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1. Learning Outcomes

After studying this module you shall be able to:

- understand digital image classification
- understand the need of digital image classification
- learn about various techniques and approaches available for image classification

2. Introduction

The image classification is a procedure, where we categorize the pixels of the satellite data into various land cover classes, known as the information classes. Classification approaches are implemented to distinguish one or more specific classes of terrain, water bodies, fallow land, water logged surface, residential area, paved surfaces, irrigated agriculture etc. within the geographical region as per requirement. The resultant thematic image has a limited number of classes, which may represent the actual land use/land cover classes as opposed to a continuous original image with varying brightness values of the original satellite data, shown in Fig 1.

a. False color composite b. Land Use/Land cover map

Fig 1. Illustration of satellite data and classified image

Thus, the objective of image classification is to identify, the features occurring in an image in terms of type of land cover, present on the ground. The basic assumption of extracting this information is that each object or surface, like water body, agriculture or fallow land has different characteristic reflectance, absorbance, emittance and radiation in the visible, near-infrared, and thermal portions of the electromagnetic spectrum. Thus, the image classification or extraction of information is based on spectral, radiometric and spatial differentiation. In other words, image classification is the process of grouping spectral classes and assigning them informational class names. For example vegetation data reflects the most in near infra-red region. So, to highlight the vegetation the band composite usually employs the near-infra red satellite band along with two visible region bands. Even this, reflectance varies for the crop in different growing seasons as well as for different crop types. For example, a wheat field has distinct color when planted as compared to mature or harvested condition. Healthy plants have a different color than pest-infested or drought-impacted plants. Thus, different features manifest varied inherent spectral reflectance, the bands can be selected which allow maximum separability between any pair of classes. This selection is based on the maximum inter-band correlation and the sum of variance being maximum. Therefore, if two bands are plotted in measurement space, the features may be separated based on localized clusters. The digital image classification for the same region can vary due to radiometric and spatial differentiation. The radiometric differentiation implies the detection of variation in brightness captured by the satellite. It may range from very coarse, $2^2=4$ for a 2-bit image to $2^8= 256$ for 8-bit image. On the other hand, spatial resolution implies understanding or evaluating the potential for mixing of the spectral signatures of multiple objects into the recorded spectral values for a single pixel. For example, a LANDSAT image with a resolution of 30 m, may not be able to distinguish within trees planted within a distance of less than 30m as compared to a satellite data whose spatial resolution may be higher, even upto 5 cm. Thus, during an image analysis, it is important to consider the size of the objects to be discovered or studied compared to the ground sample distance of the sensor.

3. Classification approaches

Satellite image classification methods can be broadly classified into three categories manual, automatic and hybrid. The satellite image can be manually classified through visual interpretation by relying on the shape, size, pattern, tone, texture, shadows, and association. However, the quality of recognition depends on the expertise of analyst and visual perception as the spatial resolution of satellite data is usually coarser (30 m for LANDSAT Thematic mapper). Thus, more and more computer assisted image classification is being conducted, known as the digital image classification or automatic classification, in which the interpretation relies mainly on brightness values, i.e. digital numbers found in different bands of an image. In other word, digital image classification uses the quantitative spectral information contained in either multispectral or hyperspectral image and relate it to the composition or condition of the target surface. Lastly, hybrid approach involves utilization of both manual and automatic classification together. This approach applies automated satellite image classification methods to do initial classification, which is then manually edited to correct the errors of pixel misclassification. It is has been noted that either of the two classification methods, manual and automatic result in pixel misclassification. Therefore, the hybrid approach is usually considered the most appropriate. Hybrid classification takes advantage of both the supervised classification and unsupervised classification as first an unsupervised classification is preformed, then the result is analyzed on the basis of reference data. The same image is again reclassified using a supervised classification with the aid of the statistics of the unsupervised classification as training knowledge. The digital image classification techniques can be further categorized based on the following possibilities

1. Type of learning
2. Number of outputs for each spatial unit
3. Assumption on data distribution

4.1 Type of learning

4.1.1 Supervised classification

In a supervised classification information classes are first identified, which are then used to determine the spectral classes and classify the image for land use/land cover. Information classes implies the actual land cover of the regional area under consideration that is classes, which the analyst wants to be identified like vegetation cover, urban or water bodies. Thus, in a supervised classification, training sites, representative of different surface cover types are identified and are required to formulate the discriminant function based on statistical analysis describing the spectral attributes of each class of interest. The various discriminant methods utilized include:

1. Parallelpiped or box classifier–based on range or variance of class DNs
2. Minimum Distance-to-Means – based on mean class DNs
3. Maximum Likelihood– based on probability of class membership
4. Spectral Angle Mapper– class membership is based on minimum difference from the n-dimensional spectral vectors of the classes

4.1.2 Unsupervised classification

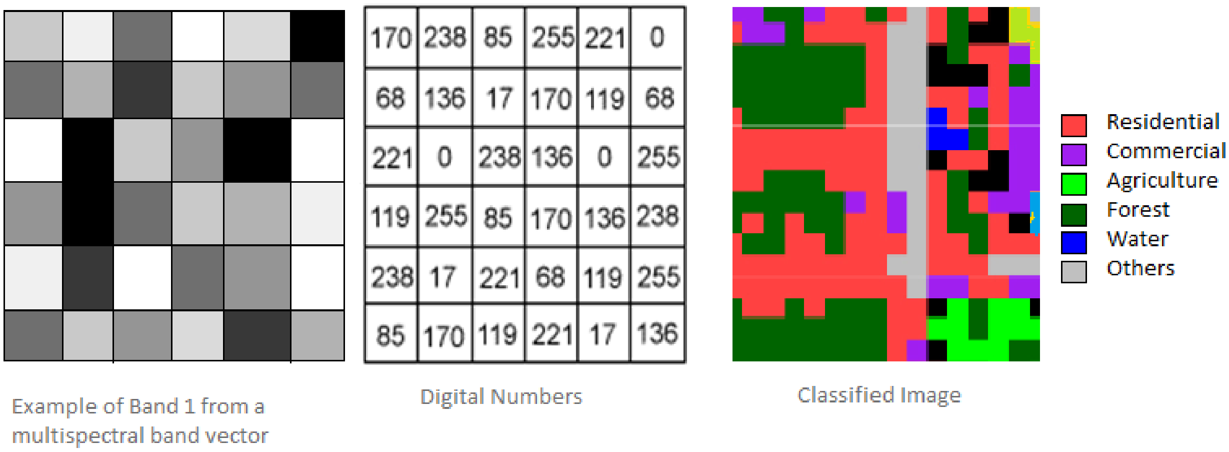
When unsupervised classification is utilized, prior ground information is not required and the image is classified based on the spectral variations. Statistical algorithms group similar pixels into various spectral classes which the analyst must then identify and combine into information classes. Thus, the algorithm does not evaluate the pixel data based on training sites, rather it separates the clusters of data based on the similar properties of the data itself. The basic assumption in unsupervised classification is that a particular land cover would form a single cluster. The grouping of the spectral classes involves utilization of statistical techniques like nearest neighbor and cluster analysis.

Further details of these two methods are discussed in the next module as they are the major classification techniques utilized in digital image classification.

4.2 Number of outputs for each spatial unit

4.2.1 Per-pixel classification

Per-pixel classification algorithm categorizes each input pixel into a spectral feature class based solely on the individual multispectral vector of the pixel and does not consider neighborhood association of the concerned pixel as shown in Fig 1. Thus, this classification technique is also known as hard classifier as we obtain discrete categories of one class per pixel. This technique is highly efficient, when we require to classify a nearly homogeneous region. However, the real Earth surface is not as homogeneous as we may want it to be and is actually quite heterogeneous in nature. The hard boundaries obtained through this approach may sometime be an issue as the pixel may not fall clearly in to one of the land use/land cover classes as the pixel may represent mixed class. This concern usually arises when the satellite image being utilized for classification may have a spatial resolution even higher than 1km. In a region like India, one can observe a major land cover change within 1 km area. Thus, the existence of heterogeneous pixels creates a problem. Hence, a classification is required where in the boundaries between different land cover classes are fuzzy and they gradually blend into one another.



170	238	85	255	221	0
68	136	17	170	119	68
221	0	238	136	0	255
119	255	85	170	136	238
238	17	221	68	119	255
85	170	119	221	17	136

Fig 2. Pixel-based classification

4.2.2 Object-oriented classification

Object-oriented classification groups the input pixels into spectral features using an image segmentation algorithm. Thus, using this approach we actually consider shape, size, tone, geo-location as well as spectral content. The approach considers the fact that the relationships between objects can play an important role in their identification and classification. This approach is also known as the fuzzy classification scheme as it allows a proportional assignment of multiple classes to pixels and decomposes the image into homogeneous image patches. Use of fuzzy sets for partitioning of spectral space involves determining the membership grades attached to each pixel with respect to every class. In fuzzy classification, each pixel is not assigned a single class, rather probability is attached for all the considered classes at the pixel. The probability is based on identification of image objects, or segments, that are spatially contiguous pixels. These methods can be more effective than pixel-based methods especially for classifying high-resolution image due to large within-class and between-class spectral variations. High resolution images usually have more spectral variability even for pixels belonging to the same class, due to capturing of shadows etc. Thus, considering the pixel group as one object brings in a range of spectral characteristics together. Unlike, the pixel based classification, where the spatial resolution remains intact, in this approach the objects generated are at different scales, as shown in Fig 3. The second important difference lies in the fact that this method supports the use of multiple datasets for multi-resolution segmentation and classification. For example, Infra-red satellite band data can be simultaneously utilized with other ancillary datasets like elevation and shape files can to classify the objects in an image. Multiple layers can have context with each other in the form of neighborhood relationships, proximity and distance between layers. The image segmentation is based on the Mean Shift approach. The technique uses a moving window that calculates an average pixel value to determine which pixels should be included in each segment. As the window moves over the image, it iteratively recomputes the value to make sure that each segment is suitable. The result is a grouping of image pixels into a segment characterized by an average color. The characteristics of the image segments depend on three parameters: spectral detail, spatial detail, and minimum segment size. One can vary the amount of detail that characterizes a feature of interest.

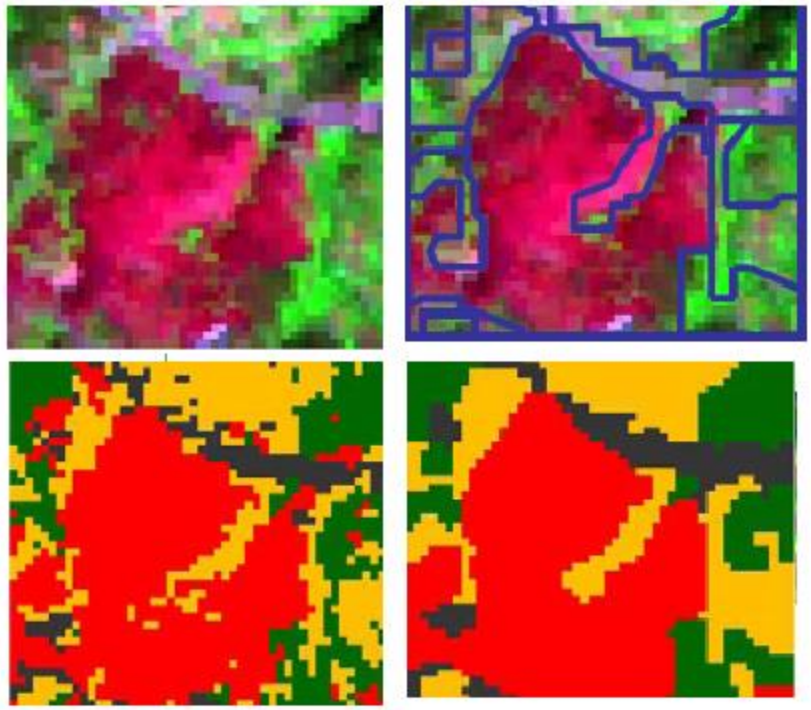


Fig 3. Illustration of pixel-based and object-based classification

4.3 Assumptions on data distribution

4.3.1 Parametric classification

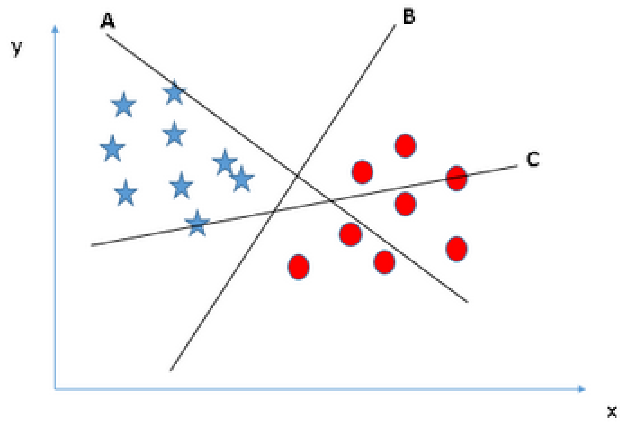
Parametric classifiers are based on the assumption that the data set is normally distributed, thus prior knowledge of class density function is considered known. The performance of a parametric classifier depends largely on how well the data match the pre-defined models and on the accuracy of the estimation of the model parameters. The method may not sufficiently integrate ancillary data as in fuzzy classification or non-parametric classification. For example maximum likelihood is one of the parametric method.

4.3.2 Non-Parametric classification

Non-parametric classification are not based on any assumption of the distribution of training dataset. The various methods, which are non-parametric include nearest-neighbor classification, support vector machines (SVM), fuzzy classification and artificial neural networks (ANN).

1. Artificial neural network - Neural network classifies images in analogous to neural nerves. An ANN consists of a series of layers, each containing a set of processing units (i.e. neurons). All neurons on a given layers are linked by weighted connections to all neurons on the previous and subsequent layers. It does not assume normality for the training sets, but rather it is learning based. The neural network memorizes what it sees or learns from the training data and then assign the class membership to each pixel in the image.

2. Support vector machine - SVM is a non-parametric classifier that differentiates and divides the classes by determining the boundaries in feature space and maximizes the separability between the classes. The surface is known as optimal hyper-plane as shown in Fig. 4. The points closest to the hyper plane are called support vectors. Classes are not separated by statistical learning theory means as in the maximum likelihood classifier. SVM includes a penalty parameter that allows a certain degree of misclassification, which is particularly important for non-separable training sets. The penalty parameter controls the tradeoff between allowing training errors and forcing rigid margins. SVM really works well with clear margin of separation and is effective in high dimensional spaces.



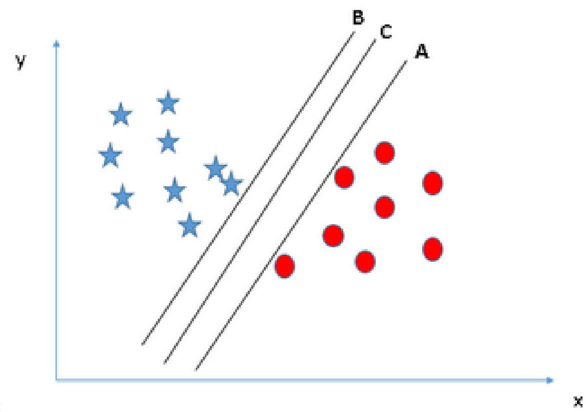


Fig 4. Illustration of optimal hyperplane. In 1st Fig B and 2nd C is the optimal hyperplane

6. Advantages and limitations of digital image classification

The results of image classification are rarely perfect. Numerous factors affect the classification results, with important ones being the objective of the classification, the spectral and spatial characteristics of the data, the timeframe(s) of the data, the natural variability of terrain conditions in the geographic region, and the digital classification technique employed. Frequently, the classification effort may require preparatory processing prior to classification and the refinement of classes after classification with the use of ancillary data such as terrain elevation and other parameters that influence land cover, its varied conditions, and the disturbances within it. In some cases, it may be useful to merge interpretations derived and digitized from higher resolution satellite data or aerial photography into lower resolution digital image classification results to provide useful detail in areas of concentrated human activity, such as urban regions.

Due to their digital format, the results of digital image classification provide distinct advantages that may make some amount of error tolerable. These advantages allow the results to be 1) readily provided in hardcopy map form; 2) compiled in tabular form to provide area, perimeter, and proximity information (such as edge relationships) for each class; and 3) entered into a geographical information system for subsequent merging and joint analysis with other spatially formatted data.

FAQs

Q 1.Define parametric classification method

Ans. Parametric classifiers are based on the assumption that the data set is normally distributed, thus prior knowledge of class density function is considered known. The performance of a parametric classifier depends largely on how well the data match the pre-defined models and on the accuracy of the estimation of the model parameters. The method may not sufficiently integrate ancillary data as in fuzzy classification or non-parametric classification. For example maximum likelihood is one of the parametric method.

Q2. Differentiate between hard and soft classifiers

Ans: Per-pixel classification algorithm categorizes each input pixel into a spectral feature class based solely on the individual multispectral vector of the pixel and does not consider neighborhood association of the concerned pixel. Thus, this classification technique is also known as hard classifier as we obtain discrete categories of one class per pixel.

Object-oriented classification groups the input pixels into spectral features using an image segmentation algorithm. Using this approach shape, size, tone, geo-location as well as spectral content is considered. The approach considers the relationships between objects. This approach is also known as the fuzzy classification scheme as it allows a proportional assignment of multiple classes to pixels and decomposes the image into homogeneous image patches. Use of fuzzy sets for partitioning of spectral space involves determining the membership grades attached to each pixel with respect to every class. Unlike, the pixel based classification, where the spatial resolution remains intact, in this approach the objects generated are at different scales and thus an soft classifier.

Q3. Name the various approaches for image classification

Ans. The digital image classification techniques can be further categorized based on the following possibilities

1. Type of learning
2. Number of outputs for each spatial unit
3. Assumption on data distribution

The explanation is given in e-text above.

Q4. If in histograms of bands sample training dataset, a band has a bimodal peak, what does it represent?

Ans: The bimodal peak indicates that the training site data set chosen by the analyst to represent a category is in fact composed of two subclasses with slightly different spectral characteristics. These subclasses may represent two different varieties or different illumination conditions, and so on. Thus, the classification accuracy will generally be improved if each of the subclasses is treated as a separate category.

Q 5. Explain spatial pattern recognition

Ans: Spatial pattern recognition involves the categorization of image pixels on the basis of their spatial relationship with pixels surrounding them. Spatial classifiers might consider such aspects as image texture, pixel proximity, feature size, shape, directionality, repetition, and context. These types of classifiers attempt to replicate the kind of spatial synthesis done by the human analyst during the visual interpretation process. Accordingly, they tend to be much more complex and computationally intensive than spectral pattern recognition procedures.

Q6. Explain SVM

Ans: SVM is a non-parametric classifier that differentiates and divides the classes by determining the boundaries in feature space and maximizes the separability between the classes. The surface is known as optimal hyper-plane and the points closest to the hyper plane are called support vectors. Classes are not separated by statistical learning theory means as in the maximum likelihood classifier. SVM includes a penalty parameter that allows a certain degree of misclassification, which is particularly important for non-separable training sets. The penalty parameter controls the tradeoff between allowing training errors and forcing rigid margins. SVM really works well with clear margin of separation and is effective in high dimensional spaces.

Ans: MCQs

1. Per-pixel classification is a soft classifier technique
   a) True
   b) False

Ans: b

2. __________ has unimodel histogram
   a) one pixel
   b) one peak
   c) one valley
   d) one intensity level

Ans: b

3. Intensity levels in 8-bit image are

a) 128

b) 255

c) 256

d) 512

Ans: c

4. Box-classifier is a hard classifier technique

   a) True

   b) False

Ans: a

5. Information classes is same as spectral classes

a) True

b) False

Ans: b

6. These are non-parametric classifiers

   a) Nearest- neighbour and SVM

   b) Nearest-neighbour and Box-classifier

   c) SVM and box-classifier

Ans: a

7. Object-based classification involves segmentation of image

   a) True

   b) False

   Ans: a

Summary:

In summary, any type of digital image classification, be it pixel-based or object-based, will be, at best, semi-automated. The success of automation is in having the computer classify the "easily predictable portions of the landscape, while retaining human efforts for final editing and classifying those areas that cannot be reliably predicted." The larger the area being studied, the greater the potential benefits and savings of semi-automated techniques. With the availability of various classification methods, a comparative analysis helps in improvement of classification. To summarize, one can use either of the soft or the hard classifiers. Hard classifiers are easy to implement and perform really well in homogeneous and coarse resolution images while the soft classifiers work efficiently in heterogeneous and high resolution images as they classify the image not only on the basis of spectral characteristics but also on the basis of tone, texture and spatial association.

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