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Automatic road detection from orthophoto images

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ABSTRACT

Aerial photos and satellite images tell us about the land surface. It provides a variety of information such as particularly human-built objects such as buildings, roads and bridges and the location and characteristics of the vegetation. Except for aerial photographs and satellite imagery, the collection, evaluation, and updating of the required data with other data collection methods is a time-consuming process and more costly. Data from aerial photographs and satellite images have long been detected manually by conventional methods and by operators. The automatically of these detections increases the speed of the project process and contributes to the reduction of the expenses spent. The projects carried out within the scope of the extraction and classification of objects are mostly concentrated on buildings and roads. Because roads and buildings; Due to the characteristic features such as having sharp lines and easy determination of the geometric shape, the identification of the detail lines in the objects is easier than determining the details of other objects. In this study, aerial photographs of a certain area of Afyon/Turkey were obtained by using unmanned aerial vehicles (UAV). The raw data obtained were evaluated and the object-based classification approach was used to automatic detection and classify the roads of the university in the digital environment.

1. INTRODUCTION

The information available in high-resolution images in many areas such as urban planning, meteorology, forestry, agricultural geology, and landscape detection are needed for various purposes. In order to investigate the full value of this data, useful information must be extracted in a standard manner. Previously, the extraction of the required details was done manually by the operators. This situation had a negative effect on time and cost. Automatic detection of the required objects has become faster and easier thanks to improved detail extraction methods.

In recent years, important developments in digital photogrammetry and remote sensing technologies and satellite sensors/camera systems have led to the emergence of new and different research topics and applications. With the development of digital camera technology since the 1950s, the production of orthophotos with high spatial resolution and positional accuracy has become possible. To obtain information from images such as Orthophoto, digital surface model (DSM) and digital terrain model (DTM) acquired with high-resolution satellite imagery and UAV, we need to use spatial and contextual knowledge of an object and its surroundings. These orthophotos are used successfully in the extraction of detail and thematic classification. Due to the high spatial resolution, the object-based approach has gained importance and became widespread in the thematic classification instead of the traditional pixel-based classification approach (Sabuncu et al., 2017).

In most of the studies, the pixel-based classification method has been used. In this method,

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the color values of the pixels and the neighboring relations of the pixels are evaluated. The main purpose of this method is to automatically combine each pixel in the image according to terrain characteristics. Pixel-based approaches only use spectral information. Therefore, Pixel-based approaches cannot meet the classification of high-resolution satellite images and orthophotos, and information extraction is based solely on gray level thresholding methods. This results in a large amount of data. To overcome this situation, an object-based approach is applied. Therefore, in today's image processing technologies, in addition to classical methods, object-based methods are frequently used.

The object-based method interprets an image not only with respect to a single-pixel but also with meaningful image objects and interrelations. Object-based information extraction depends not only on the spectrum character but also on the geometry and structure information (Wenxia et al., 2005). Although the object-based method appears to be an alternative to the pixel-based method, it is, in fact, complementary to the pixel-based method.

In the object-based approach, spectral values are based on fuzzy logic, which enables the completion of a broad spectrum of different object properties such as shape, texture, and density. The basic processing unit of object-based image analysis is image segments or objects. In the object-based approach, classification is done through image objects (Hofmann, 2001a). The classification step begins by converting neighboring pixels into meaningful regions that can be considered in the next step of the classification. Such segmentation and topology occurrences should be adjusted according to the resolution and scale of the objects. This method not only classifies individual pixels but also creates homogeneous image objects during the previous segmentation step. While this segmentation can be performed at different resolutions, it also allows distinguishing layers of object categories. In addition, the conventional pixel-based method performs the extraction of details based on the gray value of the pixel. For this reason, only spectral information is used effectively in the classification stage. The object-based image approach is preferred to eliminate these and other limitations (Kanber ve Yavuz, 2015).

The most important factor affecting the accuracy of the methods used in detail extraction studies is the resolution of the orthophoto. Image resolution has a significant and powerful effect in determining roads and other objects. Objects that can be identified in high-resolution orthophotos may not be clearly identified in low-resolution orthophotos. Especially in high-resolution images, the roads have a certain width and the roads are interrupted due to the effect of trees, buildings, and vehicles. On the other hand, low-resolution images are observed in a single line, so no breaks occur. For these and other reasons, object-based classification is better based on pixel-based classification for object extraction from high-resolution images in settlements.

Object-based information extraction consists of two main steps: segmentation and classification. For a successful segmentation step, several test applications are performed in the image data of the workspace. After the segmentation step, classification is made by setting different parameters for the image data used and the desired detail extraction is performed.

In this study, image data obtained by UAV were evaluated photogrammetrical and automatic road extraction was performed by the object-based classification method.

2. OBJECT-BASED CLASSIFICATION

The object-based approach considers the structure, textures and spectral information. This classification step begins with the grouping of neighboring pixels into meaningful regions that can be considered in the next step of the classification. Such segmentation and topology formation should be adjusted according to the resolution and scale of the objects to be removed. With this method, not only the individual pixels are classified, but also homogeneous image objects are created during the previous segmentation step. This segmentation can be performed at different resolutions, while at the same time distinguishing layers of object categories. In addition, since pixel-based classification is based solely on a statistical analysis of pixels, the object-based classification method, which groups the pixels in the segmentation stage and uses many features such as color, frequency, and nearest neighborhood, gives more meaningful and positive results for the thematic class. At the same time, the object-based classification process can be continuously updated with ruleset or fuzzy logic algorithms. Definiens eCognition, which is the most widely used object-based image analysis software, offers a similar approach to the pixel-based approach with its nearest neighbor classification method and gives the same meaningful results in a more practical way (Kalkan et al., 2010).

3. WHY OBJECT-BASED CLASSIFICATION METHOD IS NEEDED?

The conventional pixel-based method performs the extraction of details based on the gray value of the pixel. For this reason, only the spectral information is used effectively in the classification stage. The object-based image approach is preferred to eliminate these and other limitations. In the object-based approach, spectral values are based on fuzzy logic, which makes it possible to complete the broad spectrum of different object properties such as shape, texture, and density. In contrast to conventional image processing methods, the basic processing unit of object-based image analysis is image segments or objects, not individual pixels.

Here, the classification is done via image objects. One reason for the object-based approach is that most image analysis applications are expected to have real-world objects in actual classification and actual shapes. This expectation cannot be achieved by conventional pixel-based approaches (Hofmann, 2001a, b, c).

In addition, the object-based classification method allows for fuzzy logic classification compared to the pixel-based classification method. In this case, each object can have more than one class membership. Class memberships are represented by a number ranging from 0 to 1. In this value scale, 1 represents the full membership of the pixel for that class, and 0 indicates no membership. Values between 0 and 1 indicate that members will be in proportion to their size (Boyacı, 2012). Another reason why the object-based method is preferred is that in most image analysis applications, the expected result is that objects are assigned to the real class and are in their actual shape. This expectation cannot be met by conventional pixel-based approaches (Hofmann, 2001a).

4. MATERIALS AND METHODS

4.1. Study Area

This study was conducted in a designated area in Afyon Province shown in Figure 1.

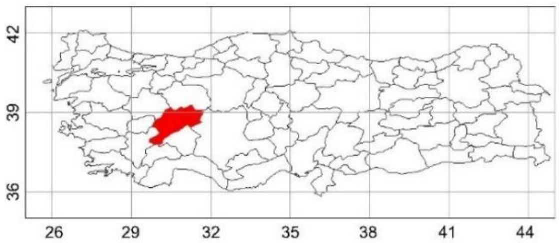

Figure 1. Study area

The work flow chart of the study is shown in Figure 2.

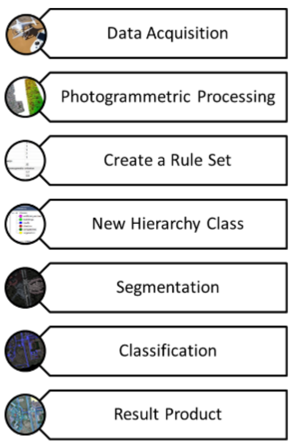

Figure 2. Work flow charts

4.2. Collection of Data

One of the methods adopted to obtain the spatial data needed in recent years is the use of unmanned aerial vehicles (Yılmaz et al., 2018). With the development of technology, UAV technology is being used more efficiently especially in the field of mapping.

Unmanned aerial vehicles are designed for special purposes, capable of taking off and landing from any area, remote-controlled, semi-automatic or fully automatic flight capability. These vehicles can be airplanes, helicopters or zeppelin according to their flight capabilities (Eisenbeiss, 2009; Cömert et al., 2012).

In this study, the photographic data of the field were obtained with the help of Phantom 3 Pro UAV (figure 3).

Figure 3. UAV used in study (URL-1)

A total of 800 photographic images were obtained from different angles and overlays from a height of 120 meters. 6 ground control points were surveying for reference purposes.

4.3. Methods

In this study, the object-based method which is explained in detail in Chapter 2 was preferred.

5. PROCESS of UAV DATA

Using the images collected with the help of UAV, the orthophoto of the study area was produced in Pix4D software. The Ground Sample Distance of the orthophotos produced has a resolution of 3.7 cm. The orthophoto and digital surface model (DSM) of the study area are shown in figure 4.

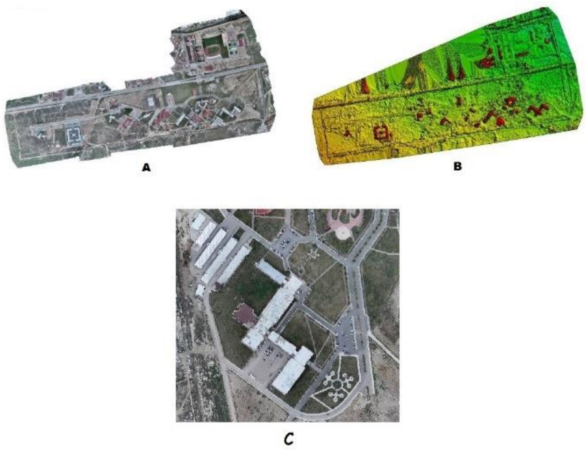

Figure 4. A) Orthophoto of the study area B) DSM of the study area C) The area designated for study

Afterward, detail extraction process steps were performed by using the object-based classification method with the help of Definiens eCognition software over the produced orthophoto.

6. TECHNICAL INFORMATION ABOUT SEGMENTATION

The most important and first step in object-based classification is segmentation. Segmentation is the process of grouping pixels with similar spectral properties and creating image objects. The purpose of segmentation is to divide the image into different subsections and create meaningful objects from the image (Baatz et al., 2000). It is also among the objectives of segmentation that in most cases it is possible to automatically extract the desired objects of interest in an image for a task. Segmentation works as two different methods from top to bottom and from bottom to top (Definiens, 2012).

The basis of top-down management is the process of splitting the whole into small parts. There are 3 different top-down segmentation methods. These; chessboard segmentation, quadtree-based segmentation, and contrast split segmentation algorithms. The second strategy of segmentation is bottom-up segmentation. In this approach, small pieces are obtained as large pieces taking certain criteria into consideration. The most important method used for bottom-up strategy is the multi-resolution segmentation method (Benz et al., 2004).

In the multi-resolution segmentation algorithm, the parameters are set by the user. These parameters are scale, color/shape, and softness/density. The parameters should be entered as close to the truth as possible. The most important of the 3 parameters entered is the scale parameter. The softness/density and Color/shape parameters complement each other to 1.

The Color and Shape criteria generate image objects consisting of relatively homogeneous pixels using the general Segmentation Function (SF) formulated in equation (1).

$$Sf = w_{color}\, h_{color}\, (1 - w_{color})\, h_{shape} \qquad (1)$$

where the user-defined weight for spectral color or shape is $0 < w_{color} < 1$.

Spectral (i.e., color) heterogeneity (h) of an image object is computed as the sum of the standard deviations of spectral values of each layer (σ_k) (i.e., band) multiplied by the weights for each layer (w_k):

$$h = \sum_{k=1}^{m} w_k . \sigma_k \qquad (2)$$

The color criterion is computed as the weighted mean of all changes in standard deviation for each band *k* of the *m* bands of remote sensing dataset. The standard deviation is σ_k weighted by the object sizes n_{ob} (i.e. the number of pixels):

$$h_{color} = \sum_{k=1}^{m} w_k \left[n_{mg}.\ \sigma_{k^{mg}} - (n_{ab1}.\sigma_{k^{ab1}} + n_{ab2}.\sigma_{k^{ab2}} \right] \quad (3)$$

(where *mg* means merge).

Compactness:

$$cpt = \frac{l}{\sqrt{n}} \qquad (4)$$

Smoothness:

$$smooth = \frac{l}{b} \qquad (5)$$

(Karakış et all., 2006)

n is number of pixels in the object, l is the perimeter, b is shortest possible border length of a box bounding the object

$$h_{cpt} = n_{mg}.\frac{l_{mg}}{\sqrt{n_{mg}}} - \left(n_{ob1}.\frac{l_{ab1}}{\sqrt{n_{ab1}}} + n_{ab2}.\frac{l_{ab2}}{\sqrt{n_{ab2}}} \right) (6)$$

$$h_{smoth} = n_{mg}.\frac{l_{mg}}{b_{mg}} - \left(n_{ob1}.\frac{l_{ab1}}{\sqrt{n_{ab1}}} + n_{ab2}.\frac{l_{ab2}}{\sqrt{n_{ab2}}} \right) (7)$$

$$h_{shape} = w_{cpt}.h_{cpt} + \left(1 - w_{cpt}\right).h_{smooth} \qquad (8)$$

7. TECHNICAL INFORMATION ABOUT CLASSIFICATION

The main purpose of the classification process is to analyze multiple georeferenced images or bands together and to form groups of groups with similar statistical characteristics in these images (Geçen et al., 2007).

The classification is divided into a numerical and a contextual part, that are applied one after another. The context analysis is used as additional information to support the numerical classification. Classification algorithms analyze image objects according to defined criteria and assign them to a class that best meets them.

8. DETAIL OBJECT DETECTION FROM ORTHOPHOTO IMAGES

After orthophoto was produced from UAV data, the detail extraction process was started in Definiens eCognition software. In the Definiens eCognition software, segmentation is performed first. The most important and first step in object-based classification is segmentation. Segmentation is the process of grouping pixels with similar spectral properties and creating image objects. Segmentation is applied to create meaningful objects from the image data used. The multiresolution segmentation approach is often used for the segmentation algorithm. Before starting the segmentation process; scale, softness/density, and color/shape.

Scale Parameter: This parameter indirectly affects the average object size. In fact, this parameter specifies the maximum value that permits the heterogeneity of objects. The larger the scale parameter, the larger the objects.

Smoothness/Compactness: When the shape criterion is greater than 0, the user can decide whether the objects should be more complete (dense) or softer.

Color/Shape: With these parameters, the effect of homogeneity of color and shape conflict on object production can be corrected. The higher the shape criterion, the less the effect of spectral homogeneity on object production (Marangoz et al., 2005).

These 3 parameters entered in the segmentation stage were tried under different criteria and 60 were selected for scale parameter, 0.8 for softness/density parameter and 0.2 for color/shape parameters. The defined segmentation parameters are shown in table 1.

Each classification process depends on an exact scale. For this reason, it is very important that the average resolution of image objects corresponds to the desired scale. The image information can be presented at different scales depending on the average size of the image objects (Marangoz, 2009).

Table 1. Segmentation parameters

Parameters	Value
Scale	60
Shape	0.2
Compactness	0.8

The segmentation result of the selected parameters is shown in figure 5.

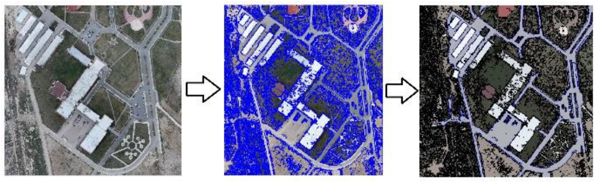

Figure 5. Segmentation result product

After the segmentation process, the classification process was started in Definiens eCognition software. The software has two basic classifications. These are fuzzy membership and nearest neighborhood functions. In the nearest neighbor classification function, the user defines classes using sample objects for each class. In the fuzzy membership classification function, the ranges of the properties of objects belonging to a certain class or where they do not belong are defined.

In the classification stage, the values of the road class were determined first. Then the roads were determined by identifying and extracting the properties of the objects that do not belong to this class. After the roads were determined, it was seen that some segments that should be in the road class were not assigned to the road class. A new range has been assigned for objects that must be in the road class and the roads have been assigned to the class to which they belong. After determining the road class, merge and border reshape operations were applied. Some indexes used in the classification process are shown in Table 2.

Table 2. Some indexes used in classification

Name	Index Name	Formula
GRVI	Green-red vegetation index	$\frac{(Green-Red)}{(Green+Red)}$
RRI	Red ratio index	$\frac{(Red)}{(Blue+Green+Red)}$
GRI	Green ratio index	$\frac{(Green)}{(Blue+Green+Red)}$
Brgt	Brightness	$\frac{Blue+Green+Red}{3}$

The class assignments created are shown in table 3.

Table 3. Class assignments

Class	Class Color
Road	Blue
Red Roofed Building-Camelia	Red
White Roofed Building-Sidewalk	Turquois
Vegetable	Green
Other objects	Pink

After the necessary parameters have been defined, the objects whose detail is extracted are assigned to the class they belong to. The assigned classes are shown in Figure 6.

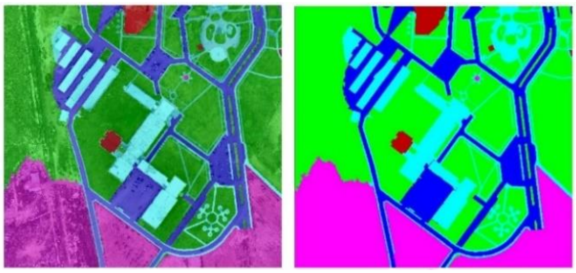

Figure 6. Roads detected on orthophoto

The detected road classes are shown in Figure 7.

Figure 7. Roads detected on orthophoto

The data extracted from the eCognition software and the vector data generated by the geodetic methods of the study area are compared in Figure 8.

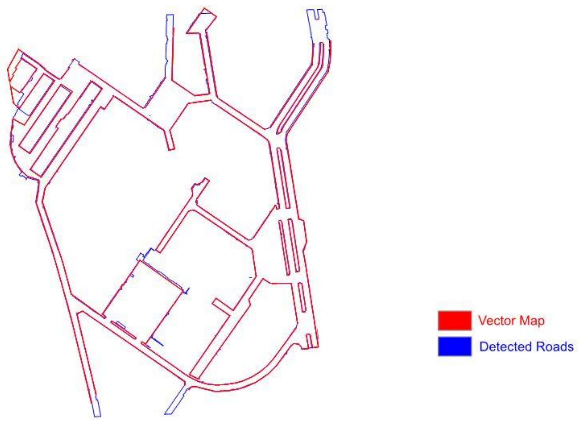

Figure 8. Comparison of vector data with detection of road detail

The road areas calculated from the vector map of the study area are 3.30 hectares. Road areas determined by the object-based classification method are 2.92 hectares. According to the field data, there is an 88% consistency between the vector map road areas and the detected road areas.

In addition, the road line shown in red in Figure 9 was measured 71.67 meters on the vector map. The same road line was measured 70.80 meters at the end of the detail determination study.

Figure 9. Length-based comparison of the road line

As a result of the length comparison of the road line, there is a consistency of 98%.

9. CONCLUSION

From our study, classification and detail extraction are largely successful with the object-based approach. Furthermore, it can be said that the object-based approach is efficient and feasible for the following reasons.

- First, the use of multiple properties of the object, including spectrum, shape, texture, shadow, context, spatial location.
- Second, the object-based information extraction approach ensures the accuracy of classification by making full use of high-resolution image information.
- Third, it is possible to make multi-scale, image object resolution adaptable to specific requirements, data and tasks by manually setting different parameters.

As a result of segmentation by using the object-based approach algorithm which replaces the pixel-based approach used for many years, the classification of the objects is largely accomplished. With the object-based classification software Definiens eCognition, the classification process can be performed faster and more up-to-date. In addition, mistakes or wrong class assignments can be corrected quickly, and the classification result can be converted to vector format and integrated with geographical information systems.

As a result, it has been observed that the classification of the objects with the object-based approach has been done successfully, but there are deficiencies like every algorithm. For example, there were difficulties in distinguishing roads and pavements with close attributes. In future studies, these deficiencies and difficulties can be solved by using data such as digital elevation model (DEM), DSM and DTM in addition to orthophotos. Or, when collecting image data from the field, using image data with close infrared (NIR) bands in addition to RGB (Red-Green-Blue) bands may contribute to the elimination of the problems encountered.

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