AUTOMATIC EXTRACTION OF DIGITAL TERRAIN MODEL AND BUILDING FOOTPRINT FROM AIRBORNE LiDAR DATA USING RULE-BASED LEARNING TECHNIQUES

By

HAMIDREZA MASKANI JIFROUDI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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June 2021

Chairman : Dato' Professor Shattri bin Mansor, PhD
Faculty : Engineering

Topographic information such as feature maps and digital terrain models (DTM) has always been a basic requirement in many engineering sciences. This is even more important in urban environments, because it is very difficult to update city maps, and this is more difficult in large cities due to the high rate of change. On the other hand, there is an increasing need for up-to-date maps, and this need is greater in larger cities due to the numerous map-related land uses. However, updating the maps takes a long time and incurs huge costs, which will prevent it from being done in short periods of time. Therefore, in this research an algorithm has been created which can achieve the following goals.

1) To generate DTM only with LiDAR data without the need for layers and other information from the area

2) To create a building footprint from the LiDAR data by removing the tree cover effect

3) To create an automatic system that can perform the production process of DTM and footprint without the intervention of an expert.

To achieve the first goal, the last reflection is separated from the LiDAR point cloud and the effective distance was calculated. In the next step, noise and roof errors were removed using KNN filter and a new network was created and re-evaluated based on the shortest distance in the LiDAR point cloud to create an integrated DTM. Finally, DTM that has been generated in this research compared by DTM that was created manually.
In the next step, after taking the filtering steps, the Buildings Footprint was created and was saved as a vector file in the output path by keeping the first reflectance, filtering the nearest neighbor, filtering based on intensity, creating a new network, applying the

height filter, filtering based on a closed range, applying the size filter, creating the initial boundary, performing noise removal at the boundary, correcting boundary fluctuations, and finally using the decision tree. Finally, the Buildings Footprint developed based on the algorithm was compared with the Buildings Footprint developed manually to assess the accuracy of the results.

In the last section, to achieve third goal, all process was written in Python computer language and DB-creator program was created and in a fully automatic process, the DTM and the Buildings Footprint were created and saved.

Based on the results, the RMSE value are ±0.62 meter for the urban and ±0.28 meter for rural buildings footprints. Also, Kappa coefficient that is 0.95. Considering the technical properties of LiDAR data used, the results could be considered completely accurate as compared to the accuracy of the available data. Therefore, it can be concluded that, although the DTM built in this study differs from the hand-built DTM in areas with synthetic structures, field studies have shown that this DTM can provide more details on synthetic environments and is more accurate due to the effects on the study areas of DTM made in this research.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENYARIAN AUTOMATIK MODEL TERAIN DIGITAL DAN JEJAK BINAAN DARIPADA DATA LIDAR BAWAAN UDARA MENGGUNAKAN TEKNIK PEMBELAJARAN BERASASKAN PERATURAN

Oleh

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Maklumat topografik seperti peta fitur dan model terain digital (DTM) senantiasa merupakan keperluan asas dalam kebanyakan sains kejuruteraan. Perkara ini adalah lebih penting dalam persekitaran bandar, disebabkan ia adalah sangat sukar untuk mengemas kini peta bandar, dan hal ini adalah lebih sukar dalam bandar besar disebabkan oleh kadar perubahan yang tinggi. Sebaliknya, terdapat keperluan yang meningkat bagi pengemaskinian peta, dan keperluan ini adalah lebih ketara di bandar yang lebih besar akibat begitu banyak penggunaan tanah berasaskan peta. Walau bagaimanapun, pengemaskinian peta tersebut memerlukan masa yang panjang dan menelan kos yang besar, yang akan mengelakkannya daripada dilaksanakan dalam tempoh yang singkat. Oleh sebab itu, dalam penyelidikan ini suatu algoritma dibina yang dapat mencapai matlamat berikut.

1) Untuk menjana DTM hanya dengan data LiDAR tanpa keperluan bagi lapisan dan maklumat lain dari kawasan tersebut

2) Untuk membina jejak binaan daripada data LiDAR dengan menghapuskan kesan kanopi pepohon

3) Untuk membina suatu sistem automatik yang dapat menjalankan proses penghasilan DTM dan jejak tanpa intervensi pakar.

Untuk mencapai matlamat pertama, refleksi terakhir telah diasingkan daripada takat awan LiDAR dan jarak yang efektif telah diukur. Dalam langkah seterusnya, kebisingan dan ralat bumbung telah dihapus menggunakan turas KNN dan rangkaian baharu telah dibina dan dinilai semula berdasarkan jarak terdekat dalam takat awan LiDAR bagi membina DTM bersepadu. Akhirnya, DTM yang dijana dalam penyelidikan ini telah dibandingkan dengan DTM yang dibina secara manual.

Dalam langkah selanjutnya, selepas langkah penurasan, Jejak Binaan telah dibina dan disimpan sebagai fail vektor dalam laluan output melalui penyimpanan kepantulan pertama, penurasan jiran terdekat, penurasan berdasarkan intensiti, pembinaan rangkaian baharu, pengaplikasian ketinggian penuras, penurasan berdasarkan julat terdekat, pengaplikasian penuras saiz, pembinaan sempadan awal, pelaksanaan penghapusan kebisingan di sempadan, pembetulan ginjatan sempadan, dan akhirnya penggunaan pepohon keputusan. Akhirnya, Jejak Binaan yang dibangun berdasarkan algoritma telah dibandingkan dengan Jejak Binaan yang dibangunkan secara manual bagi menilai ketepatan dapatan.

Dalam seksyen terakhir, bagi mencapai matlamat ketiga, semua proses telah ditulis dalam bahasa komputer Python dan program DB creator telah dibina dan dalam proses automatik sepenuhnya, DTM dan Jejak Binaan telah dibina dan disimpan. Berdasarkan dapatan kajian, nilai RMSE ialah ±0.62 meter bagi bandar dan ±0.28 meter bagi jejak binaan luar bandar. Di samping itu, koefisien Kappa ialah 0.95. Memandangkan sifat teknikal data LiDar yang digunakan, dapatan dianggap amat tepat berbanding dengan ketepatan data yang sedia ada. Oleh sebab itu, dapat disimpulkan bahawa, walaupun DTM yang dibina dalam kajian ini berbeza daripada DTM buatan tangan di kawasan berstruktur sintetik, kajian lapangan telah menunjukkan bahawa DTM dalam penyelidikan ini dapat memberikan perincian yang lebih mengenai persekitaran sintetik dan ia adalah lebih tepat akibat kesan kawasan kajian DTM yang dibina dalam penyelidikan ini.

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Thanks to God Almighty that despite all the problems, I was able to finish my dissertation and achieve the desired goals. I hope that the results of this research can be a small step towards the development of science and knowledge in order to serve humanity.

Here, I consider it necessary to express my gratitude to my dear supervisor, Dato' Professor Dr. Shattri B Mansor, because it would not have been possible to reach this stage without his sincere support. I would also like to thank Professor Dr. Biswajeet Pradhan for paving the way in the beginning of this research with their valuable guidance. I also consider it necessary to thank my dear friend and professor, Professor Dr. Hashemi, because it would not have been possible to start this path without his sincere support and cooperation.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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INTRODUCTION

1.1 Background

In the past three decades, the generation of ground data has undergone drastic changes, as it has shifted, in the first step, from traditional and ground surveys to passive surface measurement and recording techniques (such as photogrammetry and remote sensing) and, in the next step, to active techniques (such as radar and LiDAR). This is because since a long time ago, the topographic information such as feature maps and digital terrain model (DTM) has been considered one of the basic needs of many experts working in the areas such as urban management, power transmission management and design, road and highway construction, and coast and water resources management (Ackerman, 1999; Flood, 2001; Rezaei et al., 2018).

The experience has shown that the previous data collection methods, though bringing tremendous success to human society, have always been confronted with the shortcomings. Therefore, the discussed methods were more and more completed to solve some of the existing needs and problems. In fact, it can be stated that new methods complement the previous ones with new innovations. Light detection and ranging (LiDAR) is one of the most sought-after methods owing to the high speed and good accuracy. LiDAR consists of two types: terrestrial and aerial.

The terrestrial type is used as fixed on the ground or moving on the car. The aerial type can be installed in aircraft and includes the components such as GPS, inertial measurement unit (IMU) and LiDAR scanner which make it possible to perform the data collection process. It is evident that each of the tools has a specific task. For example, the IMU, which is directly connected to or installed near a laser scanner, is responsible for recording the acceleration and rotation during the data collection. The combination of components such as GPS and IMU allows to reconstruct the flight path with an accuracy better than 10 cm.

Modern scanners are capable of generating 20 gigabytes of data per hour by emitting about 300,000 laser pulses per second; however, with the combination of GPS and IMU, the ability to collect data will be a little more than 0.1 gigabytes of laser pulses per hour (Vosselman and Mass, 2010) which is still a significant number. The result of using this system is a cloud of points with X, Y and Z coordinates. The processing of the point clouds is usually based on the application of various filters to extract ground surface points.(Klapste et al., 2020) The raw data (from laser scanners) includes all points of ground surface and all terrain features such as vegetation, trees, buildings, etc., which is called digital surface model (DSM). In order to obtain the DTM model, different filtering methods are used, and the output usually leads to the division of points into the terrain and off-terrain groups, which is obtained after DTM interpolation (Farshad & Farzaneh, 2018). A very important point to note in LiDAR data point clouds is the possibility of examining the DTM and DSM of the same data type, which highlights the importance of LiDAR data, because the change in any environment is manifested by the changes both in the terrain and in the existing features.

Examined across the terrain, digital terrain model (DTM) is, in fact, a statistical representation of the continuous surface of the earth using a number of points with specific coordinates (Amini Amirkolaee et al., 2017) in the raster format. It is considered one of the most important products of photogrammetry and remote sensing and forms the basis for many practical projects, and has always been considered by various experts (Seif & Mahmoudi, 2013).

This is because the planning in a wide range of executive works such as surface water collection, change of river course, environmental changes leading to change in the course of water flow and many other operations related to the urban and environmental planning requires the DTM terrain map. However, due to climate and traffic characteristics, the terrain is constantly changing even in the cities that have no construction. However, in many cases, the urban topographic map is prepared by surveying a few points in each area and creating a topographic map in the form of contour lines. While any change in the situation of the roads, albeit small, can change the flow of surface water and subsequent urban planning, however, despite the importance of the above map, existence of tall buildings and various urban features, the fast and accurate generation of the terrain map by traditional techniques is faced with serious problems.

In theory, however, LiDAR can generate the digital model of the ground surface at a high speed with comparable accuracy to the traditional methods (Flood, 2001; Fowler, 2000). Because of this, LiDAR is now widely used in earth-related sciences. So that, studies on the physical properties of trees (Wang et al., 2020; Cosenza et al., 2020; Wang & Lin, 2020), vegetation extraction (Hu, et al.., 2019), or water behavior related studies (Richter et al., 2021; Zhan et al., 2021)) Archaeological related studies (Štular et al., 2020) and flood-related studies (Liu et al., 2021; Atirah Muhadi et al., 2020) are only a small part of the studies that used LiDAR data. However, in urban study there are different situation. It has been proven that the extraction of the digital model from urban areas and complex and uneven environments is very difficult even using the modern methods (Sithole & Vosselman, 2004; Liu, 2008).

Another important issue for the generation of surface maps is the rapid and accurate creation of the map of features existing on the ground surface. One of the topics with which human societies are preoccupied today is the residential spaces, especially cities. Urban spaces are a social product that have been formed as a result of intelligent human relationships with the surrounding environment, and hence, the great importance of the changes in cities is not far-fetched. Meanwhile, buildings are one of the most important elements in urban spaces, as they occupy the largest urban space per capita and are the key part of information in a three-dimensional model of the city. Therefore, extracting the buildings from remote sensing data is an important step to construct the digital model of a city (Rezaei et al., 2018).

According to the research of European Organization for Experimental Photogrammetric Research (OEEPE), the most important favorite part of a virtual urban model is the three-dimensional model of buildings. This research also shows that the use of photogrammetric and remote sensing methods is the only economical solution for the generation of such models (Forstner, 1999). For this reason, identifying and extracting the buildings and their three-dimensional (3D) reconstruction has become an important research topic (Brenner, 2000). This has caused the extraction of buildings from the aerial images, followed by satellite images, to begin over the past few decades, but the problems such as the shadows and the areas hidden under other features, complexity of the 3D model of buildings and diversity in their physical form have made this a challenging issue in photogrammetry (Rottensteiner & Jansa, 2002). With the introduction of the aerial LiDAR in the field of geomatics as an active sensor generating 3D data, a great change was made in the field of preparing initial data for the generation of 3D models of urban areas (Ackerman, 1999). Subsequently, the developers and researchers in geomatics were inclined to offer various techniques for extracting the required features from the external data such as buildings and roads using the laser data (Hebel & Stilla, 2008; Liberata et. al., 2020). Another advantage of LiDAR is the penetration power of the laser pulse into the vegetation, so that by recording several returns from the emitted pulse, the primary and secondary pulses are obtained, which can extract the vegetation using the return pulses of LiDAR (Rezaei et al., 2018).

In this way, the point clouds obtained from the LiDAR data provide a large amount of information about the form of buildings, which theoretically makes it possible to automatically extract the buildings. Due to the high speed and accuracy of LiDAR data, it can survey an entire medium-sized city in a short time. For this reason, the LiDAR data is of particular importance compared to the traditional aerial mapping techniques for urban spaces (Alharthy& Bethel, 2012).

However, one thing must always be kept in mind: the number of buildings in a city is very large. Therefore, in order for the proposed methods to be operational, the buildings should be extracted in an automatic manner. Therefore, one of the most important issues in the urban environments is the automatic or semi-automatic extraction of urban features such as buildings and roads, which has been considered in remote sensing and photogrammetry. The research in this field has been started since the late 1980s and various data sources such as single-band images, color images, stereo images, multiple images and LiDAR data have been used to obtain the feature extraction (Peng et al., 2005; Zare et al., 2015).

In this respect, various data have been used for the automatic and semi-automatic extraction of buildings. These resources include LiDAR point clouds, aerial and satellite images, digital elevation models (DEMs), Digital Terrain Models (DTMs) and many other layers, and in most methods, it was tried to extract the buildings by integrating and utilizing the aerial and satellite images with LiDAR data (Rezaei et al., 2018). Today, the existence of more powerful processors and, at the same time, the direct use of 3D geo-referenced data, which is the most important advantage of LiDAR data over other data and allow to develop automated algorithms (Rabbani et al., 2007), there is a growing tendency to use artificial intelligence algorithms. However, there are still problems such as processing very large amounts of data, presence of noise in data, failure to explicitly display the edges, and lack of explicit interpretation of the texture component in the LiDAR data (MacIntosh & Kurpnik, 2002; Kavosh., 2008) that have caused many researchers to still pay special attention to integrating this data with other data sources, such as aerial imagers, existing map data, and InSAR data. However, the fact remains that it is very challenging to develop a suitable method for extracting the maps of buildings in dense urban areas (Jaynes et al., 2003), as there is no single method to extract the maps of urban buildings based on the current findings (Azizkhani & Kiamehr, 2010).

According to the explanations, in this research, it was tried to generate the DTM and building footprints using the LiDAR data based on a completely automatic structure. In this regard, two goals are pursued: 1) Produce the results with appropriate accuracy and speed, 2) Eliminate the need in a system for a new layer in order to run the process and perform the process in a completely automatic manner. The first goal will help make the process operational, because one of the problems of the executive units is the long process needed to form the required layers. For example, if there is a need to develop a plan for flood control, forming the terrain layer in the shortest time will be the first goal, and if this is not possible, one will inevitably use the previous layers or faster methods and no matter how accurate the designed mechanism is, it will not actually work in the executive processes.

On the other hand, it should be noted that the use of each layer of information means the costs incurred and the need for an expert. However, in many offices, which are the main users of these layers, there are limitations in the above cases, and it is strongly believed that the commercialization of the findings goes through the automation of the system, so that it could be used by the experts on a large scale. In order to create an automated system that can make unique decisions in different situations, it was necessary to use artificial intelligence. Since this research uses a new algorithm and it is required to compare each point with part or all of the surrounding points, therefore, there is a need to use a programming language in order to design the required structures.

The Python language is used in this study, because it is an open-source language and there is no need to purchase any of the extensions. On the one hand, this language has been selected as a development language for powerful software such as ArcGIS and ENVI, which increases the possibility of closeness and simultaneous use of product results and the results of RS and GIS software and its commercialization. On the other hand, due to the widespread use of this language in the RS and GIS studies, there are many functions and libraries to be used in the RS and GIS environments and also the raster and vector data analysis, which can be used free of charge. In addition, Python is an operating system-independent language, which makes it possible to use production algorithms on a large scale. Hence, Python is the best language for developing the required algorithms.

Here, creating a fully automatic structure is one of the main goals of this research, so a method is required that can perform all the steps automatically without expert intervention. However, it should be noted that to create a fully automatic process, it is necessary to use many filters based on which any point should be compared to other surrounding points, which creates huge computational tasks and is only possible to perform in a completely intelligent environment. Therefore, the use of programming languages and artificial intelligence algorithms is the only way to automate these processes. On the other hand, the algorithms should be designed so that they do not need quantitative and qualitative data other than the initial data.

Therefore, rules are required that a computer program could produce prototypes by comparing the rules with each other, in other words, it does not need educational examples. So, the Rule-base method was the best and only suitable method for doing this. Because it was possible to create rules to compare different situations, eliminating the need for educational examples and the possibility of producing a fully automatic method. Hence the Rule-base method was chosen

The algorithm used in this research is designed in such a way that it first takes the path of the LiDAR data file and after performing the required processes, stores the DTM file in the raster format and the building footprint in the vector format in the output path and does not require a layer or information other than the LiDAR data.

In the other word, the review of previous research suggests that most researchers believe that using the data from different sources can yield better results, because the weaknesses of each data source can be offset by another. Hence, numerous research has been conducted on the combination of images and LIDAR data for the detection and extraction of objects (Sohn & Dowman, 2002; Schenk & Csatho, 2002; Rottensteiner & Briese., 2002; Nahhas et al., 2018; Wurm et al., 2021) This may solve the problem of forming a layer of high accuracy, because the use of many layers can definitely cover the problems in each layer and increase the accuracy of the work. It should be noted, however, that adding each layer means the increased cost of purchasing the layer, more processing time and, therefore, more robust hardware and more expertise

Another point that is clearly seen in previous research is the lack of attention to layer availability. The use of very high-resolution satellite images for the separation of building footprints is only applicable to research, because the extraction of building footprints based on the remote sensing science will definitely plan for large areas and for urban environments where the rapid change is its integral part. Certainly, for the automatic extraction, a huge amount of data should be processed, and in practical large-scale works, the manual digitization is faster and less expensive than this method. In general, it can be stated that in previous research, the factor of practical use of the findings has been completely ignored, because the need for limited layers, high speed of calculations and most importantly, automatic execution of the process are the essential needs to operationalize the findings. Of course, this attitude will need to review the executive system of filters and their performance and to develop new methods for eliminating the noises.

In this research, we propose the use of a rule-based algorithm and the decision tree to extract DTM and building footprints with the aim of operationalizing the research findings only based on LiDAR data unlike previous research. The algorithm used in this research is designed to first receive the path of the LiDAR data file and then save the footprint of the buildings in the vector format in the output path after completing the necessary processes. Except for the DTM layer, which can be built using the data used and LiDAR point cloud that does not require any other layer or information. As a result, the process is mechanized and the implementation cost is reduced considerably. Besides, unlike previous research that required training samples (Nahhas et. al., 2018; Lach et. al., 2008; Shinohara et. al., 2020) or additional information on the location (Chang et. al., 2008), The algorithm used in this research creates all the information needed from LiDAR data and given that it is tried to correct the flaws in the information by comparing the points to the whole set and the fact that sometimes complex calculations are needed and the entire process has to be automated, Python programming language is used. Because the Python supports the object-oriented libraries strongly (Nys et. al., 2020). Following a brand-new approach, the present research tries to fully automate the process of building footprint map preparation process. The mechanism of the designed algorithm is in such a way that it needs no redundant layer or piece of information. In practice, the developed code receives, as input, the address where the LiDAR data is stored on the PC and saves an output vector file in the output address. The code can not only produce quick building footprint maps, but also rapidly measure the perimeters and areas of the buildings – two important factors for urban and rural planning.

1.2 Concept

The first step in this study is to develop DTM. The layer that has been developed from DSM layer in many of the previous studies. Since DTM, DSM, and DEM are used in geology sciences, they are defined as follows:

1.2.1 Digital Elevation Model (DEM)

DEM is a raster data that represents the real shape of the earth such that each pixel has an elevation characteristic in addition to its geographical coordinate. Therefore, DEM is a raster data that includes elevation on bare earth, excluding elevation profile of human-made features and vegetation. The smaller are the cells of this network, the developed DEM has a higher spatial resolution, representing more details of the earth elevation.

1.2.2 Digital Terrain Model (DTM)

DTM is a 3D model of the earth surface, including X, Y, and Z data of an area. The heights in these models is not necessarily height from earth surface and includes other features like rivers, lakes, ridges, and channels. DTMs are DEMs that specifically include characteristics like the fracture lines between features. Thus, DTMs are more realistic models of the earth's surface. Today, with the increasing power of the computers in 3D representations, DTMs have found more applications in geology and engineering. The concept of DTM can be seen in Figure 1.1

1.2.3 Digital Surface Model (DSM)

DSM represents the surficial reflections of the trees, buildings, and other features above the bare earth and the earth's surface in areas where there is no human-made feature or vegetation. DSM represents the existing status based on x, y, z data, where each cell determines its geographical coordinate and height in the current location. The concept of DSM can be seen in Figure 1.1

1.2.4 nDSM

nDSM is another layer that is widely used in remote sensing research in cities. nDSM is a layer derived from the DSM-DTM formula, which means extracting the DTM value from the DSM. In other words, it is a layer that is only non- ground objects. The concept of nDSM can be seen in Figure 1.1

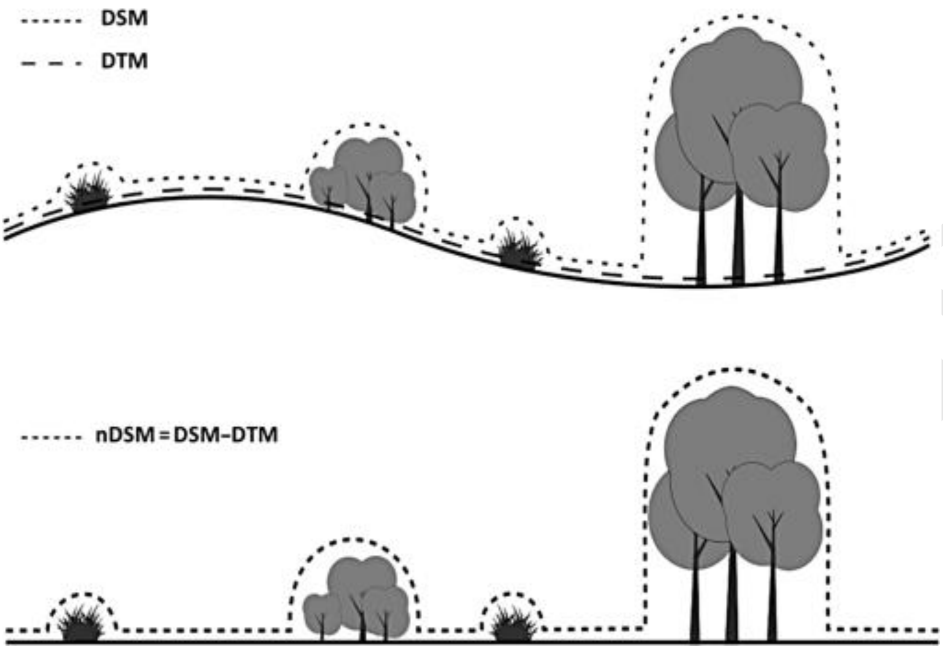

Figure 1.1 : The concept of DSM, DTM and nDSM (Miroslaw-Swiatek et al., 2016)

1.2.5 LiDAR

There are various types of Light Detection and Ranging. The type that is used here is aerial or topographic LiDAR. In general, the LiDAR system can calculate the position of the wave return point from the earth knowing the GPS (global positioning system) and INS (inertial navigation system) and calculating the round trip time and direction of the transmitted wave. The topographic LiDAR systems employ the 30000Hz frequency; and finally, the output of the LiDAR is stored as ALS data.

A LiDAR system has the following components:

- LRF (Laser Range Finder): to emit and receive laser, and determine distance
- GPS (Global Positioning system): to determine the position of the scan points
- IMU (Inertial Measurement Unit): determining status
- Computer: controlling online data reception
- Data Storage Unit: data storage

All of these components are installed on airplanes, helicopters, or any other flying vehicle that can carry it like UAV. To obtain the 3D coordinate (length, width, height) of each point of the laser pulse that has hit it, two other factors should also be known in addition to the measured length: position of the airplane that performs the measurements, and the direction of the laser altimeter. These values are usually obtained by GPS receivers inside the airplane that its reference receiver is on a specific point on the earth and INS. A laser altimeter combined with these components can be used to determine the absolute coordinate of the surface points with vertical and horizontal errors.

With the above information, the return time of a laser pulse emitted from the earth surface can be calculated to obtain the distance between the emission point from the earth surface. The round-trip time of the pulse is calculated through electronic analysis of the return pulse wave. Now, distance from the emission point of the pulse from the earth surface is obtained by multiplying the light speed in half of the round-trip time. Now, the distance of the pulse emission point from the earth surface is obtained by multiplying the light speed in half of the round-trip time. An array of the distance measurements, which is typically linear, is called “one scan”.

The distance between the points depends on the laser pulse emission rate, scanning angle, flight height, and airplane’s velocity. The flight height varies between 100m to 1km, however, the new system can be used at heights of 3km. Therefore, the distance of the points can be changed from 0.1m to 5m. Since the features on the earth are different in terms of material combination and height, the power of the returned pulse signal (echo of the emitted pulse) is also stored, and it is possible to receive multiple reflections of one pulse.

The laser signal might coincide with different objects while being transmitted towards the earth. A part of the transmitted signal might hit the vegetation and reflect to the receiver, and another part of it might hit the earth surface and its reflection is recorded by the receiver. In addition to these two returns, the laser signal might coincide with other features between these two paths and its reflection might be recorded by the measurement device. Today’s systems can record at least two different reflections for each transmitted signal, which are usually called the “first pulse” and the “last pulse”.

The first returns of the pulse are used in orthorectified generation and forestry applications and vegetation determination, while last pulses are used to measure bare earth. As the return wave type is used to measure the return time of a pulse, most systems use this to measure the power of the return pulse. This characteristic discriminates LiDAR system from conventional photogrammetry systems, because in vegetated areas, in addition to the DTM, a large part of the earth can be sampled using the last pulse and depending on the density of vegetation. (Iran Space Agency, 2019). The process of reflecting and receiving LiDAR can be seen in Figure 1.2

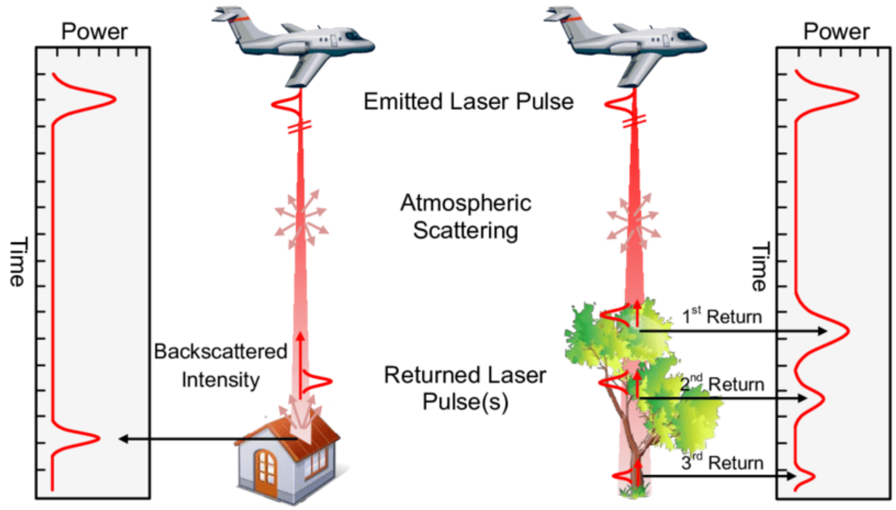

Figure 1.2 : The process of reflecting and receiving LiDAR (Yan et al., 2015)

1.2.6 Rule-Based Method

In this system, first, a set of rules is created and examined in an inference cycle of the input information based on the existing rules. One of the simplest examples of the rule-based decision-making is the algorithms used in banks, in which personal information is entered into the system and the possibility of obtaining a loan by the customer is examined based on existing laws. On the other hand, machine learning exists in this method, where the created algorithm learns from the employed data and the outcome of this training leads to a result. In this step, the human knowledge decides as rules in if-then loops. Machine learning is designed for a complex environment with various choices. However, its performance accuracy depends on its learning level, which is very costly, because for an optimal result, many records must be provided for training, and training on this data can take a long time. Thus, if choices lead to more limited results, it is better to use a rule-based approach (Carew, 2020; Shukla & Jain, 2020) in which decisions might lead to more accurate results (Wang et al., 2020).

1.2.7 Support vector machines (SVM)

Support vector machines are supervised learning methods that are used for classification and regression. The basis of SVM is linear data classification. This method tries to select a line to have a higher safety margin. In this method, the solution of finding the optimal line for data is selected by QP (Quadratic Programming) methods, which is a well-known method. This way, the optimal data boundary can be found. In simple words, SVM uses linear classification to determine how data should be separated based on defined tags or outputs.

1.2.8 Triangulated Irregular Network (TIN)

TIN is a triangulated Irregular Network. It is a representation of a continuous surface made up of triangular sides. Each triangle represents a surface in three-dimensional space, and the vertices of these triangles are three-dimensional with coordinate points. In other words, triangulated Irregular Network (TIN) is a vector model that can be used to describe the surface ground. In areas where the topography of the earth has abrupt changes, this model is a good option. Because it can show earth banks and abrupt heights changes.

1.2.9 Building footprint

This phrase is used to describe the boundaries of the outer walls of a building which is the built area that is measured and surveyed from the outside of the building. In different countries, there are changes in the agreed criteria, due to the addition/removal of patios, paths, external components of the building that are not part of the structure. In addition, if there were no walls around the building or structure, the borders of the roof or the covered area of the roof can be considered as a portion of the footprints. The concept of building footprint can be seen in Figure 1.3

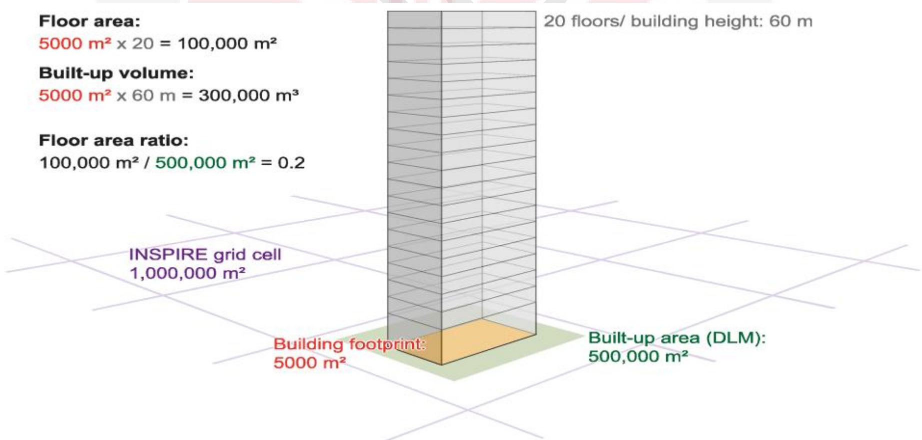

Figure 1.3 : **The concept of building footprint** (Krehl et al., 2016)

1.3 Problem statement

The man-made topographic features undergo continuous changes over time, including the destruction or variation. The variability of features requires a mechanism to study and assess the changes (Nyaruhuma et al., 2012). For example, according to the information available at the Statistics Center of Iran, about 40,000 residential projects are annually carried out in Tehran alone.

This means that the map of the city is changing every year and that in order to do the proper planning, the existing map should be updated and the elevation model of the terrain to be reevaluated. However, producing a new map for a city of about 700 square kilometers in extent will take a long time and incur huge cost, and even though the mapping for such cities is done using the existing methods and the changes are considered, as the updating of the maps is time-consuming and the changes have a high rate, the accuracy of the map can still not be guaranteed.

However, the provided statistics are only related to the official statistics and there are no accurate statistics for the unauthorized structures (unauthorized building construction or floor area ratio) and illegal possessions, which means that the rate of change is higher. Although this development is not specific to Tehran, studies have shown that 3.9 million of the world's population live in cities, accounting for 53% of the world's population (Moreno-Monroy et al., 2021), and this population has been increased by 400 million people since 2000 (OECD / European Commission, 2020) so that metropolises with more than 1 million population have grown 0.5 percent faster than other cities, although the highest population growth is in cities with more than 5 million. However, due to the growth of smaller metropolises, the number of metropolises with a population of more than 5 million people doubled in just 25 years. In addition, the population growth rate of the capitals is 0.8% faster than other metropolitan areas (OECD / European Commission, 2020).

This significant growth indicates the need to develop infrastructure, roads, buildings and anything that integrates the city structure. Its definite outcome is a change in the face of the city and, ultimately, an undeniable need to update cities' maps. Currently, in many countries, in large cities, multi-band color images with high spatial resolution are used to produce scale maps suitable for urban planning, and the power of consulting engineering companies is used for manual digitization. And for villages and small cities, the ground survey method is used using a mapping camera or dual-frequency GPS, which is a process that requires a lot of specialists.

On the other hand, the accurate location information in the immediate position is the need of countries and local resource management agencies to make effective decisions regarding the environmental management and presentation, transportation, detection of land cover change, land use, water distribution management, and municipal drainage system (Turlapaty et al., 2012) or the development planning such as virtual city development, virtual tourism development, and computer game industry development (Jiang et al., 2008).

As a result, it is necessary to produce accurate and up-to-date spatial information. This is especially manifested in the critical situations such as floods and earthquakes and the provision of urban security (Awrangieb et al., 2010). Therefore, the main problem this research addresses is that:

"It is very difficult to update city maps, and this is more difficult in large cities due to the high rate of change. On the other hand, there is an increasing need for up-to-date maps, and this need is greater in larger cities due to the numerous map-related land uses. However, updating the maps takes a long time and incurs huge costs, which will prevent it from being done in short periods of time."

1.4 Research objective

Given that the goal of this research is to create a practical system for producing the up-to-date maps of ground features, the following three specific objectives are pursued in this dissertation.

1) To create "DTM" only with LiDAR data without the need for any other layers and data
2) To create "building footprint" only with LiDAR data without the need for any other layers and data
3) To create an algorithm to create DTM and Building Footprint automatically

1.5 Research question

This dissertation tries to answer the following five questions:

1) Can the noise in the LiDAR data be removed without entering additional information to construct the DTM?
2) How can the effect of artificial structures be removed from the DTM?
3) Can the effect of trees on buildings be removed without the need for another layer?
4) Can the boundary of the parts of building that are covered with trees be reconstructed?
5) Which artificial intelligence algorithm is suitable for the automatic process of DTM and building footprint generation?

1.6 Scope of study

According to the objectives of the project, an area was selected in which various habitat conditions can be found. The area selected in this research has three main parts: 1) areas where no construction has taken place, 2) areas with rural texture, and 3) areas with dense urban texture. Therefore, it is possible to study the objectives of the project in different areas with different structural densities. LiDAR point cloud data and orthorectified which studied in this dissertation were acquired in 2015 over Universiti Putra Malaysia and part of the Serdang area by Ground Data Solution Bhd. The raw

LiDAR dataset was collected using the Riegel scanner on-board EC-120 Helicopter hovered at an average height above sea level of 600m above the terrain surface. The orthorectified (RGB color image) was captured with the Canon EOS5D Mark III camera with a focal length of 35mm, a horizontal and vertical resolution of 72Dpi, and exposure time 1/2500sec. the density of LiDAR data is about 8 points per square meter, which has a good density according to the objectives of the project, because in this research, those structures are considered as buildings that are larger than 9 square meters. Therefore, the existence of 8 points per square meter is fully consistent with the design goals.

This dissertation has two sections: generation of DTM and creation of building footprints. In the DTM generation section, the role-based method was used. This is because in this method, it is possible to remove training samples and the steps are taken based on the provided rules and the user does not need to provide additional information or process control. The accuracy of the results of this step in the first step will be based on the visual comparison of the results and the study area, and in the next step, based on the comparison between the constructed DTM and the manually-generated DTM, so that a DTM based on LiDAR data was first generated manually and compared with the automatically generated DTM. In the building footprint section, the role-based method was used to create an automatic process for extracting the building footprints. First, the filtering was done based on the building elevation and any point that was less than 2 m away from the DTM was removed. In this way, the short vegetation, large part of cars and traffic structures were removed. In the next step, in order to remove the trees from the existing points, the filter was done based on the intensity value and the trees were removed from the structures. Finally, the filtering was done based on the minimum size of a building and the form of the buildings was modified using the decision tree algorithm. This was done in two rural areas and the areas with tall buildings, and at each stage, to check the accuracy of the produced output, the existing buildings in the study area were first digitized manually. For this purpose, an RGB image with the spatial resolution of 10 cm was used. The vector layer formed based on the algorithm used in this dissertation was compared with the manually formed vector layer.

The important point to note in this dissertation is that in the research process, it was always tried to have a tangible look at the applicability of the results, because it is strongly believed that unless the results of a research are used in the executive organizations, their applicability cannot be ensured. Therefore, in this dissertation, with the knowledge of the limitations of the research and executive offices, a process is tried to be designed using a programming language and artificial intelligence algorithms to produce the required data in the shortest time with the least technical expertise. In fact, an attempt was made to incorporate the required expertise within the Python program to constantly accompany the executive and research projects.

1.7 Thesis organization

The contents of this dissertation are as follows:

Chapter 1: In this chapter, the research background is reviewed and the significance is examined by reviewing the performed studied. By evaluating the existing problems, the problem statement leading to this research is presented and research objectives and research questions are presented. On the other hand, this chapter takes a brief look at the research process, and describes the research steps generally

Chapter 2: In this chapter, the description of the study area, type of data used, and specifications of each case study are first provided. In the following, the research conducted in the past on the construction of DTM and formation of building layers or ground features is reviewed. The previous research is reviewed based on the type of filter, layers under study, and degree of automation of the process, and the results of each one were briefly evaluated in terms of speed and accuracy.

Chapter 3: This chapter discusses the research methods and designed algorithms. This chapter is divided into two distinct sections. The first section concerns the generation and verification of DTM and the second section concerns the generation and verification of building footprint. In the first section of this chapter, the topics are discussed in the following 5 sections: 1) Isolate last reflectance 2) Calculate effective distance 3) Filter step and roof errors based on KNN algorithm 4) Create initial network, interpolate and generate DTM 5) Check accuracy of DTM based on manually generated DTM.

The second section of this chapter, extraction of building footprint, is discussed in the following 8 steps: 1) Isolate first reflectance 2) Filter based on elevation 3) Filter based on intensity factor 4) Filter based on Nearest Neighbor (KNN) 5) Create initial network 6) Modify boundaries using decision tree algorithm 7) Convert modified network to raster data 8) Convert raster data to vector data and finally check accuracy of building footprint layer based on manually formed layer

Chapter 4: In this chapter, the results of the research method are discussed and the results are discussed in three study areas. The first area is a rural area with the rural coverage, one-story buildings, and scattered trees close to the building. The second area is an urban area with tall buildings, abundant cars, short vegetation, and urban concrete structures. The conditions of this area are suitable for the consideration as a dense urban area. The last area has no building structures and was used only to form the DTM layer in a manual and automatic manner.

In all area, the specifications of the manually generated DTM were first examined and then, the specifications of the DTM constructed based on the algorithm used in this dissertation were examined. In the next step, after the visual comparison between the two DTMs and comparison with the study area, the results of the comparison with two errors in the millimeter and centimeter ranges were statistically evaluated. In the second section of the first and second study area, the manually generated building footprint specifications were examined and then, the building footprint specifications created based on the algorithm presented in this research were evaluated and finally, the two vector layers were also compared. In the end, the strengths of the project results are compared with the previous conducted research and discussed and concluded.

Chapter 5: The contributions of the results of the dissertation to the development of knowledge in this field are studied and the specific scientific conclusions related to the results are presented and finally, some suggestions are made for continuing the course.

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