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Automatic detection of forest trees from digital surface models derived by aerial images

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ABSTRACT

For the sustainable management of forests, obtaining the spatial information of the tree existence (location, number, height, and crown diameter of trees, etc.) with high accuracy and quickly is very important. In this context, the study aims to detect forest trees automatically through flow analysis applied to a 5 m resolution digital surface model by geospatial analysis. The study was carried out in five sample areas with different physical and topographic characteristics in the Antalya province of Turkey. The method consists of two steps which are identifying tree populations and determining tree peaks by applying flow analysis on the surface model. First, the canopy height model was extracted by applying a morphological filter to the image-based digital surface model. Then, the tree peak points are considered sink points, and these sink points were determined on the inverted surface model by the flow analysis approach which is frequently used in hydrological studies. The results showed that the applied method gives approximately 70% accuracy depending on the terrain conditions. Tree crown diameter, distance between trees, slope of the land, and digital surface model resolution significantly affect the accuracy of the results. It is predicted that this study will be an important guide for decision-makers in the preparation of forest plans.

1. INTRODUCTION

The Republic of Turkey has a rich potential in tree inventory (Toklu 2017). To the protection of this potential and ensure sustainable management, firstly inventory of existing forest trees needs to be extracted with high accuracy (Bouvier et al. 2015; Su et al. 2016; Selim et al, 2019). Classical methods for determining the existence of forest trees require high costs in time and its budget (Mohan et al. 2017; Silva et al. 2016). In this regard, laser scanning, photogrammetry, and remote sensing techniques are important especially for the determination of individual tree existence in recent years (Ferraz et al. 2016; Magnard et al. 2016; Zhen et al. 2016; Hao et al. 2021). Laser scanning technology is known to produce direct 3D information (tree height, width, form) as well as being a very good method compared to other methods; however, it's expensive (Barnes et al. 2017; Cabo et al. 2018). Hence, the studies to obtain information at a lower cost from aerial photographs and satellite images have become important.

As the development of Remote Sensing (RS) and Geographical Information Systems (GIS) technologies, in the literature, the used methods are generally for identifying individual trees and detecting the existence of forest trees, are obtained through high-resolution images, point cloud-based laser scanning systems or a fusion of these data (Paris et al. 2017; Yang et al. 2016; Zhen et al. 2016; Dalla Corte et al. 2020). To extract forest inventory using point cloud, high-density point data are widely used (Bienert et al. 2007; Hopkinson et al. 2004; Simonse et al. 2003). For the processing of these data, analyzing, reducing noise, and applying filters are needed. Consequently, high-accuracy object detection from images with low-density data shortens the processing time and reduces the workforce.

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In this context, the study is intended to detect forest tree existence using 5 m resolution digital surface models as well as is based on low cost, high accuracy, and short time. For this purpose, Antalya province, which is one of the most important tourist destinations in Turkey, is selected as a study area. Antalya province is rich in terms of forest existence, besides ranking third among the total number of forest fires in Turkey. Since Antalya has great importance for the Turkish economy, the resources have to be monitored with short time and high accuracy, for protecting, and management purposes.

The study was conducted in five different regions in Antalya province. In this study, a morphological filter was applied to digital surface models of the test areas at first and was generated a canopy height model. Then, flow analyses were implemented and tree peak points were achieved. For evaluating the results, the derived tree points are compared with manually created points

2. MATERIALS and METHOD

2.1. Study Area

The great socio-economic and socio-cultural importance of Antalya among other Turkish cities makes it the main material of this research. Antalya's city center is based at 36°53'5.39"N and 30°42'20.71"E coordinates. Apart from it being a well-known tourism city title, the city has rich forest sources. With consideration of the topographical and physical differences, five different locations have been selected. These are respectively; towns of (1) Kumluca, (2) Kemer, (3) Döşemealtı, (4) Belek ve (5) Side (Figure 1).

Figure 1. Test area locations

Topography, the density of the forest, limited-mixed type of tree, length of tree parameters were considered in the selection of test areas. The image-based digital surface model is used as input data. The data have a 5 m grid size with +-3m vertical accuracy as reported by the data provider 'General Command of Mapping Turkey'. A database was created in ArcGIS software and analyzes were performed. Aerial photographs and orthomosaic maps were also used as materials in the study for accuracy assessment.

2.2 Method

The method consists of two stages. The first stage is detecting the tree areas, the second stage is the extraction of tree peaks by performing focal flow direction analysis on the surface model. The flowchart of the proposed method is shown in Figure 2.

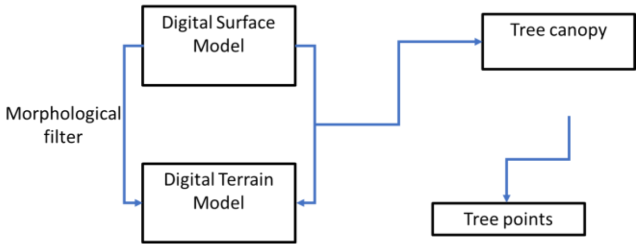


Figure 2. Processing workflow

Regarding extracting the tree canopy, as used and confirmed its performance by Demir (2018), the terrain surface was extracted from the image-based digital surface model with a morphological filter (Zhang et al. 2003). Subtracting the terrain model from the original DSM would give the canopy height model which represents the tree cover.

In the morphological filtering process, a secondary surface was obtained by using the erosion and dilation functions on the elevation model. The difference of height values in the kernel window moving on the elevation model is decomposed as a tree or terrain by the support of a threshold value.

As shown in the equation below, the height difference threshold value (dh) was calculated using the predefined maximum terrain slope (s). The size of the filtering windows (dhT, K) was increased and the derived surface was used as an input for the further process.

The filtering parameters are selected as same as Demir (2018) without any further trials and listed in Table 1. The used threshold is calculated as proposed by (Zhang et al. 2003).

$$d_{h_{T,k}} = \begin{cases} dh_{max} & \text{if } d_{h_{T,k}} > dh_{max} \\ s(w_k - w_{k-1})c + d_{h_0} & \text{else if } w_k > 3 \\ dh_0 & \text{else if } w_k \leq 3 \end{cases}$$

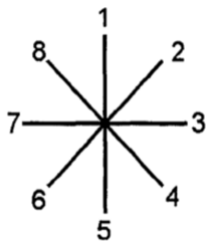
c is the grid size.

Table 1. Filtering parameters

Parameters	Value
Estimated surface model accuracy	0.2 m
Maximum height difference	3 m
Determined terrain slope	0-10 %
Grid size	0.25 m
Window size	3 m

Regarding the tree peaks, flow analysis, which is frequently used in hydrological studies, is applied to detect them. In the flow analysis, the sink points in which fluids are collected on a surface, are identified. For this, the surface model is inverted.

The flow value of the grid pixels is calculated with the use of directions as the power of 2. Then the center pixels flow value is calculated with a sum of power of 2. The degree of power is determined with directions of the neighbor cells from 1 to 8 (Figure 3).



-35	-27	-30
-30	-29	-24
-25	-31	-38

8	7	6	5	4	3	2	1
0	0	1	0	0	1	0	1

Figure 3. Cell direction, flow direction and flow value calculation

The flow value of the center cell (-29) was computed as 73. This process was applied to the whole inverted surface model. All cells with a maximum value of 255 were converted into vector data and separated as potential tree peaks.

3. RESULTS

This study aims to obtain forest trees individually by using a medium resolution digital surface model held in 5 different locations where are respectively Kumluca (Figure 4), Kemer (Figure 5), Döşemealtı (Figure 6), Belek (Figure 7), and Side (Figure 8). In the following figures, (a) represents the tree crown's area, (b) indicates the trees that were detected from DSM (c) detected trees shown on orthophoto. Yellow marked zone at (c) points correction analyses applied areas.

Kumluca area is located on the east of Antalya center based at 36°18'13.76"N latitude and 30°19'44.84"E longitude (Figure 4). Generally, natural forest communities are common in this region and the terrain has a flat structure. The diameter of forest trees which don't have a specific distribution pattern varies between 5m and 25m in the region and there are also some shrub groups in section by section. The distances of trees with one another are changed and the trees are highly dense in the selected region, especially in the middle of the northwest-southeast direction. In this test site, the proposed method by using DSM was applied for tree detection and approximately 70% of the count of trees was detected. The communities of trees that are shorter than 10 m and dense, complicate the detection of individual trees from 5 m resolution DSM and reduce accuracy.

An area of 150x150 m from terrain was randomly selected and accuracy analysis was performed. In the applied accuracy analysis, tree numbers were compared and 44 out of 62 trees were detected. In this context, the accuracy rate has been obtained 70% for the Kumluca region. The number of unidentified trees is 18. Kumluca has some of the tree communities located high dense and there are many trees under 10 m, as a consequence of this, accuracy was decreased.

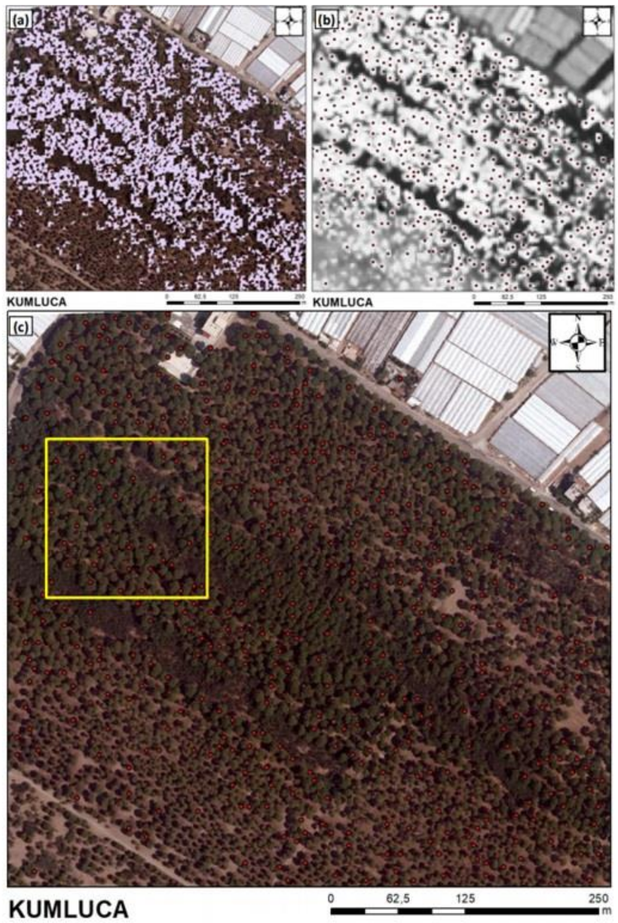


Figure 4. Tree detection results of test area 1

Test site Kemer is at the east of Antalya with 36°35'30.16"N latitude and 30°33'0.23"E longitude (Figure 5). The area is generally covered by natural forest and the terrain has a sloping structure. Forest trees in the area settle in a dispersed and the diameter of trees are varied between 5m and 30m and in section by sections, shrubs groups shall be seen. The method that uses DSM determined 133 trees in line with borderline in Figure 4. The area consists of shrub communities and trees with a crown diameter below 10 m. The test area has a 10-30% slope in the north-south direction. Accuracy analysis was applied in a randomly selected 250x250m area. The used method in this analysis was able to find 17 trees out of 31 existing trees. In this context, the accuracy was obtained to be 55% for the Kemer region. The number of unidentified trees was 14. Since the slope of the whole test area was in the range of 0-3% and the overall diameters of tree crown were below 10 m, the accuracy obtained was low.

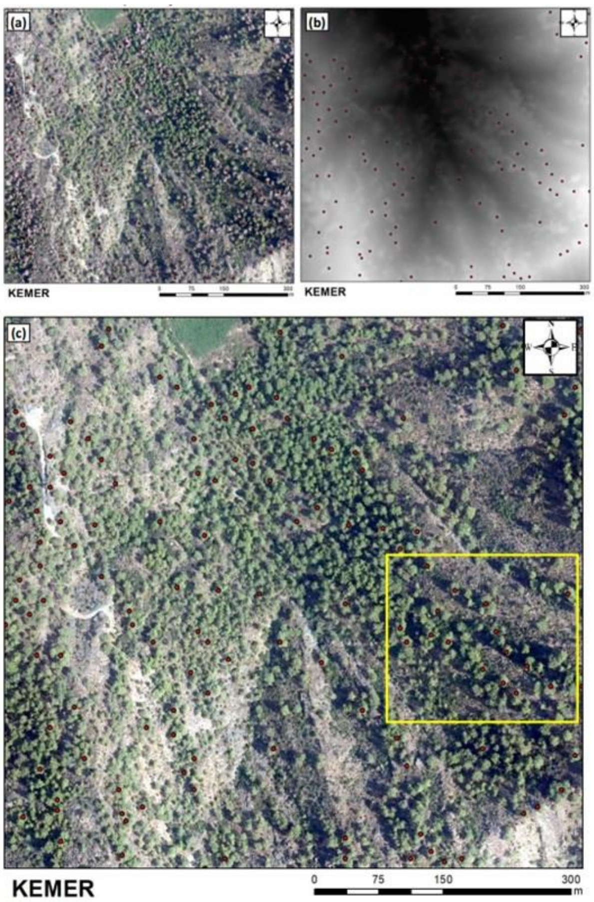


Figure 5. Tree detection results of test area 2

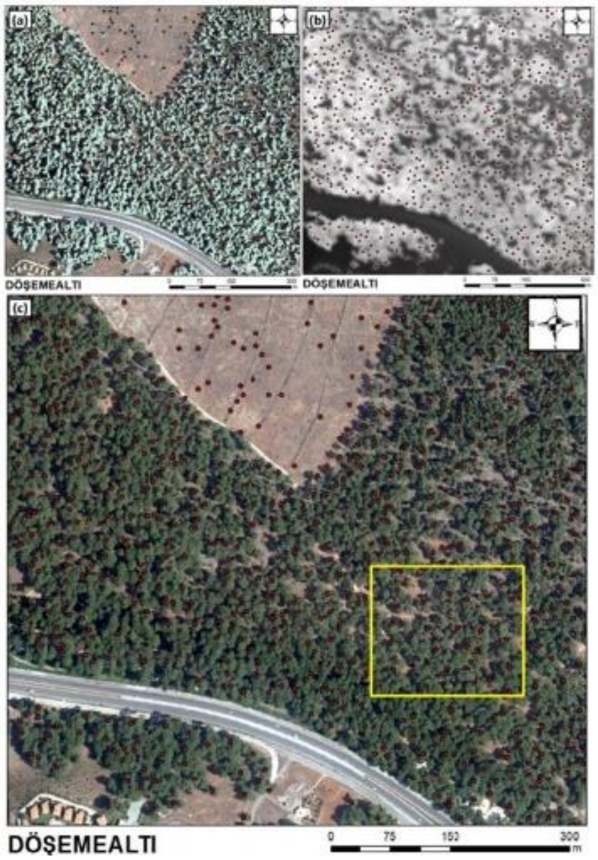


Figure 6. Tree detection results of test area 3

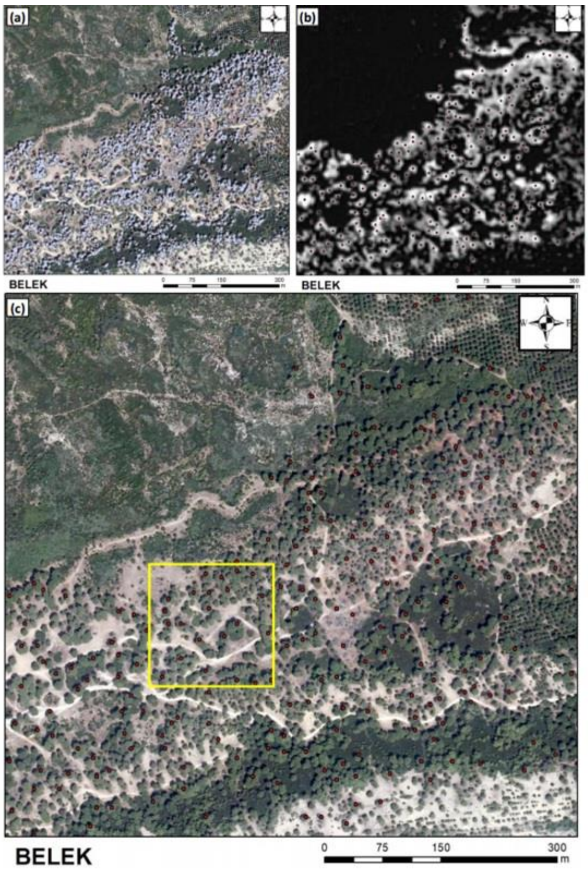


Figure 7. Tree detection results of test area 4

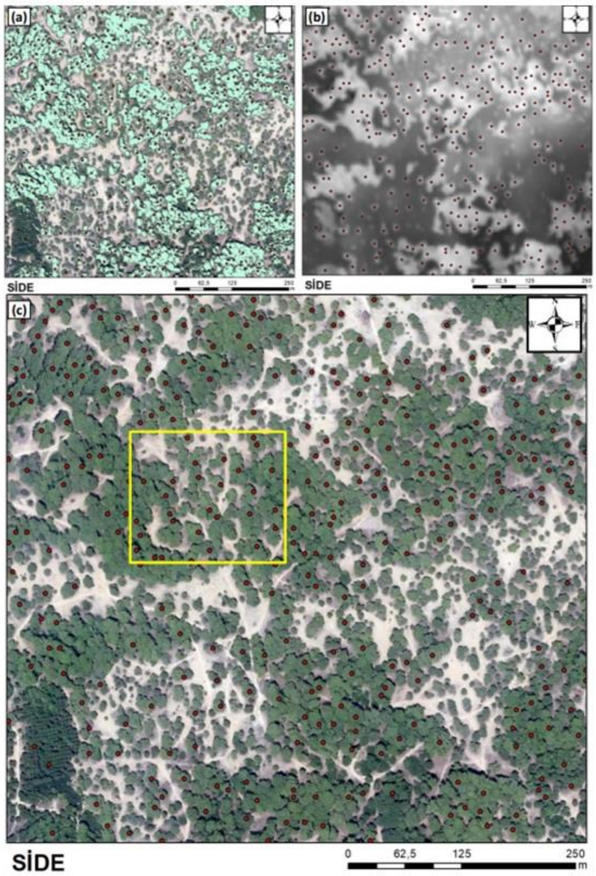


Figure 8. Tree detection results of test area 5

Döşemealtı area is at 36°57'58.03"N latitude and 30°35'54.03"E longitude in the north of Antalya center (Figure 6). In general, the diameters of the tree communities in this region are varied between 8 m and 15 m. In addition, trees with a crown diameter of 5 m and below exist inside of the forest. The method that uses DSM determined 621 trees in line with borderline in Figure 5. The forest located to the north of the test area is turned into an open area and the used DSM is old dated. Due to these reasons, the number of detected trees is 40. According to the current orthophoto map, the number of trees was detected to be 581.

Accuracy analyses were held in randomly selected 200x200 m areas. The used method in this analysis was able to find 54 trees out of 83 existing trees. Hence, one could say 65% accuracy was observed in the Döşemealtı region.

Belek region is located to the east of Antalya city center between 36°51'34.27"N latitude and 30°56'22.57"E longitude (Figure 7). In the area, there are tree communities and shrubs with different diameters. The distances between rows and columns of culturally generated forests have been examined and their distribution is partially equal; however, natural forests do not have a specific distribution. The method that uses DSM determined 131 trees in line with borderline in Figure 6. The freegan communities in the northwest of the area are composed of multi-trunk shrub groups and cannot be detected because their crown diameters are smaller than 5 m. In the northeast of the Belek region, the culturally generated forest area could not be detected by using DSM, due to a crown diameter of smaller than 10 m. In this site, the used method detected forest trees with a crown diameter of 10 m or more.

Accuracy analyses were held in randomly selected 150x150 m areas. The used method in this analysis was able to find 23 trees out of 53 existing trees. Hence, one could say 43% accuracy was observed in the Belek region.

The Side area's geographic coordinates are 36°45'57.71"N latitude and 31°26'10.40"E longitude where it is located in the east of Antalya center. The area is mainly covered by natural forest groups. Forest trees in the area settle in dispersed and the diameter of trees are varied between 5m and 30m. The method that uses DSM determined 336 trees in line with borderline in Figure 8. The area is mainly covered by forest trees, however, section by section, shrubs groups shall be seen. In the southwest of the test site where afforestation is carried out, there are trees with a regular range of rows and columns.

Accuracy analyses were held in randomly selected 250x250m areas. The used method in this analysis was able to find 71 trees out of 85 existing trees. Hence, one could say 85% accuracy was observed in the Side region. The number of unidentified trees was 13. Since the slope of the whole working area was in the range of 0-3% and the overall diameters of the tree crown were above 10m, the method provided remarkable accuracy results.

4. DISCUSSION

In this study, it is shown the potential use of a medium resolution digital surface model to detect single trees. With comparison by authors previous study (Demir 2018), which has been performed with UAV based surface model, the produced results are strongly related to the density of trees, and also the topography. High-resolution surface models (below 1 m) allow detecting the trees regardless of the surface topography. But decreasing the resolution will require homogenous topography, like on the test site Side. The terrain slope of the Side region is in the range of 0-3% and which is the smallest among the others, and the method has reached its maximum accuracy. Belek also has a similar terrain slope, but the existence of a group of scrub and freegans creates conflict on satellite data, and distinguishing of tree-brier becomes complicated. Consequently, the accuracy rate decreased. Dosemealti has 65% accuracy, but the region is a developing area with growing new trees, although the reference orthoimage is new, the user input surface model is old, so the result is reasonable with missing newly added trees. Kemer has high slope terrain, the accuracy is reached 55%.

Similarly, to our method, but with some exceptions such as applying Gaussian filtering, Pitkänen and Maltamo (2004) find the local maxima among high-resolution LIDAR-based surface models, and they have reached 84% accuracy for a test site where the terrain slope is low.

5. CONCLUSION

This study shows the performance of the use of medium resolution surface models in tree peak points detection. The main concept of the method is a flow analysis that obtains points in a surface where the fluids accumulated.

The method has been applied to 5 different regions which have different physical properties. These physical differences can be listed as topographical structure such as differences in slope, aspect values, tree coverage such as the average diameter of the crowns, and plant diversity.

Essentially, the method was applied on image-based DSM, the results are evaluated with manually created tree peak points data over orthoimage.

In this study, a minimum of 65% of tress is successfully detected among test sites. The reasons for failure are the use of a medium resolution digital surface model which is 5 m which is difficult to detect the trees that have a small crown diameter. Another item that affects the accuracy is slope variation of the test site's topography. Not only detection of tree peaks with flow analysis, but also the extraction of tree canopy with morphological filter is affected by the factors listed above.

The method can be improved with the integration of image features and use as additional supporting information to increase the accuracy.

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Author contributions

Serdar Selim: Data curation, Writing-Reviewing and Editing, Validation, Visualization; **Nusret Demir:** Conceptualization, Methodology, Software; **Selen Oy Şahin:** Writing-Original draft preparation, Visualization

Conflicts of interest

The authors declare no conflicts of interest.

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