Automatic building extraction by Margon model

Mehran Dizbadi- Behrooz Arastoo- Mehran alizadeh Pirbasti-Samira Blori

Master of Civil Engineering - Remote sensing - Islamic Azad university of Shahrud

Mehrandizbadi.surveyor2008@gmail.com

Ph.D. in Remote Sensing and GIS - Agrayan Armenia- B.arastoo@areeo.ac.ir

Master Student in Remote sensing - Hekmat institute of higher education, Qom -0000-0003-2283-499X- mehran8official@gmail.com

Ph.D. in Remote Sensing and GIS- Department of Remote Sensing- Hekmat institute of higher education, Qom -0000-0002-3631-0153- sbloori@webmail.hekmat-qom.ac.ir

Abstract

In recent years, rural spatial information has become one of the most important tools in applications such as creating and updating the existing databases, and so on. The building is one of the most important features in rural areas. Extracting buildings from the images consists of two general sections: Building detection, which means determining the location of each building within the data set used, and building reconstruction, which means to reconstruct the two-dimensional or three-dimensional geometric model of each building. it is necessary to implement and develop new and effective methods for image processing (active curve models) in order to extract important features such as a building. In the present study, the image of the worldview-2 satellite was used to extract the boundary of the building from the image of Shahru in Hormozgan province. After preprocessing the image and applying the maximum likelihood classification method, the Margon model was implemented in the MATLAB programming environment to identify the primary areas of the building. To evaluate the results, the output of the proposed method was compared with the map, which was generated in the ArcGIS environment manually. The results indicate a total accuracy of 90%.

Keywords: Remote sensing, Building extraction, Active curve, World view-2 satellite, Margon model, Maximum likelihood method

1. Introduction

Today, due to the particular importance of buildings as one of the most crucial development infrastructures in each country in different applications, their information extraction has become an important challenge in related sciences. One of the technologies that have been widely used in this field is remote sensing along with the science of digital image processing. Currently,

identifying and mapping features from aerial and satellite images provided by expert operators will account for the most significant part of the cost and the time taken to produce a map of these images. Therefore, the automatic extraction of features from these images is one of the fundamental research questions of photogrammetry and remote sensing, followed in the direction of automatic mapping. The automatic extraction of features can be known as identifying and determining the location of features in images without the direct involvement of the human factor. This leads to reducing the required time and subsequently increasing the efficiency and cost-effectiveness of the spatial information production methods by reducing or eliminating the role of the human factor in producing the map. The automatic extraction of aerial and spatial images is part of a high-level image processing analysis, and a comprehensive system that can automatically extract features without any intervention of the human operator is not marketed yet. Thus this branch of science is in the research phase. Today, rapid population growth, urban development, and natural resource constraints have created such problems for humans that planning is considered necessary for all countries. The evacuation of villages, the expansion of cities, and the urbanization tendency, especially in Third World countries, have such complications that ignoring them will increase social and economic problems. The majority of the significant and strategic decisions taken by managers and planners are related to the situation and location of human handicaps in urban and rural areas. One of the cases that can be cited in the planning and analysis of the experts is the maps resulting from aerial and satellite images. The building is one of the most important terrains in large-scale urban and rural maps. Photogrammetric and remote sensing methods, in terms of the extension of the covered area on the one hand, and the acceptable accuracy of these methods, on the other hand, are known as suitable methods for producing and updating spatial information and covert maps. Therefore, its detection from aerial and satellite images is one of the major concerns of photogrammetric and remote sensing specialists. Increasing speed, reducing the role of the human operator, increasing accuracy, and reducing the cost are the reasons which increase the need for automatic and semi-automatic extraction through processing and analysis of images.

1.2. Literature Survey

In this field, Shouji Du et al. in 2017 presented a method for extracting buildings from LiDAR point cloud data by combining point-based and network-based features. To accurately distinguish buildings from vegetation, they proposed a point property based on the variance of natural vectors. For robust building extraction, a diagram cutting algorithm was used to combine the features and consider neighboring texture information. As the network feature calculations and diagram cutting algorithm are performed on a network structure, a DSM interpolation method with the feature retained in this paper is presented (Shouji Du et al., 2017).Wen Hao et al., in 2013 they present a complete strategy for extracting buildings from ground-based laser scanning data. First, a new partitioning method was proposed to facilitate the building extraction work. First, points were grouped based on standard and adjacent relationships. Second, flat surfaces were identified based on the results of segmentation based on Gaussian image properties. Finally, buildings are extracted from urban point clouds based on point sections such as shape, natural direction, and topological relationship (Wen Hao et al., 2013). Masakazu Iwai et al., in 2020, by accelerating the computational speed, used the automatic building extraction method, which used a diverse inferential Gaussian mixture model to perform color

clustering (Masakazu Iwai et al., 2020). Arvind Pandey et al., in 2020, aimed to automatically extract the building of an urban area using high-resolution data and fuzzy membership logic to classify the image object using electronic recognition software. As a result, the object-oriented method was implemented, and high-resolution Quick-Bird images were used for the automatic extraction of buildings (Arvind Pandey et al., 2020). Yuting Zhu et al., in 2021, To solve the convolutional neural network (CNN) problem in their research, a new semantic segmentation neural network called Edge-Detail-Network (E-D-Net) was proposed to divide the building from visible aerial images. The results showed that the proposed ED-Net offers significantly stronger and higher building extraction performance (Yuting Zhu et al., 2021). Yuwei Jin et al., In 2021, they built a new network with a conscious loss of a specific boundary is embedded, called the Boundary-Aware Refined Network (BARNet). They extracted BARNet performance on two popular datasets that include different urban scenes and various building patterns (Yuwei Jin et al., 2021). Nitin L. Gavankar & Sanjay Kumar Ghosh, In 2018, proposed a Top-hat morphological filter method and the K-means algorithm for extracting buildings with light and dark roofs.(Nitin L. Gavankar., Sanjay Kumar Ghosh., 2018) Also, other researches have been conducted in this field (Shrivastava, N., Rai, P.K., 2015; Pushparaj, J., Hedge, A.V., 2017; Raikar, A., Hanji, G., 2016; Aguilar et al., 2014; Gharibi et al.; Amarsaikhan D et al.; 2009; Zhang J., 2009; Floyer, E.A., 1882; N. Haghipour, J.P. Burg. 2014; Rottensteiner et al., 2005; Baillar d and Maitre, 1999; Vestri, 2006). Geometrical active contours consist of two significant types of edge-based and region-based active contours. Edge-based methods primarily use gradient information to locate object boundaries in the images; one of the famous models in this topic is snake mode. In 2005, S.D. Mayunga et al. Showed that modified snake models and the developed radial casting algorithm improved this extraction rate by 23% and made a significant contribution to improving building extraction from high-resolution satellite imagery. (S.D Mayunga and Y. Zhang et., 2005). Thanh Huy Nguyen et al., in 2019, motivated by the limitations of existing snake models in building extraction, presents an unattended and automated snake model for extracting buildings using optical images and unregistered LiDAR data set in the air, without manual starting points or training data (Thanh Huy Nguyen et al., 2019). Selassie Mayunga in 2016 A semi-automatic method for extracting buildings in planned and informal settlements in urban areas from high-resolution images has been introduced. The proposed method uses a modified snake model and a radial casting algorithm for the initial start of snake lines and the correction of building lines (Selassie Mayunga in 2016). Zhenfeng Shao et al., in 2020 They proposed a new deep learning network, called the Remaining Rehabilitation Network (BRRNet), for accurate and complete building extraction. The BRRNet consisted of two parts: the prediction module and the remaining purification module (Zhenfeng Shao et al., 2020). In 2010, Mustafa Kabolizade et al. improved the border extraction method based on the GVF snake model. Using a genetic algorithm, the snake model requires fewer operators and increased speed. Experimental results showed that this model could work intensely with images taken from urban areas with buildings with complex structures. (Mustafa kabolizade and et al., 2010). In 2010, Salman Ahmadi et al. built an improved active contour model and used aerial imagery to extract buildings automatically. other researches have contributed to improving this model (Siddiqi et al., 1998; Pi et al., 2007; Ying et al., 2009a,b; Lu D., Weng Q., 2007; D. Koc-San et al., 2014; S. Ghaffarian, 2014).

One aspect of the innovation in this research is the use of the output of the maximum probability classification method to determine the location of the initial curves of the model. Another aspect of the innovation in this study is to limit the production of the Margon model to the boundary of buildings. In order to determine the initial curves of the Margon model, the maximum probability classification method was used, which is described below.

2. Materials and methods

According to the flowchart (Flowchart1), the steps involved in this research are as follows:

- 1. Collecting the required research data including, satellite imagery, large-scale maps of the area, and ...
- 2. Preprocessing and preparing input data

Preparing input data to conduct this research requires preprocessing, which makes the desired results achievable. Preprocesses include geometric correction, radiometric correction, integration, or panchromatic image.

- 3. Determining the initial curves of the Margon model

As previously mentioned in the description of the Margon model, an initial curve is guided to the edge and boundaries in a repeat process. Therefore, a number of initial curves on the surface of the image are needed. The researchers have adopted various methods to determine the initial curve, each of which has its advantages and disadvantages. In this research, the production of the margon model is limited to the border of buildings. In order to determine the initial curves of the Margon model, the maximum probability classification method was used.

Thus, in the first step, the user needs to introduce the points of the building area in the input image of the algorithm. These points will be considered as educational data in the maximum likelihood classification method.

Then, a plot like an area and size apply to the results of the previous step. Also, to improve the performance of the Margon model, changes were made to the results of the previous step to determine the initial curves of the Margon model.

- 4. Preparing the input of the Margoon model

The input of the initial Margon model is a single-band image. The image used in this research is a four-dimensional multivariate image. In general, the goal of remote sensing projects is to use the complete spectral and geometric information in the image with minimal computational cost. Therefore, selecting the optimal input in accordance with the Margon model is another aspect of innovation of this research.

- 5. Implementing the Margoon Curve Model

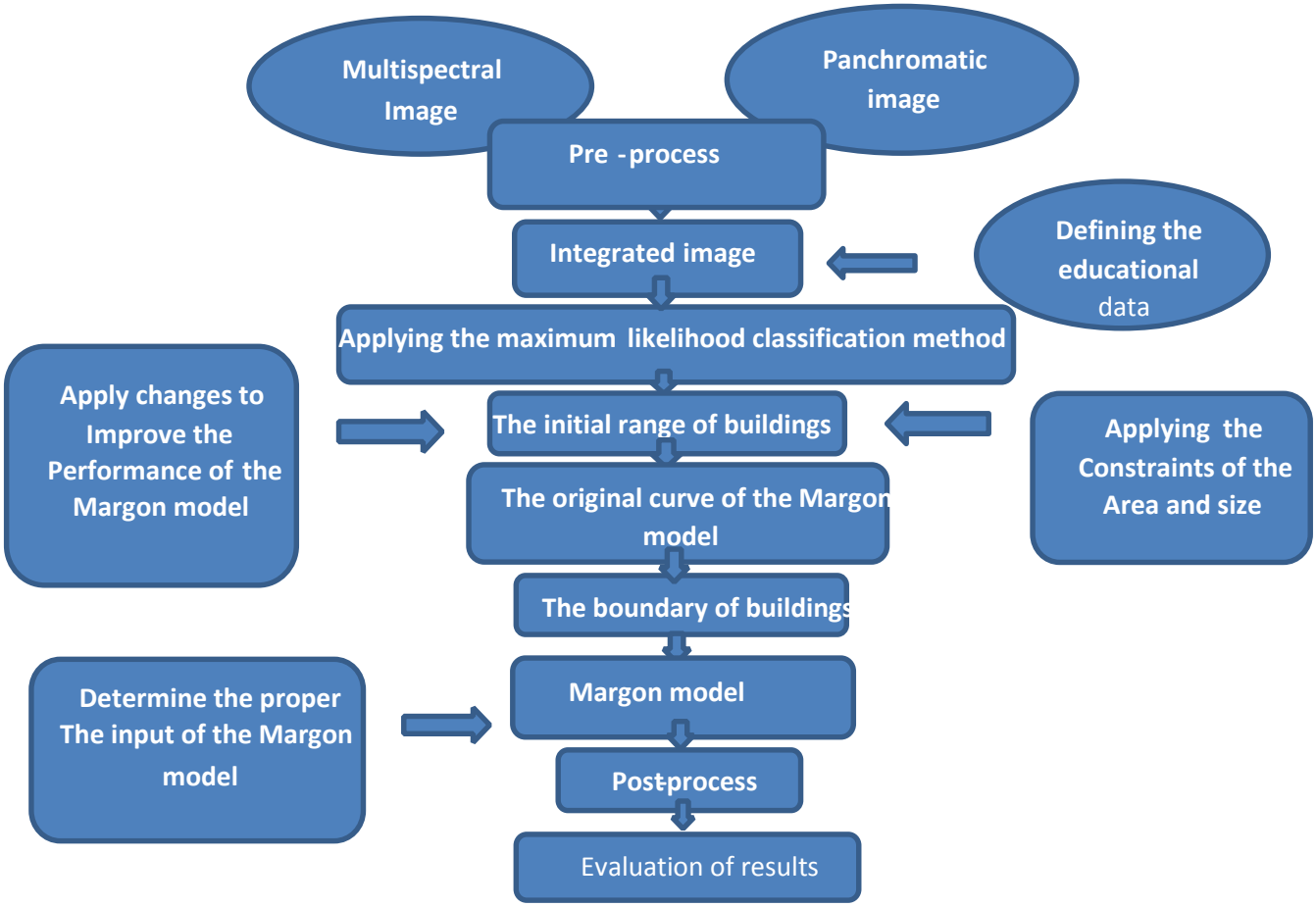
After determining the initial location of the curves and preparing inputs of the Margon model, it is necessary to implement the model. The steps in this section are implemented in MATLAB programming environment.

- 6. Post-processing

At this stage, processes need to be applied to the outputs of the Margon model. The result of these processes will improve the outputs for loading in the spatial information systems.

- 7. Evaluation of results

Ultimately, outputs are required to be evaluated.

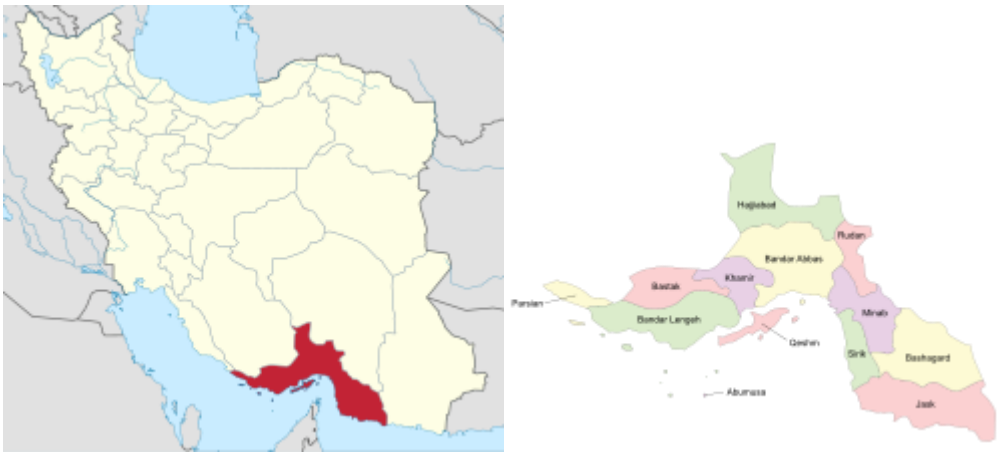


(Flowchart 1): The steps are taken in this research

2.2 The study area and data

Hormozgan is one of the southern provinces of Iran, and it is situated in the north of the Strait of Hormuz. Hormozgan province is located between northern latitude 25^0 24' to 28^0 57' and eastern longitude 53^0 41' to 59^0 15' from the Greenwich meridian (Fiq1). Due to its urban planning and geomorphological importance, the area has undergone numerous investigations since the

18th century; (i.e., Floyer, 1882, Lees, 1928, and Haghipour and Burg (2014)). Despite the attention it has received, this area has yet to receive the coastal classification. In this study, the world view-2 image was used (Table 1). The area in this study is Shahru in Hormozgan province, and the image was taken on March 21, 2017, from this region



(Figure 1)- Hormozgan Province location

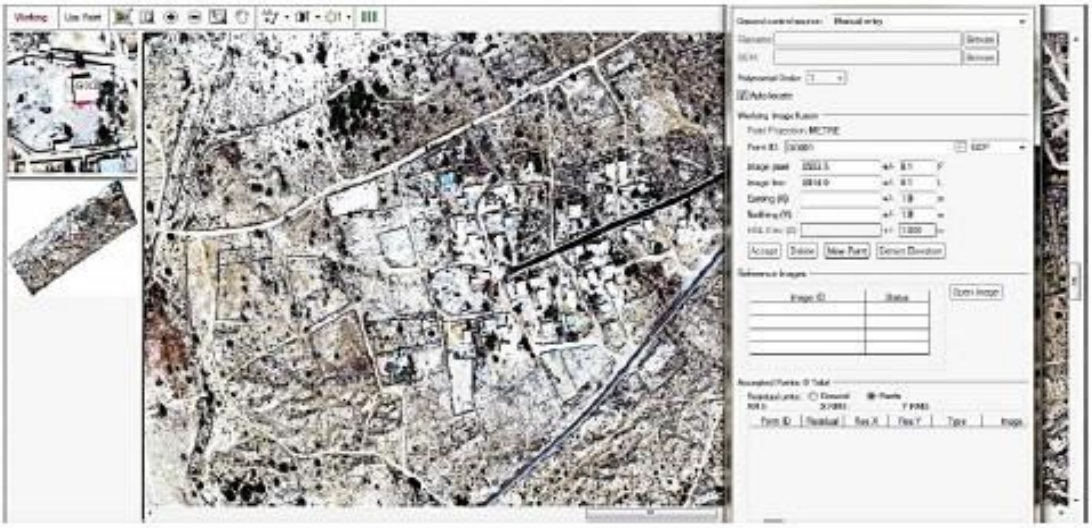
Launch time into space	2009
The height of the satellite orbit	770 km
The angle of the satellite orbit	97.2 °
Swath width	16.4 km
Radiometric resolution	11 bits
Band number	8 spectral band
Panchromatic spatial resolution	46 cm
Multi-spectral spatial resolution	1.84 m

(Table 1) The technical specifications of the satellite world view-2

3. Result and Discussion

3.1 Pre-process

For this purpose, the image obtained from the integration process was corrected geometrically, with the help of 10 control points in the image and in *PCI geomatica* software environment with a precision of 0.7 pixels. In addition, required control points were extracted from the large-scale map of the existing area for geometric correction. In the below figure (Figure1), the process is shown in the software environment mentioned above.

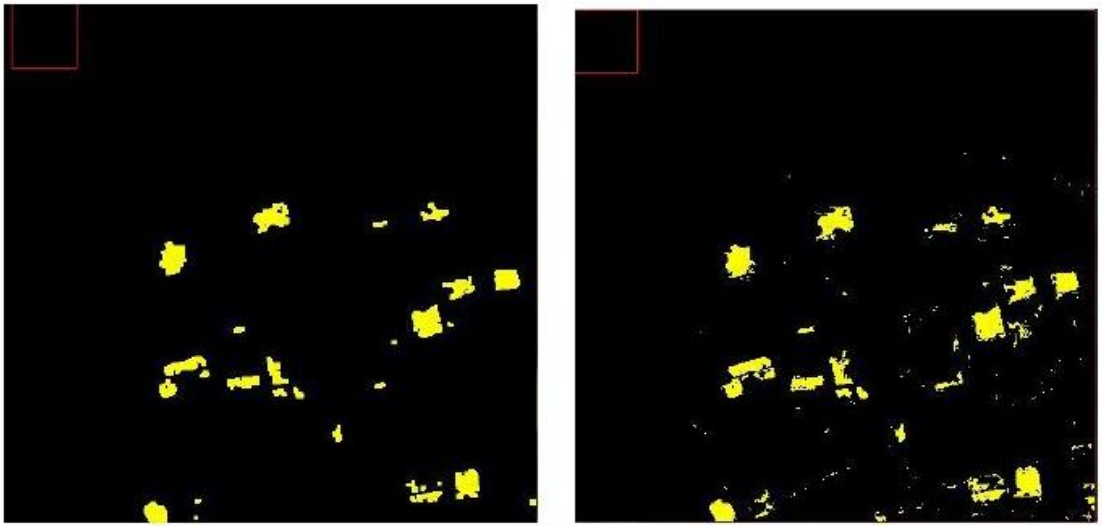


(Figure 1) Geometric Correction of integrated Image in PCI Geomatica Software

3.2 Applying morphological filter on classification results

After applying the classification method, constraints like size and area of building pixels are applied to classification results according to the research objectives that extract the boundary of the building in rural areas. For this purpose, morphological filters were used. (Figure 2)

- Dilation operation
- Erosion operation
- Opening operation
- Closing operation



(Figure 2): The impact of the threshold on eliminating terrain. Right (before applying), Left (after applying)

This step is significant from two perspectives: first, unwanted effects; in other words, output noise will be minimized. Secondly, you can control the size of the extracted effects by changing the size of the threshold. In other words, the extraction precision of the boundary of the building will increase.

Relationship (3-1):

$$\boldsymbol{P(w_i|x)^n = \frac{p(x|w_i)P(w_{i)}}{p(x)}}$$

$P(x)$: Probability Density Function x

$P(w_i)$: Posterior probability of class i

$P(w_i|x)$: Probability of belonging x to the class i

$P(x|w_i)$: The conditional probability density function of class i

3.3 Preparing the input of the Margon model

Margon model works with a single band. In other words, the input of this model is just a visual band. The image used in this study is multi-spectral with four bands of blue, green, red, and near-infrared. Principal Component Analysis is a conversion that is often used to reduce the dimensions of the data. Principal Component Analysis was performed on the quad-band image of the preprocessing stage in the ENVI software environment. (Figure3)



(Figure 3): The first component of the principal component analysis

3.4 Implementing the input of the Margon model

After determining the initial position of the curves and preparing inputs of the Margon model, it is necessary to implement it. The steps in this section are implemented in MATLAB programming environment so that the inputs of the Margon model can be stored in *.tiff* format. Then, they are called in the MATLAB environment. In the present study, the input image was considered as the first component of the PCA conversion. The stop condition was also considered as algorithmic repetitions. In a way, those different repetitions were tested 5, 10, and 15 times. The output of the proposed method for repetitions 10 and 15 is shown in the following figure. (Figure4 & Figure5)

Relationship (3-2):

$$\boldsymbol{E(c) = \mu.length(c) + \nu.Area\big(inside(c)\big) + y_{10}\int_{outside(c)} |u - c_{in}|^2 dxdy + y_{20}\int_{outside(c)} |u - c_{out}|^2 dxdy}$$

Relationship (3-3):

$$\boldsymbol{Quality\ percentage = 100 * (\frac{TP}{TP + FP + FN})}$$

Relationship (3-4):

$$\boldsymbol{Completeness} = \mathbf{100} * (\frac{\boldsymbol{TP}}{\boldsymbol{TP} + \boldsymbol{FN}})$$

Relationship (3-5):

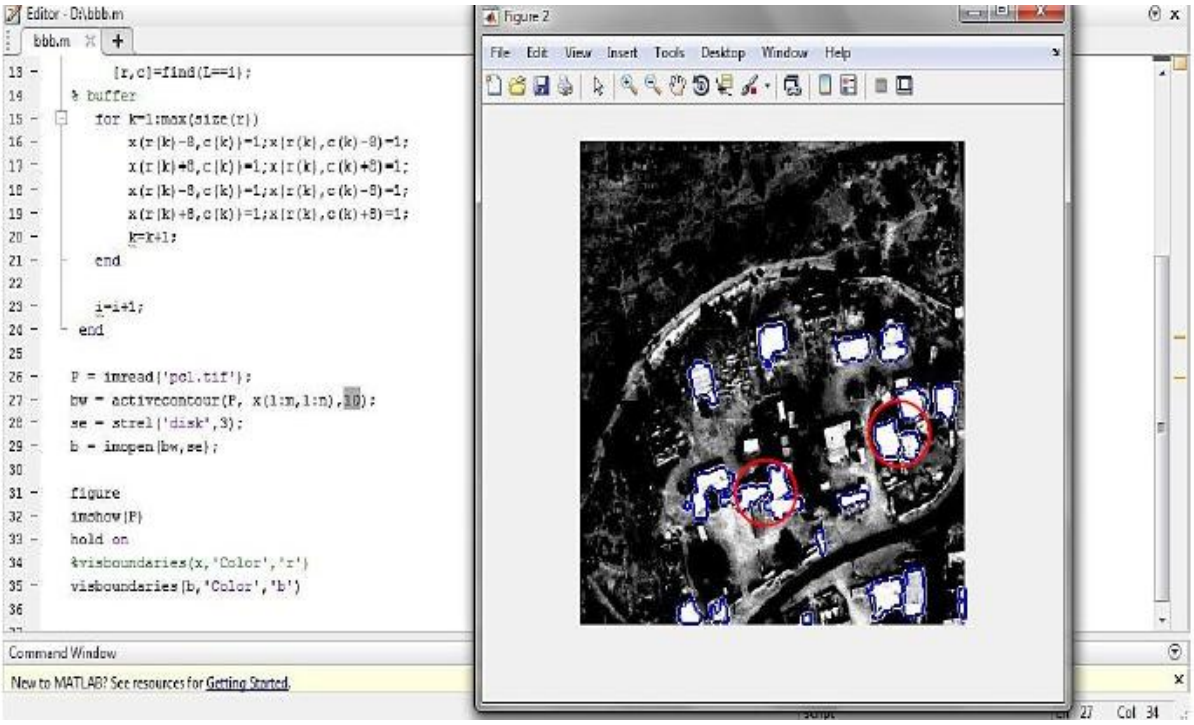
$$\boldsymbol{Correctness} = \mathbf{100} * (\frac{\boldsymbol{TP}}{\boldsymbol{TP} + \boldsymbol{FP}})$$

Relationship (3-6):

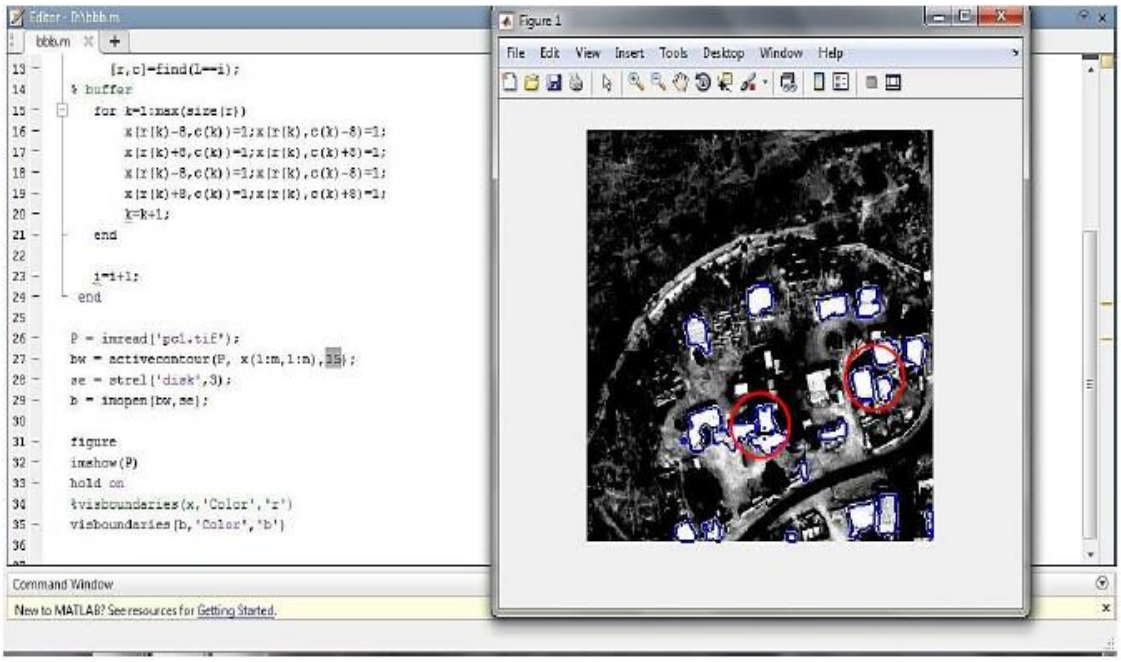
$$\boldsymbol{Omission} = (\frac{\boldsymbol{FN}}{\boldsymbol{TP} + \boldsymbol{FN}})$$

Relationship (3-7):

$$\boldsymbol{Commission} = (\frac{\boldsymbol{FP}}{\boldsymbol{TP} + \boldsymbol{FP}})$$



(Figure 4): The output of the proposed method in 10 repeats



(Figure 5): The output of the proposed method in 15 repeats

By comparing the above shapes in the areas of red circles, one can find the effect of repetition on the output of the proposed method. Repetition has completely removed the boundary of the building in the neighboring buildings. By evaluating the results of repetition 15, the output associated with this is optimal. For this purpose, the range of buildings within the image was manually digitized inside the ArcGIS software environment. Then, the base image was used as a comparison of the results. The figure below (Figure7) shows how to create the base image and digitize the construction boundaries in the software environment.



(Figure 7): production of the base map

4. Conclusion

The most common way to express the accuracy of the maps generated from remote sensing images is to provide a superficial percentage of the image that has been correctly classified. The overall accuracy percentage represents the percentage of units that the result is correct. By comparing the base map and the output of the proposed method, the percentage of accuracy was calculated and equated to 90%. In other words, in the area studied in this research, 90 percent of buildings have been extracted correctly. No building has been extracted in the yellow square by examining the abovementioned figure and comparing the results of the proposed method and the input image. In the proposed method of this research, the classification method has been used as an innovation to determine the initial curves of the Margon. This is one aspect of the difference between the proposed method and the other methods developed by researchers in invalid papers. Using the classification method for determining the location of the initial curves has advantages such as increasing the speed of convergence of the algorithm, reducing the implementation time, and increasing the accuracy of the outputs. Furthermore, the proposed method in this research can be used to detect the boundary of other features such as path, vegetation, etc., in the image. In other words, the proposed method of this study is highly capable of generalizability compared with other methods developed invalid papers. In the early stage of education, it is sufficient to introduce the desired terrain as educational data to the algorithm.

Classification is one of the methods used to process images for the automatic extraction of features. Our proposed method is usable in post-classification analysis to increase the accuracy of outputs. This is another advantage of the proposed method in comparison with the methods of other researchers in the world. Using the maximum likelihood classifier is one aspect of innovation to determine the initial curve in this research. The benefits are as follows:

- This research aims to extract only the boundaries of buildings, not all in the picture. The boundaries of the buildings have to be only extracted. Thus, by adopting the proposed solution, the algorithm's output will be limited to the boundaries of the building.
- Despite the many advantages and widespread use, classification methods are primarily defective. For example, the classification and extraction of buildings influence outputs by any change in the ceiling of the houses like a shadow, color, or other effects in rooftops. However, in the proposed method, the detail of the interior does not affect the quality of the results due to the movement of the curve from the outside to the edges of the building. This is an important issue in increasing the level of detection of buildings.
- The proposed method can be applied as post-processing of classification methods. In this way, the disadvantages of the methods are covered.

Data Availability

Open license

5.Sources and references

[1] Neeti Shrivastava, Praveen Kumar Rai., 2015. Remote-sensing the urban area: Automatic building extraction based on multi-resolution segmentation and classification. Malaysian Journal of Society and Space 11 issue 2 (1 - 16)

[2] Jagalingam Pushparaj, Arkal Vittal Hegde, 2017. A comparative study on extraction of buildings fromQuickbird-2 satellite imagery with & without fusion, ELECTRICAL & ELECTRONIC ENGINEERING, 4: 1291118. https://doi.org/10.1080/23311916.2017.1291118

[3] Amit Raikar, Geeta Hanji., 2016, Automatic Building Detection from Satellite Images using Internal Gray Variance and Digital Surface Model. International Journal of Computer Applications 145(3):25-33. DOI: 10.5120/ijca2016910418

[4] Manuel Ángel Aguilar, María del Mar Saldaña, Fernando José Aguilar. 2014. Generation and quality assessment of stereo-extracted DSM from GeoEye-1 and worldview-2 imagery. IEEE Transactions on Geoscience and Remote Sensing, 52(2), 1259-1271.

[5] Hossein Arefi, H Hashemi, Thomas Krauß, M. Gharibia.,2014, Updating LiDAR DSM using high-resolution stereo-based DSM from Worldview-2, The 1st ISPRS International Conference on Geospatial Information Research, 15–17 November 2014, Tehran, Iran. DOI: 10.5194/isprsarchives-XL-2-W3-59-2014

[6] D. Amarsaikhan, H.H. Blotevogel, J.L. van Genderen, M. Ganzorig, R. Gantuya & B. Nergui.,2010, Fusing high-resolution SAR & optical imagery for improved urban land cover & classification, International Journal of Image and Data Fusion, Vol. 1, No. 1, 83-97, 2009. https://doi.org/10.1080/19479830903562041

[7] Jixian Zhang.,2009, Multi-source remote sensing data fusion: status and trends, International Journal of Image and Data Fusion Vol. 1, No. 1, 5–24, 2009. https://doi.org/10.1080/19479830903561035

[8] D. Lu, Q. Weng.,2007, A survey of image classification methods and techniques for improving classification performance, International Journal of Remote Sensing, Vol. 28 No.2, 823-870,2007. https://doi.org/10.1080/01431160600746456

[9] Dilek Koc San, Mustafa Turker,2014, Support vector machines classification for finding building patches from IKONOS imagery: the effect of additional bands, Journal of Applied Remote Sensing, Vol. 8, No.1, 2014.

[10] Saman Ghaffarian, Salar Ghaffarian, Automatic building detection based on Purposive FastICA (PFICA) algorithm using monocular high-resolution Google Earth images, ISPRS J. Photogramm. Remote Sens., vol. 97, pp. 152–159, Nov. 2014.

[11] Floyer, E.A., 1882. Unexplored Balūchistan: A survey, with observations astronomical, geographical, botanical, etc., of a Route through Mekran, Bashkurd, Persia, Kurdistan, and Turkey, Griffith & Farran.

[12] G.M. Lees.,1928, The geology and tectonics of Oman and parts of south-eastern Arabia. Q. J. Geol. Soc., 84 (1–4) (1928), pp. 585-670

[13] Negar Haghipour, Jean, Pierre BurgJean,2014, Geomorphological analysis of the drainage system's growing Makran accretionary wedge. Geomorphology, 209 (2014), pp. 111-132, DOI: 10.1016/j.geomorph.2013.11.030

[14] Yuting Zhu, Zili Liang, Jingwen Yan, Xiaoqing Wang, E-D-Net: Automatic Building Extraction From High-Resolution Aerial Images With Boundary Information, 2021, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing PP(99):1-1, DOI: 10.1109/JSTARS.2021.3073994

[15] picture of Hormozgan, https://en.wikipedia.org/wiki/Hormozgan_Province

[16] Ying, Z., Guangyao, L., Xiehua, S., Xinmin, Z., 2009b. Geometric active contours without re-initialization for image segmentation. Pattern Recognition.

[17] Ying, Z., Guangyao, L., Xinhua, S., Xinmin, Z.,2009a.A geometric active contour model without re-initialization for color images. Image and Vision Computing

[18] Shouji Du, Yunsheng Zhang, Zhengrong Zou, Siyang Chen, Automatic building extraction from LiDAR data fusion of point and grid-based features, 2017, ISPRS Journal of Photogrammetry and Remote Sensing 130:294-307, DOI: 10.1016/j.isprsjprs.2017.06.005

[19] Thanh Huy Nguyen, Sylvie Daniel, Didier Guériot, Jean-Marc Le Caillec, 2019, Unsupervised Automatic Building Extraction Using Active Contour Model on Unregistered Optical Imagery and Airborne LiDAR Data, DOI: 10.5194/isprs-archives-XLII-2-W16-181-2019

[20] Salman Ahmadi, Mohammad Javad Valadan Zoej, Hamid Ebadi, Ali Mohammadzadeh.,2010, Automatic urban building boundary extraction from high-resolution aerial images using an innovative model of active contours, International Journal of Applied Earth Observation and Geoinformation 12(3):150-15712(3), DOI: 10.1016/j.jag.2010.02.001

[21] Wen Hao, Yinghui Wang, Xiaojuan Ning, Xiaopeng Zhang, Automatic Building Extraction from Terrestrial Laser Scanning Data, 2013, Advances in Electrical and Computer Engineering 13(3):11-16, DOI: 10.4316/aece.2013.03002

[22] Christophe Vestri, 2006. Using range data in automatic modeling of buildings. Image and Vision Computing 24, 709–719. DOI: 10.1016/j.imavis.2005.12.015

[23] Baillarda C, Maîtreb H, 1999. 3D reconstruction of urban scenes from aerial stereo imagery: A focusing strategy. Computer Vision and Image Understanding 76 (3),244–258. https://doi.org/10.1006/cviu.1999.0793

[24] S.D Mayungaa , Dr. Y. Zhanga, and Dr. D.J. Coleman., 2005. Semi-automatic building extraction utilizing Quickbird imagery. IAPRS XXXVI (Part 3/W24), 29–30.

[25] K Siddiqi, Y B Lauzière, A Tannenbaum, S W Zucker, 1998. Area and length minimizing flows for shape segmentation. IEEE Transaction on IP 7 (3), 433–443. DOI: 10.1109/83.661193

[26] Arvind Pandey, Mriganka Shekhar Sarkar, Gajendra Singh, Manish Kumar, Robust and Reliable Technique of Automatic Building Extraction from High-Resolution Imagery, 2020, In book: Geoecology of Landscape Dynamics, DOI: 10.1007/978-981-15-2097-6_6

[27] Mostafa Kabolizade, Hamid Ebadi, Salman Ahmadi.,2010. An improved snake model for automatic extraction of buildings from urban aerial images and LiDAR data, Computers Environment and Urban Systems 34(5):435-441, DOI: 10.1016/j.compenvurbsys.2010.04.006

[28]

[29] Zhenfeng Shao, Penghao Tang, Zhongyuan Wang, Chatpong Sommai, 2020, BRRNet: A Fully Convolutional Neural Network for Automatic Building Extraction From High-Resolution Remote Sensing Images, Remote Sensing 12(6):1050, DOI: 10.3390/rs12061050

[30] Masakazu Iwai, Takuya FUTAGAMI, Noboru HAYASAKA, Takao ONOYE, Acceleration of Automatic Building Extraction via Color-Clustering Analysis, 2020, IEICE Transactions on Fundamentals of Electronics Communications and Computer Sciences E103.A(12):1599-1602, DOI: 10.1587/transfun.2020SML0004

[31] Nitin L. Gavankar & Sanjay Kumar Ghosh., 2018, Automatic building footprint extraction from high-resolution satellite image using mathematical morphology, European Journal of Remote Sensing, 51:1, 182-193, DOI: 10.1080/22797254.2017.1416676

[32] Franz Rottensteiner,John C. Trinder, Simon Clode, Kurt Kubik., 2005. Using the Dempster–Shafer method for the fusion of LIDAR data and multispectral images for building detection. Information Fusion 6 (4), 283–300. DOI: 10.1016/j.inffus.2004.06.004

[33] Ling Pia, Yaxin Peng, Chunli Shen, Fang Lic, 2007. Color image segmentation for objects of interest with modified geodesic active contour method. Journal of Mathematical Imaging and Vision 27 (1), 51–57. https://doi.org/10.1016/j.jmaa.2008.10.050