The most important advantage of the decision tree is the explanation capability by extracting classification rules directly from the tree [13]. Further, such rule based approaches are very flexible in handling high-dimensional data and large size datasets that may have errors and/ or have missing values [14]. Literature survey also indicates that texture information [5], [6], [8], [9], [15], [16], [17], surface temperature [6], digital elevation models (DEM) [18], etc., have been studied as ancillary data in the classification of images acquired by various remote sensing sensors. Among the several types of ancillary data, the grey-level co-occurrence matrix (GLCM) based texture statistics derived from the image data are reported to be performing satisfactorily in RS classification [15], [19].
1.3 The present study

As mentioned earlier, the ultimate goal in all classification techniques is to best exploit the spectral, spatial, temporal resolutions and polarisation signature of the data and other inherent characteristics associated with it, and devise classification techniques which show improvements in accuracy, stability and speed. The motivation behind this work is the fact that accurate classification of RS data into various LU/LC information is a prerequisite and indispensable issue in the efficient monitoring and management of natural resources and quick delivery of the end products. But it seems that the present traditional approach of classification fails to make the best use of the rich data available through the advanced sensor systems and cripples in taking advantage of the capabilities of today’s high speed computational machines. The performance of the classifier also varies from sensor to sensor in respect of its spectral and spatial resolution; from class hierarchy levels to type of study area in respect of distribution of various LU/LC features; and from data pre-processing to size of the training data and data dimensionality. Anderson et al. [11], in 1976 itself, opined that there is no single ideal classification approach for LU/LC, and it is unlikely that one could ever be developed. Because, there are different perspectives in the classification process, and the process itself tends to be subjective even when an objective numerical approach is used.

In the above context, the current research work is primarily aimed at developing an efficient and reliable classification strategy by integrating advanced image processing techniques and non-parametric classification algorithm to facilitate improving classification accuracy of high spatial resolution RS data over semi-urban LU/LC features. In this regard, a decision tree classification algorithm to learn and classify data, effectiveness of ancillary data in decision tree classification, and image texture analysis for characterising the spatial variations within imagery as a means of extracting information form the basis of this research work. The related studies are carried out on a high resolution multi-spectral satellite data of 2.5m spatial resolution

The results and discussion of this research work hopes to pave way for further development of more reliable and accurate classification models for land feature classification using decision tree classifier and texture-based approach. It is also believed that the outcome of the work would greatly help the planning and resource managing agencies in their studies and development of newer classification methodologies.
1.4 Organisation of the thesis

This thesis is structured in seven chapters. Chapter 1 provides a brief introduction to remote sensing and classification. The motivation and aim of the research work have also been spelt briefly in this chapter.

Chapter 2 reviews the literature related to various data fusion techniques, feature selection criteria, classification algorithms and integration of ancillary data with emphasis on classification of urban/semi-urban LU/LC features. The chapter also discusses the metrics used for the quantitative assessment of fused images and classification accuracy.

Chapter 3 presents the decision tree classification algorithm that is being studied and outlined along with design approaches and the factors affecting its performance. The chapter also provides fair information about the GLCM based texture measures and the parameters affecting texture feature extraction which are under investigation in the present work.

Chapter 4 gives greater insight into the problem formulation, aim and objective of the present research work.

Chapter 5 focuses on the framework developed for the entire study with detailed description about the methodologies adopted to meet the objectives. Description is also provided on the study area, the data products and some data pre-processing techniques required for this work.

Chapter 6 discusses the experimental results obtained from the studies and investigations carried out in the present work. The performance of the classifications are compared qualitatively (visual assessment) and quantitatively (accuracy assessment). The results of data fusion, the performance comparison of decision tree and maximum likelihood classification algorithms, and the classifiers’ performance at different class hierarchy levels are also discussed. Outcome of the investigations conducted on integrating texture features into multi-spectral bands in classification are also presented in this chapter.

Chapter 7 summarises the findings of this research work and draws the major conclusions. This chapter also provides recommendations for future research and developments.