DERIVING GIS-READY THEMATIC MAPPING INFORMATION FROM REMOTELY SENSED MAPS USING OBJECT-ORIENTED IMAGE ANALYSIS TECHNIQUES

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ABSTRACT

Deriving GIS data from historical maps will provide the ability to compare historical geographic patterns to more recent GIS-layers. In this example, USGS topographic maps, scanned at Western Michigan University's W.E.Upjohn Center for Global Change provide experimental sources for the feature extraction techniques. USGS topographic maps contain standardized symbols and uniform colors, and the Digital Line Graphs that correspond to the scanned quadrangle provide a baseline for checking the accuracy of extractions. Vector line features and polygon features were extracted from scanned maps using an object-oriented image analysis technique. The Definiens eCognition™ software provides the benefit of isolating the target objects in the map according to the difference in spectral, shape, and context. Polygon features could extract with spectral difference, but vector lines' extraction is required to employ all three factors. Extracted polygon features are acceptable to export as a shapefile directly, but extracted vector line features usually contain a lot of "noise data". When extracted vector line features are exported as shapefiles, the exported vector lines are constructed with many discrete lines. These problems were overcome to some extent with the ArcScan extension of ArcGIS™. The quality of extracted vector line features also improved using morphological processes in ArcScan.

Key words: Feature Extraction, Object-oriented Remote Sensing, Definiens

INTRODUCTION

Most remote sensing images are recorded in digital form and then processed by computers with image analysis techniques (Sabins, 2000). With the introduction of new commercial satellites, their high spatial resolution digital sensors are not suitable for traditional image analysis techniques. For this reason, the traditional classification algorithms based on single pixel analysis are not capable of extracting the information we desire from high spatial resolution remote sensing data (Jensen, 2006). The traditional image analysis techniques were focused on improving low spatial resolution imagery to make the image useful (Sabins, 2000). Furthermore, the single pixels in high spatial resolution imagery are not big enough to represent land use or artificial objects. The development of new object-oriented methods of image processing, which use groups of homogenous pixels rather than single pixels for image analysis, can use human intelligence for a solution to high spatial resolution imagery classification (Lang, 2008).

Digital image processing did not originate with remote sensing (Sabins, 2000). Many image-processing techniques were developed in the medical field to process X-ray images and other sophisticated body-scanning devices. As a reason, object-oriented image analysis techniques can be applied other types of remotely sensed images for deriving useful data.

Maps represent useful spatial information with pre-assigned symbols. Oxford's Dictionary of Geography defines a map as:

> *"A map is a cartographic representation of specifically chosen spatial information. The information is transmitted through images constructed from symbols. Map reading is the process whereby people interpret and analyze map image, and an understanding of the physical and psychological means used in map reading helps cartographers to improve the maps they produce."*

A chronological series of maps can show changes in many human aspects of the environment and applied land use change through time. If historical mapping information can be used as thematic layers in GIS-environment, this process will contribute to an enhanced understanding of chronological change of the earth environment. Extracting vector objects from high spatial resolution digital imagery is a challenging problem especially for road networks (Hu *et al.*, 2007). Efficient feature extraction requires an overall understanding of object-based image classification. For this reason, high spatial resolution imagery does not always guarantee clear feature extraction. However, improvement in methodologies could increase precision, reduce cost, save time, and expand resource inventory and analysis.

Fundamental to object-oriented remote sensing's knowledge base is an expert system. A knowledge-based expert system combines a computer's routine processing ability and a human expert's knowledge base for solving problems. A knowledge-based expert system is widely used for decision tree methods for land cover classification and for detecting environmental changes (Jensen, 2004).

This research creates Digital Line Graphs (DLG) from scanned maps using an automated image extraction process. A series of USGS topographic maps will be the experimental source for extracting individual vector features. USGS topographic maps are a standardized representation of the earth's surface. The distinctive characteristic of topographic maps is that objects on the Earth's surface are shown by topographic symbols, so topographic maps contain standard line and symbol representations of natural and artificially created objects. These extracted features provide land use information from historical maps. Extracted features can be used for change detection, both of previous land use from scanned historical maps and current land use in satellite images. An accuracy assessment of extracted features from historical topographic maps will be performed using GIS-layers created from existing DLGs. This quality test will provide feature extraction's maximum error and determine the compatibility of the generated GIS-layer with feature extraction techniques. This testing information will show potential utility and quality assurance of image extraction processes from historical maps or other images, which do not have any reference for validating those images' geographical information.

For this research, high resolution USGS topographic maps, which were scanned at the Western Michigan University's W.E. Upjohn Center for the Study of Geographical Change, were used for extracting vector features. The W.E. Upjohn Center is a unique facility for scanning maps and historical documents with very high resolution scanners, which also providing experimental sources for testing the feature extraction techniques.

The main objective is to extract vector features from scanned maps using object-oriented image analysis techniques. This requires the development of an optimal image extraction procedure that works well for multiple maps segments. Steps in developing this model are:

- Create optimal segmentation model using Definiens eCognition^{TM} object-oriented image analysis software.
- Develop an algorithm for feature extraction.
- Record features references used for image classification for building a knowledge-based expert system
- Create automated image analysis process for feature extraction.
- Develop effective post-processing techniques for creating thematic mapping layers for the ArcGIS^{TM} environment.

METHODS

This part introduces the vector feature extraction procedures including image and auxiliary data preparation and processing. It also explains the quality assurance and quality control methodology in which existing USGS Digital Line Graphs (DLGs) in USGS are compared with the image classification results for quality assurance.

Data Preparation

Lumiere-Technology's high resolution scanners at the W.E. Upjohn Center for Global Change at Western Michigan University scanned 7.5 minute USGS topographic maps at 500 Dots per Inch (DPI) true optical with a maximum x-y error of 0.0002 inches. USGS topographic maps contain standardized symbols and uniform colors, and the Digital Line Graphs (DLG) and Digital Raster Graphics (DRG) that correspond to the scanned quadrangle provide a baseline for checking the accuracy of extractions.

7.5 minute USGS topographic maps were geo-referenced using the World Geodetic System of 1984 (WGS-84) datum before performing the feature extraction analysis. The original hard copy topographic maps used the North American Datum of 1927 (NAD-27). Topographic maps for Kalamazoo, Michigan and its adjacent area are initially used for this project. However, the eCognition Professional object-oriented image classification software didn't support this datum. Also, DLGs for those selected maps couldn't be found from the USGS geo-database, but nine other maps of Youngstown, Ohio had 1:24,000 DLGs. As a result, The Youngstown maps were scanned at reduced resolution (250 DPI versus 500 DPI), because a 500 DPI image is over 400 MB. These file sizes required longer time processing and often crashed the computer while running Definiens eCognition.

Polygon Feature Extraction

Several segmentation methods are available in Definiens eCognition software. Multi-resolution segmentation was mainly used for this research. The multi-segmentation algorithm is a heuristic optimization procedure, which locally minimizes the average heterogeneity of image objects for a given resolution. It can be applied at both the pixel level or image object level domains (Definiens, 2006b).

The first step to construct an image segment data model is the specification of the composition of homogeneity criterion, which is determined by scale parameters incorporation both color and shape parameters. Optimal homogeneity levels for segmented objects are determined by three criteria, which are color, and shape that divides into two categories of smoothness and compactness. In this regard, the target scale defined maximum allowance of heterogeneity pixels in the segmented object (Definiens, 2006b).

The most influential parameter for creating a segmentation model from the scanned topological maps was color, because vegetation (Green), water bodies (Blue), and urban (Red) had distinguishable colors that distinguished them from the other polygon features. Through trial and error, it was determined that balanced parameters of shape and color (0.5 and 0.5) generated meaningful segments for vector polygon features (Figure 1).

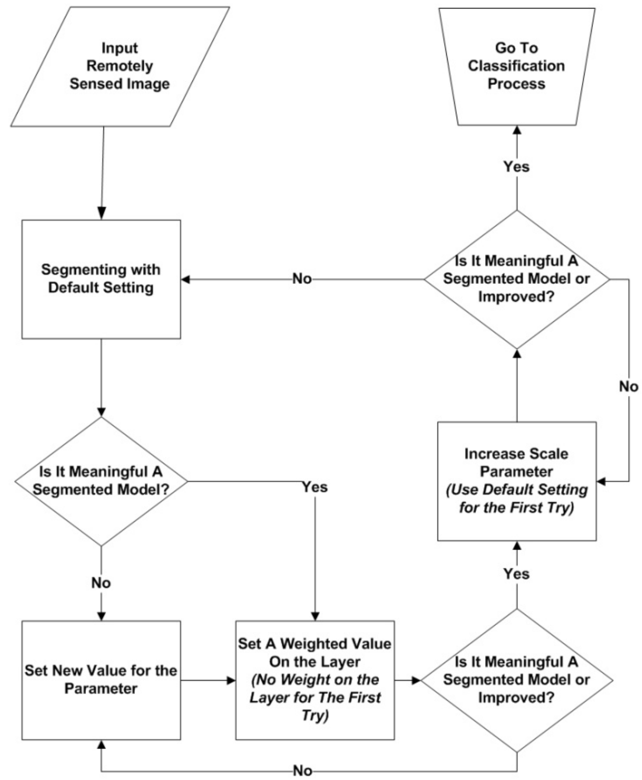


Figure 1. Segmentation procedure.

Polygon and linear features require the user to develop different combination of compactness and smoothness because these two features have obviously different shape figures such as different ratios of boundary length and area. Polygon features usually generated meaningful segments, when the parameter corresponding to these features was set with balanced values. When multiple stages of segmentation were performed, the second stage segmentation used color without any shape factor. The color of polygon features usually showed unique patterns, so it could merge the small objects into larger objects.

Linear features provide better meaningful segmented models when smoothness set as higher parameter because smoothness generates objects with clear boundaries. As a result, the higher smoothness value helps to isolate long and narrow features' borders more clearly because the smoothness parameter optimizes linear objects for further classification.

Image Classification Process

For developing rule-sets for remotely sensed image analysis, suitable information needs to be acquired from image objects (Definiens, 2006a). An image object's detail information could derive from feature references, which provide mean, standard deviation, and shape figure values for the three RGB bands. Each feature reference was carefully tested to create a list of optimal feature references. Furthermore, individual feature references can be improved by maximizing the distinguishable factors of respective feature references. For example, when both layer-1 (Red) mean and band-3 (Blue) standard deviation values have higher values for vegetation, this distinguishable factor of vegetation can be emphasized by a simple multiplication operation between the two chosen layer values. Individual spectral reference values often shifted a lot, but the ratio of spectral values had less variance. So, ratioing spectral information could provide more solid feature characteristic for image classification.

Classification processes were designed in several stages based on reference features' characteristics. Each classification process was also constructed to eliminate unnecessary objects efficiently (Figure 2). This classification procedure consisted of three stages:

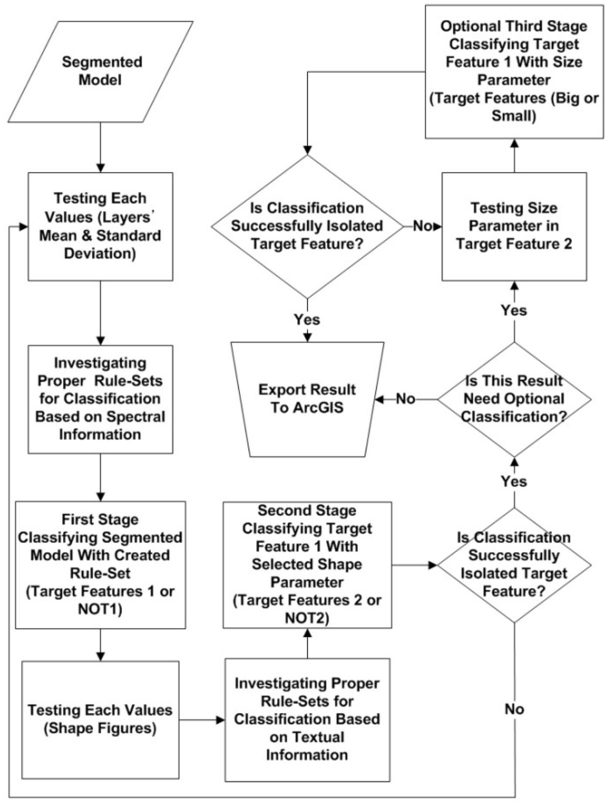


Figure 2. Classification procedure.

1. Isolate target objects based on spectral information alone. Classification functions were based on layers' mean and standard deviation values. This level had strengthened to classify overall target objects based on its spectral signatures, which were reflected by unique color of the target objects.
2. Eliminate noise objects and indentify the target object's boundary clearly. Classification was performed based on physical figures of classified target polygon features from the first stage.
3. Separate the classified target objects based on size to distinguish between big and small polygons features.

Post Processing Procedure

Polygon features in the scanned map were usually fragmented by other line features and often contained holes in the classified image where text labels and a variety of point features were located. As a result, extracted polygon features showed randomly placed holes or were fragmented. Extracted features were generalized by using mathematical morphology operators contained in the ArcScan extension to ArcGIS (Figure 3).

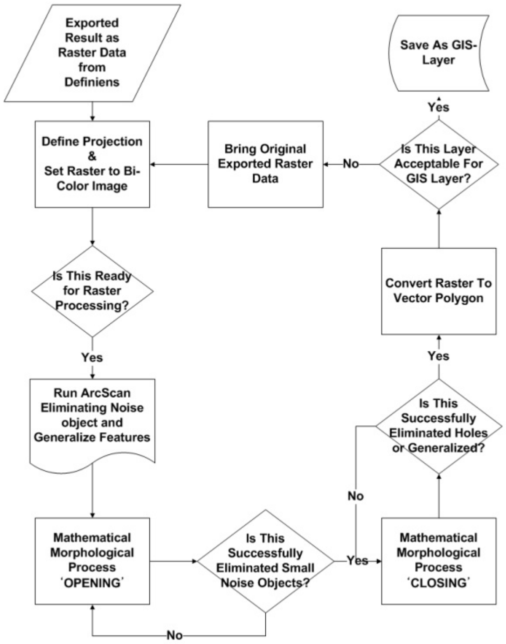


Figure 3. Raster processing procedure for polygon features.

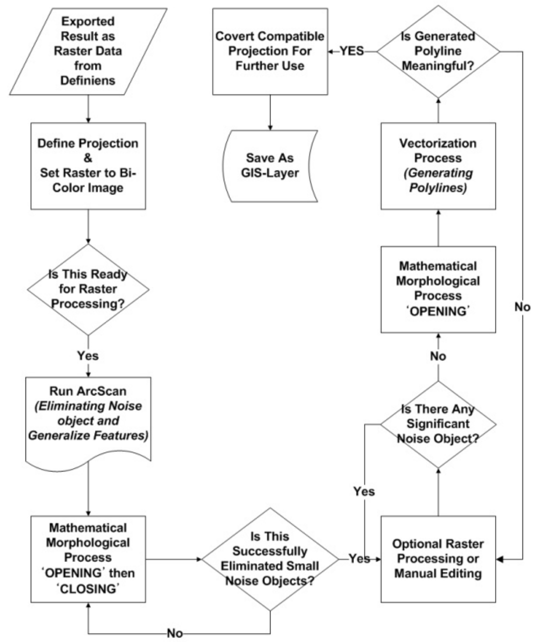


Figure 4. Raster processing procedure for linear features.

USGS 7.5 minute topographic maps contain a variety of linear features. Only highway features were successfully extracted. Because some highway features are represented as dashed lines, they had to be vectorized as smooth lines that are more useful as GIS layers. Second, even if connected, smoothed line features from the scanned map, those lines contained discrete portion after classification. Some highway symbols did not have uniform color. The classification process extracted the exact shape of highways as multi-lines of highway, clover leaf intersections, and loops, which were too complicated for use as a GIS-layer. Those needed to be generalized before being useful thematic layers (Figure 4).

Accuracy Assessment

This research extracted features from scanned USGS 7.5 minute topographic maps and the classification quality assurance was tested with DLGs. DLGs data are digital vector representations of cartographic information (USGS, 1998). Large-scale DLGs were not available for the western Michigan region, so features were extracted from the USGS quadrangles for Youngstown, Ohio, which did have corresponding DLGs.

Nine different DLGs layers are available but only the Hydrography, Transportation, and Vegetation Surface Cover layers were used for the quality test. However, USGS didn't have all series of large scale DLGs for the region of interest. As a result, I could only find and use Hydrography and Transportations' DLGs for the region of interest. Hydrology and highway features were supplement to test quality assurance. Furthermore, the DLGs were originally created with the NAD 1927 projection system, so classified results were converted back to NAD 1927 for quality test (Table 1).

Table 1. Criteria for quality test.

	Polygon Features	Linear Features
Basic Method	Compare extracted features and corresponding DLGs	Compare extracted features and corresponding DLGs
Quality Test	Total number of polygon features & Total area of all selected polygon features	Total length of selected linear features
Shape Preservation Test (Visual test)	Observe extracted features boundary and DLGs boundary	Observe two linear features by overlaying each other & Test over-generated lines

RESULTS

Image Extraction Result

The classification procedure for vegetation features required a series of rule-sets. Classification processes were constructed for two stages. The first stage was based on each layer's mean value. Four different formulas were used to distinguish vegetation clearly. This stage was able to extract vegetation polygons from other polygon features, but this result contained too many linear features, especially the contour lines, which are an important attribute of topographic maps. As a consequence, this procedure failed to provide acceptable vegetation features for export as GIS-layer.

The second stage focused on eliminating linear features from the first stage classification's results. The rule-sets for the second stage classification were based on the shape measure of target objects to eliminate noise features with other than mean layer values. The second stage classification was successful at extracting vegetation features with considerably less noise. However, some problems arose in the classification process. First, vegetation features that were located on steep slopes, often failed to extract because the vegetation feature's color was altered by contour lines, so the procedure couldn't provide the unique color reference value to the classification procedure. Second, extracted vegetation features were sometimes cut by contour lines, labels, and wetland symbols.

The classification procedure for water features also required a series of rule-sets. There were several major problems related to the classification of hydrology features. First, hydrology features represented as thinner line features often did not have distinguishable color patterns. Second, wetland features were often categorized as hydrology features. Only hydrology features that represented larger water bodies could be clearly extracted.

The hydrology classification processes were developed in three stages with a single object-merge process. The first and second stages of classification was similar to that developed for vegetation features, but rule-sets for the second stage classification were based on shape measures of objects, especially the size parameter because noise objects were generally smaller than hydrology objects. Furthermore, hydrology features were usually adjacent features, so classified hydrology features could be merged as single segmented objects by merging connected classification segments. The extraction procedure also improved classification at the third stage because connected objects increased unity of shape measures, especially size factors for the classification. Extracted hydrology features often contained many complicated features due to the variety of hydrological features in the topographic maps. The third stage distinguished major hydrology features such as large lakes and rivers, which had significantly larger areas than water bodies such as ditches and wet lands.

A major problem for converting classified hydrology features to a GIS-layer resulted from a lake's name appearing as a hole in the extracted feature. Small patches of hydrology features on the final classification results also added noise to the final output. Extracted hydrology features need to be improved or generalized for further use as GIS-layers.

The classification procedure for urban features occurred in two stages. The first stage used each layer's mean value and standard deviation. In this stage, the classification extracted urban features incorporating many noise objects such as contour lines and road features, which displayed as a red or brown color on the image. The second stage required more shape measures than other polygon extraction processes because classified urban features from first stage contain many noise objects. Extracted urban features consisted of small discrete patches, so it was necessary to merge the many pieces of urban features to form single polygons. This was also necessary for further use of the information as GIS-layers.

The classification procedure for revised urban features occurred in two stages as well. The first stage's result produced a clear extraction for revised features, but it contained noise, which were usually generated by water body boundaries or individually revised features, which had the same color as revised polygon features. The second stage focused on eliminating unwanted small patches from first stage classification result. Extracted revised urban features had the same problems with extracted urban features, so they also required generalization for further use as GIS-layers.

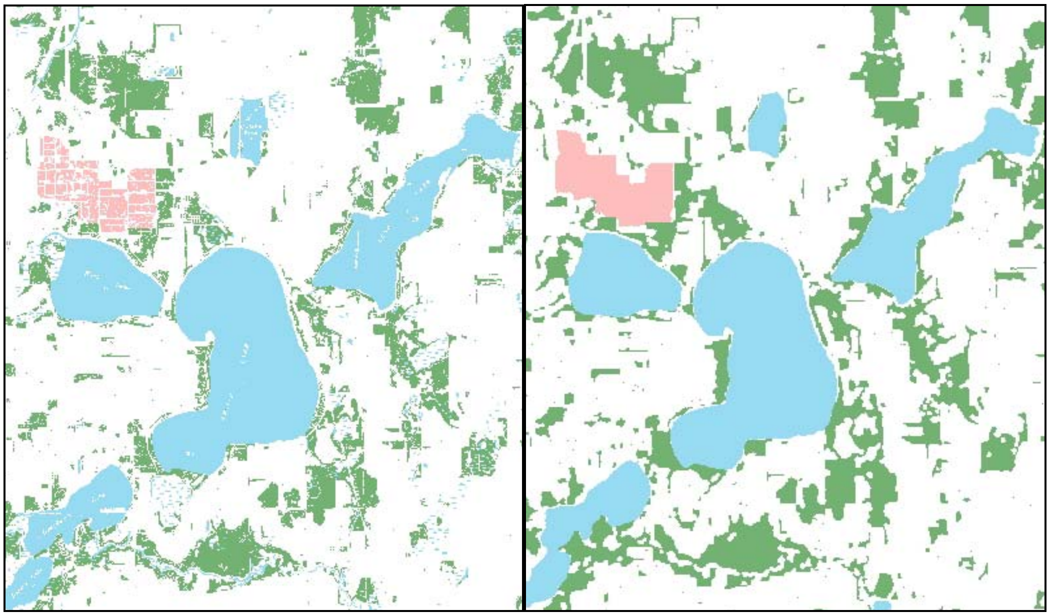
The classification process for highway features at the lower resolution was based on each layer's mean values and standard deviation. No second stage classification was necessary. When chessboard segmentation was performed, it weakened the shape figures of the segmented model. As a possible explanation, an average highway width is around 5 pixels, but the chessboard segmentation converted 5 by 5 pixels to single pixel. So, single pixels couldn't represent corresponding shape of features in the same way as traditional pixel-based classification.

The classification result for highway features was very clear with only a small number of noise objects, which could be eliminated with post-processing in ArcScan. The line features extracted very clearly, but there were some problems to overcome before the features were of sufficient quality for use in a GIS-layer. First, the line was usually disconnected because parts of the line feature failed to extract because of interference with other features. Second, some of highway features were represented as dashed lines, so this could not be directly used as a GIS-layer.

Post Processing

Mathematical morphology operations are mainly used for raster improvement. ArcScan supports only binary (black/white) raster images, so extracted features were exported in raster format from Definiens eCognition. The mathematical morphology operation consisted of two-steps. The first step was designed to improve raster image through the elimination of noise objects from the image. The raster image was cleaned up with an opening operation. This operation eliminated noise pixels by reducing the boundaries then enlarging the boundaries of objects. The opening operation eliminated isolated small noise pixels, and then recovered the original objects, while preserving the original area and shape of objects. The second step generalized polygons by removing holes or converting fragmented polygons to single polygons. Raster generalization was performed with a closing operation, which connected and filled fragmented polygons. In this way, polygons are turned into clean and generalized objects. This operation was based on enlarging the boundaries then reducing the boundaries of objects within the parameters. The mathematical morphology process successfully produced generalized and improved thematic layers for GIS environments (Figure 5).

For linear feature cleanup, a combination of opening and closing operation was also used, because small noise objects could be removed with opening but at the same time, line features also lost their own shapes. A closing operation was used for preserving line features' shape after performing the opening operation. An additional consideration for mathematical morphology operations is that if the opening value was too big, the original shape of area could not be preserved because highway features were thin line features. Sometimes, large noise objects were eliminated with smaller scale of mathematical morphological process. This problem could be solved with a raster cleanup process or minimal manual editing in ArcScan.



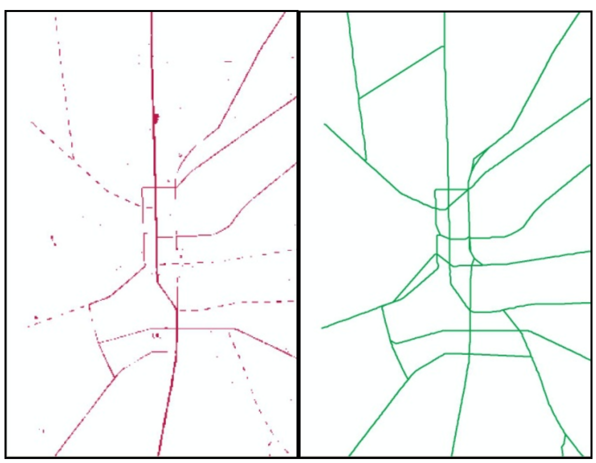
(a) (b)

Source: USGS Topographic Map from ArcGIS

Note: (a) Extracted features from Definiens eCognition, and (b) Generalized features from ArcGIS ArcScan

Figure 5. Polygon feature generalization process.

The vectorization process connected existing points to generalize lines, so it was very sensitive to each pixel (Figure 6). For example, even if only a pixel of a point feature is left over as noise, it could cause extra lines to be vectorized, which distorted the shapes of some linear features.



(a) (b)

Source: USGS Topographic Map from ArcGIS

Note: (a) Classification Result from Definiens eCognition, (b) Raster cleaned and Vectorized by ArcGIS ArcScan

Figure 6. Linear feature generalization and vectorization process.

Accuracy Assessment

Extracted features from the Columbia, Ohio (O40080H6) USGS 7.5' topographic map were used for a quality assurance test. Because only larger hydrological features were extracted, lakes and larger river polygons were selected to compare the extracted result's quality assurance. Extracted small water bodies often had distorted shapes, but the shape of larger water bodies was usually well preserved. The biggest lake from the region of interest preserved 99.61% of the original area and the total area of all extracted lakes were also preserved at 94.6% of the mapped lake area from the DLG. Size preservation was accurate but the number of lakes was not because many of small lakes were not extracted (Table 2).

Table 2. Quality test result of water features.

	Lakes from Extraction	Lakes from DLGs	Difference	Accuracy
Number of Lakes	36	140	104	25.71%
Lake (Biggest)	1928164.36 m^2	1935787.27 m^2	7622.91 m^2	99.61%
Total Lake Area	2829152.39 m^2	3007720.06 m^2	178567.67 m^2	94.06%

However, this research was focused on significant size of water bodies. Even if, lots of small lakes were eliminated, lake count accuracy didn't much effect to original lake coverage.

Extracted highway features from the Warren, Ohio (O41080B7) USGS 7.5' quadrangle were selected for the quality assurance test. This map contained the most mixed map features, so its quality test could explain the major problems in linear feature extraction and vectorization. Extracted highway features contained some noise pixels, but overall highway shape was well preserved. When this classified result was processed from ArcScan, it successfully removed noise pixels, but unfortunately, it often generated extra lines. ArcScan's vectorization is very sensitive to line shape because the priority direction for line generation is determined by any given line edge's angle or shape. Line connection priority was also determined by the line's shape, not the gap distance between lines.

Overall line distance accuracy was 96.61% (Table 3). However, about 4% of lines were over-generated. Line feature extraction is needed to improve vectorization accuracy.

Table 3. Quality test result of highway features.

	Highways from Extraction	Highways from DLGs	Difference	Accuracy
Highway (Total)	170253.02 m	164485.28 m	5767.74 m	96.61%

CONCLUSIONS

This research shows that useful vector GIS-layers can be generated from scanned maps using object-oriented image analysis techniques. With the advent and proliferation of high spatial resolution remote sensing, object-oriented image analysis techniques are used in many extractions of road network features and land use change detection. This technique can be expanded to validate historical land uses from digitized paper maps. If useful object-oriented image analysis knowledge is developed from a feature extraction process from scanned maps such as Digital Raster Graphics (DRG), this knowledge could be applied to other types of scanned images, such as digitized historical maps and high spatial resolution satellite images.

Using a high resolution optical scanner, topographic maps can be digitized as very high resolution images, which can be used to distinguish very tiny symbols in a map. This is usually an impossible task for traditional DRGs which have much lower resolution. This project developed an optimal object-oriented vector feature extraction procedure using scanned maps. The framework of this research could be utilized to generate useful thematic information from a wide variety of scanned maps and remotely sensed data.

Unique object-oriented image analysis techniques were applied for each type (polygon or line) of target object, based on the distinctive characteristics of these objects. Every type of object has standardized procedures for segmentation, classification, and post-processing, but the segmentation algorithms and classification rule-sets were developed separately based on each characteristic. Successful object-oriented analysis techniques are based on creating meaningful segmentation models. The multi-resolution segmentation process isolates polygon features successfully and the chessboard segmentation process for linear features helps to get rid of complexity between a wide variety of linear features reproduced on the maps in same color. Furthermore, an optional hierarchical segmentation process can help to create solid polygon segmented models, which have better shape and spectral representation of polygon features.

Optimal classification rule-sets are a primary requirement for the image classification procedures in this research. Optimized rule-sets developed by testing several references and recording values for each object. The collected information was converted to rigorous classification algorithms through simple mathematical combination. Simple mathematical combinations of the references were used to develop the specialized algorithm for only target object. For example, the mean of layer-1 (red) can separate vegetation and water features from the image but it cannot be used for single features. When the mean layer-1 value was multiplied by the standard deviation of layer-3 (blue), which could separate vegetation, urban, and highway features from the image, the resulting formula is able to isolate only vegetation from the image. Polygon features were successfully extracted with specialized algorithms, but the extraction of linear features was not as successful. Definiens eCognition Professional 5.0 supported very rigorous classification rule-sets for the feature extraction process. Polygon feature extraction process was successful with 250 DPI images, but linear feature extraction may need higher resolution than 250 DPI and possibly a newer version of Definiens eCognition to improve the extraction result.

For clear feature extraction, optimized rule-sets are a key element for generating clearly isolated respective target objects from other objects in the image. Binary classes provided an optimal environment to develop proper rule-sets for features. Hierarchical classification techniques are designed to eliminate noise objects based on spectral and shape differences at each classification stage. Rule-sets were developed to maximize distinguishable factors for each feature type through mathematical combinations.

The ArcScan extension in ArcGIS™ was used raster clean up and for improving extracted features' quality. ArcScan is designed to work with binary images, so it was an efficient tool for post-classification processing. It also has a very powerful mathematical morphology process as well as a vectorization function which taken together help to generate smooth vector features in a GIS-environment.

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