Forest Land Surface Area Computation in Jing-Jin-Ji region based on DEM

Shilun Kang*, Qian Li, Mianmian Cheng, Yaxin Zhai, Yilan Lou

Space Engineering University, Beijing, China

*Lanxigua67@163.com
39266158@qq.com
chmmian@163.com
aileen_lou@163.com
aileen_lou@163.com

Abstract. With increasing attention to environmental protection, forests, as the main body of terrestrial ecosystems, have increasingly become the focus of environmental engineering research. In order to improve the effectiveness of forestry engineering construction, the use of remote sensing technology to cover the area with the characteristics of comprehensive and immediate acquisition of change information, and accurate statistics of forest resources, make full use of the technical advantages of GIS technology such as spatial data analysis and integration in comprehensive application. The calculation of forest surface area based on DEM data has the advantages of high precision, short cycle and low cost. It is the future of forestry engineering and urban construction. The commonly used method of replacing the ground surface with a projection surface ignores the influence of the surface slope change on the area. This paper takes the Jing-Jin-Ji region as an example, extracts topographic information based on DEM data, uses topographic feature points to construct irregular triangulations, performs area statistics, and finally compares and analyzes the projected area obtained from remote sensing image interpretation data, 2.03% of the forest land surface area. The surface area calculation method used in this paper can make forest land resources more accurate statistics.

Keywords: GIS; forest land surface area; DEM; terrain feature points; irregular triangle net; Jing-Jin-Ji

1 Introduction

The digital elevation model realizes the digital simulation of the ground terrain through limited terrain elevation data. The GIS technology based on DEM data studies the macro-geographic world. It has powerful spatial query and analysis capabilities and is widely used in the environment, forests, hydrology, agriculture, geography and ecological aspects, such as land use and cover changes, urban planning, forest management and early warning, desertification monitoring, disaster monitoring and

V. Escudero et al. (Eds.): BADS 2022, AHCS 11, pp. 736–746, 2023.
https://doi.org/10.2991/978-94-6463-102-9_75

assessment. Area measurement is a basic work in forest resource surveys. Various environmental monitoring and surveys are carried out based on the data of area measurement. The accuracy of area measurement plays an important role in the investigation of various resources [1]. The earth is a sphere, and the land surface is a curved surface based on the ground surface. In previous studies, in order to simplify research and facilitate calculations, the projection surface is usually used as the ground surface. In large-scale and stable terrain undulations, this approach has little effect on accuracy; but in small areas and studies that pay more attention to terrain undulations, such as woodlands that are mainly distributed in mountains and slopes, the results may be larger difference.

Forest land is an important part of the earth's biosphere and a key factor in maintaining the global ecological balance. At the same time, forest resources also provide many material resources for the survival and development of mankind. The Jing-Jin-Ji region is the most developed region in China in terms of economy, technology, culture, and education. Years of urban development have resulted in a high concentration of population and industries, putting increasing pressure on the regional ecology and environment, and increasing smog. As the lung of the city, woodland plays an important role in the ecological management of the Jing-Jin-Ji region. Compared with other types of land, the site conditions of forest land are quite special, mainly in low mountain and hilly areas, with complex terrain and large undulations. Using projection planes to calculate the forest land area and resource statistics will cause large errors. Therefore, the forest area should be calculated using the surface area [2].

However, few domestic and foreign related studies use surface surfaces to summarize the area of forest land. The traditional forest area measurement is the field measurement by the operators, and then the area measurement method is used to perform fitting calculations to obtain the forest map spot area (that is, the projected area), for example, the forest inventory project in China every five years. The research of Feng showed that the accuracy of the cubic spline method is the highest [3]. However, this method can neither show the topography of forest land, but also has the problem of too long survey period and slow update of forest land information. The use of DEM for area statistics can not only improve efficiency, but also easily realize the calculation of the surface area of forest land on different slope levels, providing powerful technical support for the accurate statistics of forest land resources. In this regard, researchers have carried out many useful explorations. Jiang Fan used the compound Simpson formula to calculate the DEM area, but the accuracy of the result was not high due to the single resolution[4]; on this basis, Chen used the order Newton-Leibniz formula to classify and calculate the forest area based on the contour data [1]; Li Yiping combined topographic data with DEM, use the slope secant value to calculate the forest area [2]; Li Zhanrong generates slope point data from DEM data, and obtains the ridge area by analyzing the intersection of point data and map data [5]; similarly, Wang Xiuyun used ArcGIS software to extract the slope from DEM, calculate the secant value of the slope and combine it with raster data, and completed the statistics of the surface area of several forest lands in Nanjing at different slope levels [6], this method is more effective in calculating flat slopes with consistent slopes, but it has larger errors for curved surfaces with large terrain undulations, and this method has a large dependence on slope data. Different slopes may produce different results, statistics bring uncertainty. Researchers in related fields pay more and more attention to the efficient and accurate calculation of forest area.

Based on the above research, this paper comprehensively considers the complex and changeable geomorphic environment in the Jing-Jin-Ji region and the fragmented characteristics of forest land distribution. Based on DEM data, an irregular triangulation network is constructed by extracting topographic feature points and combining forest land. The distribution data were screened, and a preliminary exploration was made on the accurate calculation of the forest land surface area.

2 Research area and data

2.1 Study area

The Jing-Jin-Ji region includes 11 prefecture-level cities in Beijing, Tianjin and Hebei, with an area of 218,000 km^2, located between 36°03′~42°40′ north latitude and 13°27′~119°50′ east longitude. There are various types of landforms, including plains, hills, basins, mountains, plateaus. The overall terrain is high in the northwest and low in the southeast, with Taihang Mountain in the west and Yanshan Mountain in the north. The hills are mainly distributed on the eastern side of Taihang Mountain and the southern side of Yanshan Mountain. The plains are Haihe Plain and Luanhe Plain. The altitude range is -57m~2849m, and the slope is 0° ~67°.

Fig. 1. Jing-Jin-Ji region

2.2 Data introduction

Three types of data were used in this study: SRTM DEM data, remote sensing interpretation products based on Landsat imagery, and National Basic Geographic Information System data. The full name of SRTM is Shuttle Radar Topography Mission, which is mainly measured by the United States Space Agency (NASA) and the National Surveying and Mapping Agency (NIMA) of the Department of Defense. The acquired radar impact data is processed into high-precision terrain grid data, which is divided into SRTM1 and SRTM3, the resolution is 30 meters and 90 meters, respectively. The SRTM3 file contains 1201*1201 sampling point height data. The 30-meter and 90-meter DEMs in the Jing-Jin-Ji region are used in this article. Landsat is an American land exploration satellite system with an image spatial resolution of 30 meters and an image size of 185*185 kilometers. The interpretation product contains various types of land use data with a resolution of 1,000 meters. National basic geographic information data includes national boundaries, latitude and longitude networks, major highways, railways, etc. This article mainly uses provincial boundary data to cut DEM data to obtain DEM data for Jing-Jin-Ji.

3 Methods

3.1 Topographic feature points

Feature topographic points mainly refer to points that have a controlling effect on the spatial analysis and distribution of terrain on the surface. They are the basis for generating high-level topographic feature lines and surfaces, and are closely related to local topographic undulations. It mainly includes mountain vertices, depression points, ridge points, valley points, saddle points, flat points, etc. Among them, ridge points and valley points are the boundaries of the topographical undulations, describing the complex and undulating terrain skeleton structure, which controls the terrain contours, the ups and downs, trends and trends are of great significance to geomorphological research [7]. Therefore, the quality of the extracted feature points plays a vital role in the correct connection of the feature lines, the construction of the triangulation network and the accurate expression of the terrain.

The extraction of ridge points and valley points is divided into the following algorithms: methods based on image processing technology; methods based on terrain surface geometry analysis, methods based on terrain surface flow physical simulation analysis methods, and a combination of the two methods, such as using the angle tolerance method to judge the points on the contour, if the opening angle is less than the limited threshold, it is regarded as a feature point. This method is greatly affected by the points near the feature point, and the data cannot be extracted in the flat area. When the threshold is too large, the number of false feature points extracted will increase. If the threshold is too small, the micro-feature points will disappear, and the terrain details will be lost too much; the plane curvature and slope shape combination method, the width of the ridges and valleys extracted by this method can be determined by the plane curvature because the acquisition of plane curvature is more complicated, the slope direction variability (SOA) can well characterize the plane curvature to a certain extent [8]. Therefore, in the actual extraction process, the aspect variability is usually replaced by the plane curvature. The method is simple and the effect is good. Considering the complex terrain covering a variety of geomorphic features in the study area, a reasonable and unbiased aspect variability threshold is set to extract Topographic feature points.

3.2 Delaunay Triangulation

As a tool of numerical analysis, delaunay triangulated irregular network was first proposed by Delaunay in 1934. It is a set of connected but non-overlapping triangles. It has an empty circumscribed circle, maximum and minimum angles, and construction. The three characteristics of uniqueness have the characteristics of simple data structure, small storage space, easy to update, and adapt to multiple point distribution methods [9].

The divide and conquer algorithm proposed by Shamos and Hoey [10], and the point-by-point insertion algorithm proposed by Lawson [11]. Although the triangulation growth algorithm is easy to implement, its efficiency is low. It is time-consuming to find the third point. It is difficult to establish the generating point and its application is limited. In addition, from the algorithm flow point of view, the room for improvement is relatively limited, and it has been rarely used at present [12,13]. The latter two are the mainstream algorithms currently used in most studies, and both have their own advantages [14-16]. The divide and conquer algorithm is an algorithm that divides the point set data in the geometric plane and then merges it. It divides the discrete point set recursively until the discrete point set contains only 3 points to form a triangle, and then merges it level by level from bottom to top. Subnet, the final generation of the triangle network, this algorithm is the most efficient, but the efficiency of the network construction is limited by the discrete point set division method, the subnet generation algorithm and the subnet merging algorithm, and due to its frequent use of recursive operations, the program operation process is occupied a large amount of memory can not handle massive data; the implementation process of the point-by-point insertion algorithm is relatively simple, the performance is stable, and the required memory is small, which is suitable for processing massive data, so it is widely used [17-19]. According to the usage of retrieving and locating the triangle where the interpolation point is located, it can also be divided into search insertion method and topological insertion method. The search and insertion method needs to search for each generated triangle one by one and determine whether the insertion point is in the triangle. With the sharp increase of triangle data, the search efficiency will drop sharply, which is unacceptable for massive data, but it does not rely on topological relations prerequisite requirements. The topological insertion method usually finds the triangle where the insertion point is located along the path by specifying the starting triangle and searching through the direction according to the topological relationship. It is more efficient than the search and insertion method, but it is related to the maintenance of the starting triangle and the length of the search path.

3.3 Surface area calculation

The value of the surface area is the sum of the area of all triangles in the triangulation. The area of each triangle is obtained by Helen's formula, and the expression is as follows:

$$S = \sqrt{p(p-a)(p-b)(p-c)} \tag{1}$$

Among them, a, b, and c are the lengths of the three sides of the triangle, which are obtained by the elevation values and horizontal distances of the ridge points and valley points forming the triangle; p is half of the circumference of the triangle.

4 Data processing

4.1 Acquisition of DEM in Jing-Jin-Ji Forest Land

First, the DEM covering the Jing-Jin-Ji region is tailored with provincial boundary data to obtain the Jing-Jin-Ji DEM data. Then extract the Landsat TM image interpretation product, and the processed file only retains the woodland data (where the code 21 represents forest land, 22 represents shrub woodland, 23 represents sparse woodland, 24 represents other types of woodland), and performs projection transformation on it, in order to keep consistent with the DEM data, the zoning projection deformation is small, so the influence of the deformation on the area calculation can be ignored. Convert the transformed data into binarized raster data, and count the number of woodlands in the Jing-Jin-Ji region as 44671, and sum up to get the forest land in Jing-Jin-Ji area the projected area is 44671km^2. Finally, the DEM data is trimmed with the forest land data to obtain the forest land DEM data in the Jing-Jin-Ji region.

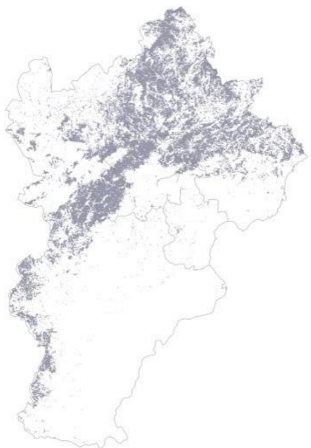

Fig. 2. Forest land distribution of Jing-Jin-Ji region

4.2 Extract ridge points and valley points

The DEM data of the forest land in the Jing-Jin-Ji region is used to extract the slope variability of the ground and the positive and negative topography of the ground. Take the large value of the positive topographic upslope variability as the ridge point, and the large value of the negative topographic upslope variability valley point, and set a reasonable slope variability threshold. If the maximum value of the local slope variability is greater than the threshold, the point can be judged as a feature point. A total of 45,673 ridge points and valley points are obtained, and the distribution is shown in figure 3. Taking into account the relatively fine distribution of part of the forest land, in order to avoid the formation of the triangulation network including other land use, the boundary breakpoints of the fragmented forest land are extracted.

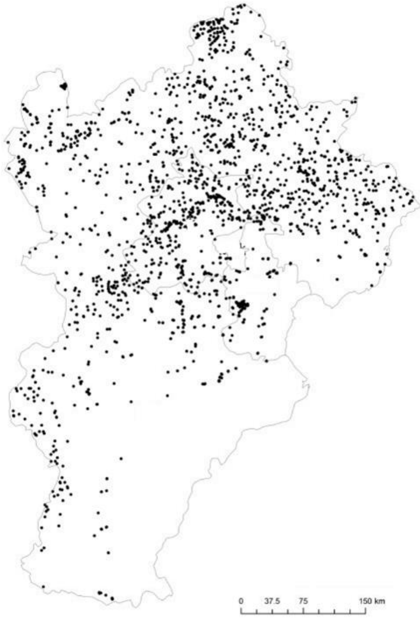

Fig. 3. Terrain feature points of forest land

4.3 Construction of Delaunay Triangulation

Taking into account the complex terrain and the large amount of data with a resolution of 30 meters in the Jing-Jin-Ji region, the study used a point-by-point insertion algorithm to construct a triangulation network. The specific process is as follows:

1. Establish an initial bounding box containing all terrain feature points and woodland boundary vertices obtained in the previous step, and construct a super triangulation network based on the initial bounding box;
2. Insert any point of the ridge and valley point into the existing triangle network, find the triangle where it is located, connect the topographic feature points with the vertices of the triangle, and generate a new triangle;
3. Repeat step 2 until all points are inserted.
4. After the insertion of all terrain feature points and boundary breakpoints is completed, the triangulation network is optimized using the local optimal criterion to ensure that it is a delaunay triangulation network, and it is superimposed with the forest land remote sensing image again, and the triangles without forest land cov-

erage are deleted. The forest triangle network in the Jing-Jin-Ji region contains 91319 triangles.

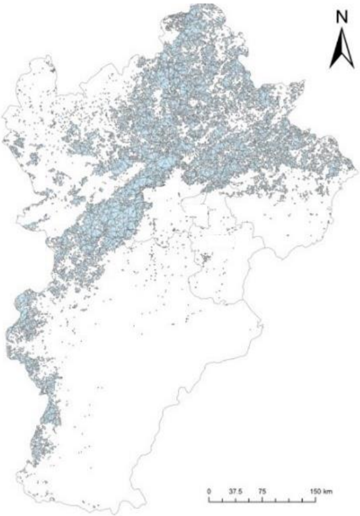

Fig. 4. Irregular triangle net of forest land in Jing-Jin-Ji region

4.4 Calculation of forest surface area

The number of triangles in the triangulation network is 91319. The calculated woodland surface area is 45577.82km^2, which is 906.82km^2 larger than the projected area. Further calculations show that the woodland surface area is about 2.03% higher than the projected area.

5 Results & Discussion

The calculation results show that the woodland surface area in the Jing-Jin-Ji region is 45577.82km^2, which is 906.82km^2 more than the projected area. Compared with conventional survey operators on-site measurement and direct calculation of projected area, area statistics using this method not only reduces manpower and material resources, but also improves efficiency, providing technical support for accurate statistics of forest land resources. Higher-resolution DEM data and remote sensing images reflect the details of the ground surface more specifically, the calculated surface area will increase correspondingly, and the amount of data will also increase significantly. The same is the DEM in the Jing-Jin-Ji region, and the grid is obtained from the 90-meter DEM. The number of units is 32386221, and the number of 30-meter grid units is as high as 291,529,693, which is 9 times that of 90-meter DEM, which places higher requirements on algorithm efficiency and computer performance. In specific research, DEMs with different resolutions can be selected according to different application purposes and research scopes. For example, for provinces and even smaller areas, 30 meters of data is more abundant, and 90 meters is more appropriate.

For the calculation of the surface area, this article is based on topographic feature points and delaunay triangulation. In the algorithm selection and design, comprehensive consideration is given to the complexity of the Jing-Jin-Ji region covering plains, hills, basins, mountains, plateaus, etc. The terrain and the huge amount of 30-meter DEM data balance efficiency and accuracy, and present the surface details as comprehensively and accurately as possible, while still being within the computational load. The terrain feature point algorithm used in this paper uses the aspect change rate to increase the plane curvature combined with the positive and negative terrain to extract the ridge and valley point position error, no offset, and the extraction effect is clear. The point-by-point insertion algorithm used in the triangulation structure inherits the advantages of the irregular triangulation in terms of terrain performance, and can flexibly change the unit size with the change of terrain characteristics, ensuring the complete presentation of the terrain and avoiding data redundancy in flat areas.

6 Conclusion

The Jing-Jin-Ji coordinated development of ecological environment protection plan" issued by the National Development and Reform Commission clearly stipulates five functional areas the Beijing-Tianjin-protected area that highlights the protection function of urban ecological space, the Bashang plateau ecological protection area that highlights the function of wind protection and sand fixation, and highlights the function of soil and water conservation the Yanshan-Taihang mountain water conservation area, the low plain ecological restoration area that highlights the ecological protection of farmland, and the coastal ecological protection area that highlights the marine ecological safety function. The Bashang plateau ecological protection zone and the Yanshan-Taihang mountain ecological conservation zone account for a large area, which is much higher than other functional areas. They belong to mountain plateaus with high slope grades and large woodland coverage, which is higher than the average level of the Jing-Jin-Ji region. Regional statistics using projection planes will produce large errors and underestimate the carbon sequestration capacity of forest land resources. The surface area measurement method in this paper can more accurately count the forest area, assess the carbon sequestration capacity and potential of the ecosystem, expand the environmental capacity and ecological space, reduce the ecological quality gradient in the region, and improve the ecological carrying capacity. The creation of an ecological pattern of green water and green mountains has important exploratory significance. With the development of 3S technology and the integrated application of the three, forestry engineering technology can quickly, accurately and efficiently obtain forest resource information, and realize the scientific management and sustainable use of forest resources.

References

1. CHEN Ji-long, WU Wei, LIU Hung-bin, “Calculation of the surface area of forestland using DEM,” Southwest China Journal of Agricultural Sciences, 2008, (05):1348-1352.
2. LI Yi-ping, WU Quan-yuan, ZOU Min, “HAN Cong-cong. Calculation of Forest Area in Longkou Based on DEM,” Remote Sensing Information, 2007, (03): 67-70.
3. FENG Zhongke, LIU Yongxia, WANG Xiaokun, “DENG xiangmi. Comparison of different survey and calculating methods of forestland area,” Journal of Beijing Forestry University, 2004, (05):17-21.
4. JIANG Fan, LV Xi ao-hua, WANG zhong-lan, “The Analysis of DEM Surface Area Based on Composed Calculus Algorithms,” Journal of Institute of Surveying and Mapping, 2005, (04): 263-265.
5. LI Zhan-rong, ZHANG Pei, “A Method for Area Calculation of Ridge of Field by DEM,” Bulletin of Surveying and Mapping, 2006, (04):39-41.
6. WANG Xiuyun, CHEN Ye, ZHOU Houhua, ZHANG Qian, “Application of DEM to Calculating the Surface Area of Forest Land,” Journal of Nanjing Normal University(Engineering and Technology), 2006, (01): 86-90.
7. CHEN Ting, ZHOU Ru·liang, ZHU Da—yun, HUANG Yu, “Comparative Study on Two Line Algorithm Methods of Terrain Feature Extraction Based on DEM,” Forest Inventory and Planning, 2011, 36 (06): 1-4+28.
8. YUAN Jianghong, Ou Jianliang, Zha Zhengjun., “Terrain Characteristic Point Extraction and Classification from Contour DEM,” Modern Surveying and Mapping, 2009, 32(03):3-6.
9. Hu J, Ma Z, Wu H, “Massive Data Delaunay Triangulation Based on Grid Partition Method,” Acta Geodaetica Et Cartographic Sinica, 2004, 33(2):163-167.
10. Green P J, Sibson R, “Computing Dirichlet Tessellations in the Plane,” Computer Journal, 1978, 21(2):168-173.
11. Lawson B C L, “Software for C surface interpolation,” Mathematical Software III. 2012.
12. Isenburg M, Liu Y, Shewchuk J, et al, “Streaming computation of Delaunay triangulations,” Acm Transactions on Graphics, 2006, 25(3):1049-1056.
13. Stearns M B, “Probability Distribution of a Network of Triangles,” Siam Review, 2006, 9(1):591-591.
14. LI Jian, “A Streaming Data Delaunay Triangulation Algorithm Based on Parallel Computing,” Geomatics & Information Science of Wuhan University, 2013, 38(7):794-798.
15. Yan H, “A MWVD-based Algorithm for Point Cluster Generalization,” Geomatics & Information Science of Wuhan University, 2013, 38(9):1088-1091.
16. Wu H, Guan X, Gong J. ParaStream, “A parallel streaming Delaunay triangulation algorithm for LiDAR points on multicore architectures,” Computers & Geosciences, 2011, 37(9):1355-1363.
17. ZHANG Zhen, “Parallel generation algorithm for Delaunay TIN with massive data,” Computer Engineering & Science,2013,35(04):1-7.
18. HUANG Quan, LIU Hao, LIANG Pingyuan, “Parallel construction algorithm of Delaunay triangulated irregular network,” Science of Surveying and Mapping, 2017,42(06):171-177.
19. YANG Jun, GAO Li, “Fast algorithm for building Delaunay triangulation based on grid division,” Science of Surveying and Mapping, 2016, 41(02): 109-114. (2015-07-21)