General Formulation of the Problems and Prerequisites
CHAPTER 2

General Formulation of the Problem and Prerequisites

2.0 General Formulation of the Problem

This chapter deals with the general mathematical formulation of the problems investigated in this thesis, prerequisites and usage of software tools needed for the investigation. The thesis comprises of eight chapters and seven models.

Chapter 1 deals with detailed introduction to the topic of research which includes scope, objective and a detailed literature survey.

Chapter 2 discusses the general formulation of the problems, prerequisites and the necessary software tools.

Chapter 3 presents the study of “Analysis and Evaluation of Parametric Classifiers using Multi-Temporal Images in Land Use (LU) and Land Cover (LC) Mapping”. Three parametric classification algorithms viz., Maximum Likelihood, Mahalanobis Distance and Minimum Distance Classifiers are compared and analyzed on two different seasonal images of the same study area. The software tools used for the purpose are ERDAS 8.5 and ArcGIS 9.2. Heggadadevannakote taluk, Karnataka is the area chosen for the study.

Chapter 4 discusses the study of “Decision Tree Classification Model for Land Use and Land Cover Mapping of HD Kote Taluk, Karnataka, India- A Case Study”. Decision tree algorithms used for land cover mapping are evaluated and compared using a remote sensed data. Here multi-spectral IRS-1D/LISS III image is used as the experimental data and the area of the study considered is Heggadadevannakote taluk, Karnataka. Classification accuracy achieved by Decision Tree Classifier are compared with those achieved by the most widely used Maximum Likelihood Classifier. The software tools used for the purpose are ERDAS 8.5, WEKA and ArcGIS 9.2.

Chapter 5 is about the study of “Analysis and Comparative Study of Image Fusion Techniques for Land Use and Land Cover Classification on Anthrasanthe Hobli, Karnataka – A Case Study.”. An attempt has been made to evaluate and test image
fusion techniques applied to Cartostat-I and LISS-IV images towards LU and LC mapping for the study area. **Six image fusion techniques** were tested to evaluate their enhancement capabilities to extract different LU and LC classes; **Principle Component Analysis (PCA), Brovey Transform, Gram Schmidt, Modified-IHS (Intensity, Hue, Saturation) method, Wavelet-PCA and Wavelet-HIS techniques** are tested and subjected to visual and statistical comparison for evaluation. The software tools used for the purpose are ERDAS 8.5, ENVI 5.0 and ArcGIS 9.2. Anthrasanthe Hobli, Heggadadevannakote Taluk, Mysore District, Karnataka is the area chosen for study.

**Chapter 6** comprises of three models studies. **Model 1** discusses “**Land Use and Land Cover Mapping using Remote Sensing and GIS Techniques**”. The present study analyzes the dynamics of LU/LC using modern geospatial techniques of Remote Sensing and GIS on Kasaba Hobli, Hoskote taluk, Bangalore District, India. The seasonal data of IRS-IC LISS-III images of the year 2005 and data collected from field visits are used to analyze the dynamics of LU / LC of the above area. ERDAS 8.5 and ArcGIS softwares were used for classification of LU/LC.

**Model 2** deals with the study of “**Assessing Horizontal Accuracy of Digitized Cadastral Map using Ground Control Points**”. The study is focused to assess the horizontal accuracy of digitized updated cadastral map using Quickbird and pansharpened Cartostat-I images by comparing the image co-ordinates with GCPs, used as reference data. The detailed analysis is done for Vabasandhra village.

**Model 3** discusses the study of “**Morphometric Analysis and Runoff Estimation for Kodasige micro watershed of Taraka watershed, Heggadadevanna Kote Taluk using Remote sensing and GIS techniques – A Case Study**”. Morphometric analysis is carried out to estimate morphometric parameters to understand the hydrological response of the catchment at the micro-watershed level. Morphometric analysis and run off estimation has been carried out on 18.78 sq km area in the Kodasige micro watershed. The software tools used for the purpose are ERDAS 8.5 and ArcGIS 9.2.

**Chapter 7** is the study of “**Analysis of Land Use and Land Cover Change and Urban Sprawl of Tumkur Hobli, Karnataka, India using RS and GIS Techniques : A Case Study**”. The present study deals with the LU and LC mapping
and monitoring of Tumkur Hobli, Karnataka, India using 2000, 2005 and 2011 LISS-III images, Google map of 2014, Survey of India (SOI) topographical map coupled with field check. Changes in the LU and LC classes over a period of ten years are analyzed. Urban sprawl has been measured using Shannon Entropy approach to describe the dispersion of land development or sprawl. The software tools used for the purpose are ERDAS 8.5, ENVI 5.0 and ArcGIS 9.2.

Chapter 8: Finally provides the general discussion about the results obtained in chapters 3-7. It also provides a structural flow of the thesis and relevance, importance, justification of the results are discussed in detail along with a brief discussion about the future work. Finally a detailed bibliography pertaining to the thesis is appended.

2.1 Prerequisites

The prerequisites for the present investigation are the algorithms like Maximum Likelihood, MaHalanobis Distance and Minimum Distance, namely J48, BFtree, REPTree and Simple cart, Modified-IHS fusion, PCA- Principle Component Analysis, Gram Schmidt fusion, Brovery Transform fusion, Wavelet - PCA fusion and Wavelet - IHS fusion. The salient features and related concepts of these algorithms are discussed in respective chapters.

2.2 Tools used in the Present Investigation are

In this section, a brief description of the software tools used are discussed.

2.2.1 ERDAS Imagine

Earth Resources Data Analysis System: ERDAS IMAGINE® is the world's leading remote sensing solution providing tool to create, manage and analyze satellite image related applications. ERDAS Imagine is raster based software that is specifically designed for information extraction from images. The product suite of ERDAS is designed to consist of three products for geographic imaging, remote sensing and GIS applications. The functions embedded involve importing, viewing, altering and analyzing both raster and vector data sets. This software is capable of handling an unlimited number of bands of image data in a single file. These bands imported into ERDAS IMAGINE are often treated as layers. Additional layers can be created and
added to the existing image file. It allows users to import a wide variety of remotely sensed imagery from satellite and aerial platforms. It is having advanced image processing, comparison and classification capabilities. The satellite image related tasks are done in this software i.e. image processing, enhancement, classification, etc. Its major product Imagine, a suite of comprehensive and sophisticated tools for digital analysis of remotely sensed data. ERDAS Imagine is offered at three levels, Essentials, Advantage, and Professional. Imagine Essentials encompasses a set of powerful tools for manipulating geographic and imagery data, such as image geo-referencing, visualization, and map output.

**Key features** of ERDAS Imagine are: **Image analysis, Remote sensing, and GIS**, Support for optical panchromatic, Multispectral and Hyperspectral imagery, radar and LiDAR data, User-friendly ribbon interface, Multi-core and distributed processing, Spatial modeling with raster and vector, operators, as well as real-time results preview, High-performance terrain preparation and mosaicking, change detection tools, ERDAS ER Mapper algorithm support, Ability to convert more than 190 image formats into all major file formats, including GeoTIFF, NITF, CADRG, JPEG, JPEG2000, ECW, and MrSID, Comprehensive OGC Web Services, including Web Processing Service, Web Coverage Service, Web Mapping Service and Catalog Services for the Web. ERDAS is used for GIS Integration, Geometric Correction, Image Orthorectification, Multispectral Classification, Image Interpretation, Image Analysis, Image Mosaicking, Digital Terrain Modeling and Map Production.

**Image Display and Output:** ERDAS Imagine has a versatile and flexible capability in image display. Single and multiple (at most three) bands are displayed in grayscale or as a color composite. Multispectral bands can be displayed simultaneously in multiple viewers. The displayed image may be panned or zoomed at will through appropriate buttons in the toolbar. Special facilities are provided for locating a particular point on the displayed image via its coordinates, expressed as row/column or easting/northing, depending on the geometric properties of the image. In addition, multiple images can be displayed on top of each other in the same viewer. Special tools (e.g., swipe) are available for viewing a portion of the top image and the bottom image simultaneously. Vector layers may be displayed on top of the displayed raster
imagery. The displayed image can be queried and processed results may be output using the Composer module that allows an image to be added to an empty map. Other cartographic elements such as legend, scale bar, and north arrow can all be added to it. The composed map may be saved in a number of formats. However, it is very difficult to produce a perfect map composition using ERDAS Composer because of its limited range of fonts.

**Data Preparation:** More than 130 image formats, even non-remote sensing DEM data, are recognizable by ERDAS Imagine. Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER), Indian Remote Sensing (IRS), Thematic Mapper (TM), and Advanced Very High Resolution Radiometer (AVHRR) data can be read directly into the system. In addition, images saved in all major graphic formats can be imported from and exported to other systems. Furthermore, ERDAS Imagine also supports some vector file formats such as ESRI shape files, and vector coverages. With ERDAS data preparation functions, it is possible to project an image to a specified new coordinate system, or geometrically rectify it using polynomial, rubber sheeting, or a predefined model for IKONOS and SPOT imagery. It is also possible to import/export cut lines, and smooth images along cut lines, and to balance imagery’s color using dodging in Imagine.

**Image Enhancement:** All kinds of image enhancement, be it radiometric, spatial, or spectral, are performed under Imagine Interpreter. Radiometric correction refers to the removal of atmospheric effects (e.g., haze) from the input image so that its pixel values correspond closely to the reflectance of targets on the Earth’s surface. Radiometric enhancement includes contrast enhancement, haze and noise removal, inversion of brightness, and de-stripping (for TM imagery only). Contrast of an image may be enhanced through a look-up table and histogram based manipulation (e.g., histogram equalization and histogram matching). Image enhancement in the spatial domain includes texture analysis, focal analysis, and image convolution. Spectral enhancements may be carried out via principal component analysis, Fourier analysis, image transformation from hue-intensity-saturation to red-green-blue or vice versa, and image indexing. With version 9.1, it is possible to pan-sharpen low resolution multispectral bands with a finer resolution panchromatic band. The quality of the sharpened image may be improved via a two-pass filtering option.
Specific tools (e.g., band normalization, spectrum averaging, profiling, spectral library, and so on) have been developed to handle hyper-spectral data. Also found in the Interpreter module are two analytical functions for both remote sensing and non-remote sensing data: GIS analysis and topographic analysis. Some GIS functions (e.g., clumping and sieving) are essential in performing post classification processing such as spatial filtering and thematic generalization.

**Image Classification:** ERDAS Imagine supports both unsupervised and supervised classification. The unsupervised classification algorithm is called Iterative Self-organizing Data Analysis Technique (ISODATA). Images may be classified using one of the four supervised methods: Parallelepiped, Minimum Distance, Maximum Likelihood and Mahalanobis. Special tools are available for selection of training samples and for analyzing their separability. Unique to ERDAS Imagine is its Knowledge Classifier that allows multiple decision rules to be combined logically to deduce the likely identity of a pixel in question. These rules are contained in a knowledge base that is created via the Knowledge Engine. All classified results may be assessed for their accuracy using the accuracy assessment routine. This tool enables evaluation pixels to be selected either randomly or via a combination of random with stratified sampling. Once the true identity of all evaluation pixels is specified, indices such as overall accuracy and Kappa are then generated automatically. The subpixel classifier module in Imagine is designed to classify images at the subpixel level. With this module it is possible to identify ground features that occupy a fraction of a pixel, or to discriminate materials with similar spectral characteristics.

**Spatial Modeler:** The flexibility and efficiency of undertaking image analysis in ERDAS Imagine is considerably improved with the use of Spatial Modeler. In this environment repetitive and complex image analysis operations are lumped together sequentially to form a deliberately built model. This complex image analysis model may be constructed from a number of fundamental built-in functions in a pick-and-mix manner using an internal modeling language without the user having to possess any programming knowledge. After a model is constructed, the analyst just needs to modify the names of import and output files in the first and last building blocks while the system sets the import and output file names in all other blocks in the model automatically. Apart from high efficiency, another added advantage of using Spatial Modeler is the disappearance of the necessity to save a huge amount of intermediate results.
**Radar**: Contained in the Radar toolbox is a suite of functions designed to process radar imagery specifically. Some of the key functions in this module are Interpreter, IFSAR, StereoSAR, and OrthoRadar, the last three being add-on modules. The Radar Interpreter module is able to perform many analyses on Synthetic Aperture Radar (SAR) images, such as speckle removal, texture analysis, image merging, slant range adjustment, radiometric and geometric calibration. A correlating pair of SAR images can then be used to generate DEMs.

**Other Toolboxes**: In addition to the aforementioned modules, ERDAS Imagine contains several more toolboxes (e.g., 3D, Vector, VirtualGIS, AutoSync and DeltaQue) for performing specialized analytical tasks. These add-on modules expand the functionalities of ERDAS to meet special image processing needs, such as radiometric correction, use of vector data, 3D analysis, and visualization. The Vector toolbox is designed to process chiefly vector data that have found increasing use in digital image analysis. Vector data may be subset, mosaicked, copied, and transformed just as with raster data. Stereo Analyst is a toolbox designed specifically to manipulate 3D models, and to collect 3D features and attributes easily and accurately. VirtualGIS is a powerful 3D analysis environment in which topographic data are dynamically visualized as fly-throughs of user defined flight paths in an interactive, real-time fashion. AutoSync is an add-on module for locating and measuring control points for geo-referencing multiple images and for image triangulation. ERDAS Imagine also contains a Developers’ Toolkit that allows the user to modify the commercial version of Imagine, or to develop entirely new applications as extensions, using a set of libraries and documentation. Several packages in the Toolkit support a number of routines, such as abstract object manipulation, file I/O and system access, GUI access, 2D and 3D visualization.

### 2.2.2 ArcGIS

ArcGIS is a software program, used to create, display and analyze geospatial data, developed by Environmental Systems Research Institute (ESRI) of Redlands, California. ArcGIS provides a scalable framework for implementing GIS for a single user or many users on desktops, in servers, over the Web, and in the field. **ArcGIS 9 is an integrated collection of GIS software products for building a complete GIS. It consists of a number of frameworks for deploying GIS:**
• **ArcGIS Desktop**—An integrated suite of professional GIS applications. Most users recognize this as three products: ArcView, ArcEditor, and ArcInfo.

• **Server GIS**—ArcIMS, ArcGIS Server, and ArcGIS Image Server.

• **Mobile GIS**—ArcPad and ArcGIS Mobile for field computing.

• **Developer GIS**—ArcGIS Engine plus software development kits for Desktop, Server, and Mobile that enable software developers to customize and extend the ArcGIS framework.

ArcGIS is based on a common modular component-based library of shared GIS software components called ArcObjects. ArcObjects includes a wide variety of programmable components ranging, from fine-grained objects (for example, individual geometry objects) to coarse-grained objects (for example, a map object to interact with existing ArcMap documents), which aggregate comprehensible GIS functionality for developers. Each of the ArcGIS product architectures built with ArcObjects represents alternative application development containers for GIS software developers, including desktop GIS (ArcGIS Desktop), embedded GIS (ArcGIS Engine), and server GIS (ArcGIS Server).

**ArcGIS consists of three components**: **ArcCatalog, ArcMap and ArcToolbox.** **ArcCatalog** is used for browsing of maps and spatial data, exploring spatial data, viewing and creating metadata, and managing spatial data. **ArcMap** is used for visualizing spatial data, performing spatial analysis, and creating maps to show the results of your work. **ArcToolbox** is an interface for accessing the data conversion and analysis function that come with ArcGIS.

**ArcGIS Desktop** is the framework that provides the user interaction and experience for GIS professionals who use three ESRI software products: ArcView, ArcEditor and ArcInfo.

ArcEditor is a desktop ArcGIS application, which enables the user to create layered maps, perform basic spatial analysis, and consists of a set of advanced tools that are required to manipulate shapefiles and geo-databases. ArcCatalog provides a catalog window that is used to organize and manage spatial and non-spatial data. It functions in a manner similar to Windows Explorer.
The main application in ArcGIS is ArcMap, which is used for all mapping and editing tasks as well as for map-based query and analysis. A map is the most common view for users to work with geographic information. It's the primary application in any GIS to work with geographic information. ArcMap represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text and a symbol legend.

There are two primary map display panels in ArcMap: the data frame and the layout view. The data frame provides a geographic "window", or map frame, in which you can display and work with geographic information as a series of map layers. The layout view provides a page view where map elements (such as the data frame, a scale bar, and a map title) are arranged on a page. For the map created in ArcMap, it will automatically append a file extension (.mxd) to map document name. All the maps composed in ArcMap are saved to an ArcMap document file named with a .mxd extension. Map document files are managed in file system folders and work with an existing .mxd by opening it in Windows. Map layer is saved as a .lyr file in ArcMap. This enables to share layer definitions and display properties with others. In ArcMap, the datasets of the study area, can be displayed, explored, assign symbols and create map layouts for printing or publication. ArcMap is also the application used to create and edit datasets. ArcMap represents geographic information as a collection of layers and other elements in a map. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text, a symbol legend and so on. ArcToolbox contains a comprehensive collection of geo-processing functions, including tools for: Data management, Data conversion, Coverage processing, Vector analysis, Geo-coding and Statistical analysis. ArcToolbox is embedded in ArcCatalog and ArcMap and is available in ArcView, ArcEditor and ArcInfo.

2.2.3 WEKA

WEKA formally called Waikato Environment for Knowledge Analysis. WEKA is widely used for machine learning and data mining that was originally developed at the University of Waikato in New Zealand. It contains a large collection of state-of-the-art machine learning and data mining algorithms written in Java. WEKA contains
tools for regression, classification, clustering, association rules, visualization and data pre-processing. **WEKA has become very popular** with the academic and industrial researchers and is also widely used for teaching purposes. The software is free under GNU GPL 3 for non-commercial purposes. WEKA has had mostly stable popularity over the years, which is mainly due to its user friendliness and the availability of a large number of implemented DM algorithms. It provides an implementation of state-of-the-art machine learning algorithms that we can apply to our datasets for extracting information about the data or we can apply several algorithms to our dataset for comparing their performance and choosing one for prediction. WEKA operates on the predication that the user data is available as a flat file or relation, this means that each data object is described by a fixed number of attributes that usually are of a specific type, normal alpha-numeric or numeric values. The WEKA application allows novice users a tool to identify hidden information from database and file systems with simple to use options and visual interfaces. WEKA presents a collection of algorithms for solving real-world data mining problems. The WEKA workbench contains a collection of visualization tools and algorithms for data analysis and predictive modeling, together with graphical user interfaces for easy access to this functionality. It also provides a number of tools for data preprocessing i.e. transforming datasets and analyzing the resulting classifier. Such tools are called filters. Thus, the main focus of WEKA is on the learning methods and the filters. WEKA offers four options for DM: command-line interface (CLI), Explorer, Experimenter and Knowledge flow (Fig 2.1). The preferred option is the Explorer which allows the definition of data source, data preparation, machine learning algorithms and visualization. The Experimenter is used mainly for comparison of the performance of different algorithms on the same dataset.

**Explorer:** It is the most important graphical user interface in WEKA. **Figure 2.2** shows the explorer interface. It consists of various tabs that are used for different tasks. First tab is the “Preprocess” tab. It is used for loading the datasets and transforming the datasets using filters. As shown in the figure, datasets can be loaded as a file from a URL or from databases using queries. WEKA allows files with specific formats e.g. ARFF, CSV, LibSVM’s format, and C4.5’s format. After data is loaded it can be transformed by using various data preprocessing tools i.e. filters.
Various discretization methods can be used for transforming these datasets or for dividing a dataset into training and testing sets using the appropriate filters.

Next is the “Classify” tab and through this tab we can use various classification and regression algorithms and applied to our preprocessed datasets. Classification algorithms typically produce decision trees or rules, while regression algorithms produce regression curves or regression trees. For a learning algorithm, the classify panel by default, performs cross validation on the dataset that has been prepared in the Preprocess panel to estimate predictive performance. Other than cross-validation, test
set can also be used. In that case, we need to provide a test dataset separately. This panel also enables users to evaluate the resulting models, both numerically through statistical estimation and graphically through visualization of the data and examination of the model. This panel also allows us to visualize classifier errors, margin curve, threshold curve and so on. Moreover, it can visualize prediction errors in scatter plots, and also allows evaluation via ROC curves and other “threshold curves”. Models can also be saved and loaded in this panel. Apart from supervised classification algorithms, WEKA also provides unsupervised algorithms such as clustering and association algorithms. The third tab “Cluster” provides access to the clustering algorithms and the fourth tab “Associate” enables users to access algorithms for learning association rules. In the “Cluster” tab we can run a clustering algorithm on the data that has been loaded in the “Preprocess” panel.

The last two tabs are “Select attributes” and “Visualize”. “Select attributes” tab is used for identifying the most predictive attributes in the data. This tab has a lot of algorithms and evaluation criteria used for identifying the most important attributes in a dataset. It allows the users to access various methods for measuring the utility of attributes and for finding attribute subsets that are predictive of the data. Robustness of the selected attribute set can be validated via a cross-validation-based approach.

Visualize tab is used for analyzing data visually. This presents a color-coded scatter plot matrix and users can then select and enlarge individual plots. It is also possible to zoom in on portions of the data, to retrieve the exact record underlying a particular data point.

Experimenter: “Experimenter” is another interface of WEKA. As stated earlier, it is not possible to have a single machine learning method that works for all learning problems efficiently. Also, there is no way to determine which learning method will work efficiently for a given problem at the beginning. For this purpose, it is better to compare the performance of machine learning methods on various criteria. This interface is used for this purpose. Although, it can also be done interactively in the “Explorer” interface, however “Experimenter” interface automates this process. This makes it easy to run the classification and regression algorithms with different parameter settings on a corpus of datasets, collect performance statistics, and perform significance tests on the results. Experiments can involve multiple algorithms that are
run across multiple datasets; for example, using repeated cross-validation. Experiments can be saved in either XML or binary form. Saved experiments can also be run from the command-line. The Experimenter interface is not used much often by data mining practitioners unlike other WEKA’s interfaces. This interface makes identification of a suitable algorithm for a particular dataset or collection of datasets easier once the initial experiments have been performed in the Explorer.

**Knowledge Flow:** When we load a dataset in the “Explorer” interface, the entire dataset is loaded into the main memory for processing. It means that problems involving large datasets are not suitable for this method. In other words, “Explorer” interface does not allow for incremental learning and is only used for small to medium sized problems. However, some incremental algorithms are implemented that can be used to process very large datasets. One way to apply these is through the command-line interface, which gives access to all features of the system. An alternative, more convenient, approach is to use the second major graphical user interface, called “Knowledge Flow” which enables users to specify a data stream by graphically connecting components representing data sources, preprocessing tools, learning algorithms, evaluation methods and visualization tools. Its data flow model enables incremental updates with processing nodes that can load and preprocess individual instances before feeding them into appropriate incremental learning algorithms. It also provides nodes for visualization and evaluation.

### 2.2.4 ENVI

Produced by Research Systems (now called ITT Visual Information Solutions), ENVI is a comprehensive icon-driven image analysis package designed especially for processing large multispectral and hyperspectral remote sensing data. ENVI provides comprehensive data visualization and analysis for images of any size and any type—all from within an innovative and user-friendly environment.

One of ENVI’s strengths lie in its unique approach to image processing—it combines file-based and band-based techniques with interactive functions. When a data input file is opened, its bands are stored in a list, where they can be accessed by all system functions. If multiple files are opened, bands of disparate data types can be processed as a group. ENVI displays these bands in 8 or 24 bit display windows. ENVI’s display window groups consist of a main Image window, a Zoom window, and a Scroll
window, all of which are re-sizeable. ENVI provides its users with many unique interactive analysis capabilities, accessed from within these windows. ENVI’s multiple dynamic overlay capabilities allow easy comparison of images in multiple displays. Real-time extraction and linked spatial/spectral profiling from multiband and hyperspectral data give users new ways of looking at high-dimensional data. ENVI also provides interactive tools to view and analyze vectors and GIS attributes. Standard capabilities such as contrast stretching and two-dimensional scatter plots are just a few of the interactive functions available to ENVI users.

ENVI’s strong visual interface is complemented by its comprehensive library of processing algorithms. ENVI includes all the basic image processing functions within a friendly, interactive point-and-click graphical user interface (GUI). Because of ENVI’s GUI, many basic processing functions are easier to use. Some of these functions include data transform, filtering, classification, registration and geometric corrections, spectral analysis tools, and radar tools. ENVI does not impose limitations on the number of spectral bands that can be processed, so multi-spectral or hyperspectral data sets can be used. ENVI also includes many advanced functions that allow for analysis of radar data sets ENVI employs a graphical user interface (GUI) in order to select image processing functions. ENVI has many unique features that are presented in four categories below.

**Data Preparation and Display:** ENVI has flexible image display and browsing capabilities. The same raster image may be displayed at various zooming levels in multiple viewing windows, on top of which vector GIS layers and annotation information may be overlaid. Comprehensive vector overlays with GIS attributes can be created, and map and pixel grids added to images. Vector data may be further queried, modified, and analyzed in ENVI. The processed results are presented in map form using map composition utilities. These results can be saved in several popular proprietary image formats (e.g., Imagine, PCI, and ER Mapper) or in generic GeoTIFF.

ENVI can recognize a wide variety of satellite data, such as AVHRR, Landsat Multispectral Scanner (MSS) and TM data, multispectral and hyperspectral OrbView-3 and EnviSat images, and even radar data (e.g., Shuttle Radar Topographic Mission). They may be subset, layer stacked, and segmented. Satellite data may be registered to a map or co-registered with another image based on ground control in the Map module. In addition, ENVI is capable of handling vector data, for example, it can
import from virtually any sources and export to ESRI shape files. Thus, it should not be viewed merely as a system with strong image analysis capabilities, but also as an integrated geospatial data management system.

**Image Enhancement:** The contrast of an image may be stretched linearly with or without truncation in ENVI. It is also possible to stretch the contrast using gaussian or histogram equalization. Displayed image may be filtered (e.g., smoothed and median filtered) or sharpened. Grayscale images can be color coded through standard color tables (e.g., density slicing). ENVI also contains an extensive range of spatial enhancement and general-purpose transform functions, including principal components transform, band ratioing, hue-intensity-saturation transformation, decorrelation stretching, and vegetation indexing. Images can be spatially filtered using convolution kernels for low pass, high pass, median, directional filtering, and edge detection methods. Other special filters such as Sobel, Roberts, dilation, and erosion are also available, along with adaptive filters such as Lee, Frost, Gamma, and Kuan.

**Image Classification and Feature Extraction:** There is a comprehensive set of image classifiers in the Classification toolbox of ENVI. Remotely sensed data may be classified unsupervised (K-means and ISODATA) or supervised (Parallelepiped, Minimum Distance, Maximum Likelihood, and Mahalanobis Distance). Moreover, ENVI offers three non-conventional classifiers: binary encoding, neural network, and Spectral Angle Mapper (SAP). All classified results may be spatially filtered during post classification processing. Post-classification processing includes clump, sieve, combine classes, and an interactive classification display tool, which allow generalization of image-maps prior to export to GIS vector files. Indices of classification accuracy, such as confusion matrix and Kappa coefficient, can all be generated in ENVI. In addition to these classifiers, ENVI also contains image processing functions, including anomaly detection, feature extraction, pan sharpening, and vegetation suppression. Another way of achieving a high level of automation is through the SPEAR toolbox. Its tools are intended for automatic spatial and temporal change detection, pan-sharpening images, and terrain categorization.

**Processing of Hyperspectral and Radar Imagery:** An extensive suite of functions designed specifically for processing hyperspectral data are found in the Spectral
toolbox. Some of these functions are Pixel Purity Index, $n$-Dimensional Visualizer, and Spectral Analyst. A wide range of radar imagery, such as EnviSat, ERS, JERS, Radarsat and Topsar, can be processed in ENVI with a full range of generic or radar-specific methods. Some exemplary routines are antenna pattern correction, slant-to-ground range correction, and generation of incidence angle images. SAR-specific analysis functions include review and reading of header information from CEOS-format data. Other radar image analysis functions include adaptive and texture filters, creation of synthetic color images, and a broad range of polarimetric data analysis methods.

ENVI is written in Interactive Data Language (IDL®), a powerful structured programming language that offers integrated image processing. IDL is required to run ENVI and the flexibility of ENVI is due largely to IDL’s capabilities.