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DTM GENERATION FROM LiDAR DATA BY USING DIFFERENT FILTERS IN OPEN – SOURCE SOFTWARE

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ABSTRACT

The goal of this study is to analyze the suitability of filtering method in Open-Source (OS) software towards the generation of Digital Terrain Model (DTM) by using Light Detection and Ranging (LiDAR) data. DTM is a digital representation of ground surface topography. It can be generated by filtering process of point clouds using either OS software or commercial software. OS software is computer software which allows user to freely download it via internet. By taking Ayer Hitam, Penang as a research area, LiDAR data of that area is processed using LiDAR OS software which is Airborne LiDAR Data Processing and Analysis Tools (ALDPAT). Five different filters in ALDPAT are used respectively to filter the same LiDAR data. In addition, commercial software, TerraScan is then used to process the same data since this software has the capability to produce high quality DTM and it is commonly used by the Department of Surveying and Mapping Malaysia (DSMM). The quality of DTMs generated by ALDPAT is evaluated by comparing them to the DTM gained by TerraScan. Two approaches are used; first, detecting differences and eliminating the results which contained obvious differences. Secondly, 3-dimensional (3D) - Deviation method is used upon the result which the differences cannot be easily detected. Elevation Threshold with Expand Window (ETEW) filter has produced almost similar DTM as the one produced by TerraScan with 47mm standard deviation.

Key words: DTM, LiDAR, Filters, Open Source Software, Point Cloud

1.0 INTRODUCTION

1.1 Background of the Research

Airborne Light Detection and Ranging (LiDAR) is relatively a new emerging technology that can be employed in surveying field with the purpose of producing accurate Digital Terrain Models (DTMs). It has received wide acceptance and popularity around the world because it is far more practical than collecting data by using aerial photogrammetry. With the technological advances of laser scanners, Global Positioning System (GPS), Inertial Measurement Unit (IMU) and airplanes, LiDAR has achieved high economic importance due to its high accuracy capability and has been recognized as one of the standard method for topographic data acquisition (Ullrich *et al.* 2008). Scanning of terrain by means of airborne laser represents an alternative to the traditional recording methods to derive a DTM (Lohmann and Koch, 1999).

DTM is a modelled surface structure which contains elevation attributes data of terrain such as ridgelines, peak points etc. (Podobnikar *et. al*, 2000). In the course of processing, higher vegetation-horizons and also buildings are removed, in order to generate a DTM (Lohmann *et al.*, 2000). Removing of the height-values is called filtering. Filtering LiDAR point clouds can be done using suitable filters provided either by Open Source (OS) software or commercial software. In order to get the best output from LiDAR data, powerful software is needed to process billions of high density 3-dimensional (3D) points which are also known as point clouds. Thus, the development of automatic and quick filtering algorithm becomes an issue of essential interest. However, the method of filtering process varies for different software and not all of the filtering algorithms will give the best DTM. Commercial software is facing enormous competitor as OS software such as Airborne LiDAR Data Processing and Analysis Tools (ALDPAT), Digital Elevation Model Open LiDAR (Dielmo Open LiDAR) and Geographic Resources Analysis Support System (GRASS) is vastly created Consumer started to shift towards OS software since it can be obtained freely via internet. It is believed to bring tremendous changes especially in mapping industry. Nonetheless, every filters in OS need to be experimented in order to recognize which one among of them can give the best DTM as to compete with commercial software.

1.2 Previous Research

As stated before, ALDPAT is an OS software developed for processing LiDAR data. Formerly, a research regarding the usage of filtering methods in ALDPAT has been conducted by research group from Netherland and Malaysia. Nonetheless, the research is only focusing on filtering LiDAR data in urban area for flood modelling application. Based on the findings from the research, Adaptive TIN filter has more promising capabilities then other algorithms tested in the present work to extract buildings and yield ground surface. The results have shown that not all of the evaluated algorithms are capable of producing reliable DEM data that can be equally suitable for the urban flood modelling work (Abdullah *et.al*, 2009). Hence, this research is conducted in order to explore the capability of ALDPAT software in filtering forestry LiDAR data.

2.0 LiDAR SYSTEM

2.1 Introduction to LiDAR

LiDAR technology was another gigantic revolution in remote sensing after the emerging of GPS. The high acquisition frequency, good accuracy and short time in acquiring the data make LiDAR technology a method of fundamental importance (Baltsavias, 1999). “It could get high precise laser clouds and digital photos, whereby when combined with GIS technology the final outcome can be widely used in many applications such as power grid construction, archeology and seismology (Zujian *et al.*, 2008)”. According to Dragos and Karsten (2008), an accuracy validation study showed that LiDAR has the vertical accuracy of 10-20 centimeters and the horizontal accuracy of approximately 1 meter. In addition, the accuracy varies with the altitude of the aircraft during data acquisition. The vertical accuracy can be better than ±15 cm at 1200 m while it can be better than ±35 cm at 3000 m. On the other hand, the horizontal accuracy is approximately, ± 1/2000 of the flying height.

2.2 Components of LiDAR System and Its Operating Principles

It is compulsory for a technology to have perfect system because it will ensure that the process of data acquisition run smoothly. As for LiDAR technology, the system comprises of several components which is laser scanner, GPS, and IMU. Each of the elements has their own functions and specifications. **Figure 1** illustrates the components of LiDAR system.

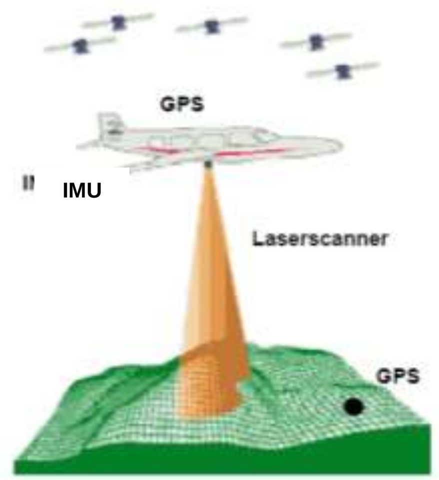

Figure 1: The main components of airborne laser scanning system (Geist and Stötter, 2002).

a) Laser Scanner System
This sub-system consists of active sensor, receiver and assembly of scanner and electronic timer which is combined in a huge rack. User also can monitor the progress of data collecting during the system works.

b) Global Positioning System (GPS)
The aircraft is equipped with GPS whereby it is used to precisely locate the position of the scanner during the measurement. The system is comprised of at least two receivers; one located on a known point on the ground and the other one located on the aircraft. It is desirable to set the on-board receiver directly above the laser scanner.

c) Inertial Measurement Unit (IMU)
IMU is used to control and determine the orientation of the aircraft in term of three axes; pitch, yaw and roll. It comprises of triads of accelerometers and gyros, digitization circuitry and a CPU that performs signal conditioning and temperature compensation (Mostafa et al., 2001). To ensure maximum accuracy, the IMU must be relatively small and lightweigt so that it can be mounted as close to the sensor's reference point (perspective centre) as possible.

LiDAR operating principles is simple; measure the time that it takes a laser pulse to strike an object and return to the aircraft, from a known location, determine the distance using the travel time, record the laser angle, and then, from this information, compute where the reflecting object (e.g., ground, tree, car, etc.) is located in three dimensions (Schmid *et al*., 2008). In practical approach, LiDAR data acquisition involves mounting a laser scanning system onboard of an aircraft along with a kinematic GPS receiver to locate an X, Y, Z position and an IMU to monitor the pitch, roll and heading of the aircraft. A pulsed laser is optically coupled to a beam director which scans the laser pulses over a swath of terrain, usually centered on, and co-linear with, the flight path of the aircraft in which the system is mounted, the scan direction being orthogonal to the flight path. **Figure 2** shows the operating principles of airborne LiDAR. The laser basically consists of an emitting diode that produces a light source at a very specific frequency (Dhanajay and Madhav, 2009a). The signal is sent towards the earth where it is reflected off a feature back towards the receiver in the aircraft.

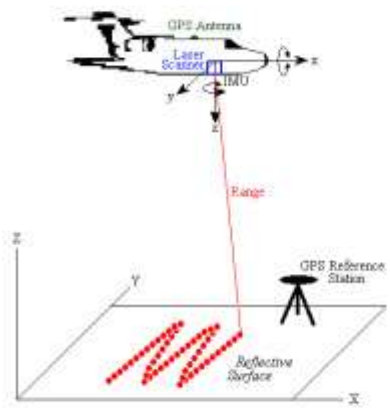

Figure 2: Illustration of airborne laser-scanning principles (Parrish, 2003)

The round trip travel times measures the time of flight for the optical pulse to travel to and from the reflected surface in order to get distance from receiver and surface. The travel times are recorded to nearly 10^{-10} s and converted to distance (Ackermann, 1999). The position of the aircraft is determined by a phase difference kinematic GPS. Rotational positions of the beam monitor together with range measurements are combined with the values determined by IMU, to obtain vectors from the aircraft to the ground points. When these vectors are added to the aircraft locations they yield accurate coordinates of points on the surface of the terrain. The width of the strip covered by the ranges, and the spacing between measurement points depends on the scan angle of the laser ranging system and the airplane height. LiDAR systems can return up to four range values and three intensity values for ground and above-ground elevation data from a single flight. This can increase the amount of data and the ability to look at the 3D structure of the “features above the ground surface,” such as the forest canopy and understory.

3.0 RESEARCH METHODOLOGY

3.1 Research Design

Figure 3 illustrates the sequence of procedures in carrying out the research. Initially, some literature studies were carried out to enhance understanding towards the topic chosen. Secondary information is very helpful for the understanding purposes. The next step is the data acquisition process whereby the data is obtained from Department of Irrigation and Drainage Malaysia (DIDM) and in the form of XYZ format. The data is then processed using ALDPAT and TerraScan software to generate DTMs. Five filtering algorithms in ALDPAT are used to filter the same data while in TerraScan only one filtering algorithm is provided to produce DTM.

Five outputs are gained from ALDPAT and each of them is compared to the DTM generated by TerraScan. The output can be displayed using Point Cloud 1.0.1 software for 3D point cloud view while for 3D surface and shaded relief view, Surfer 8.0 can be used. During the first comparison process, two types of view are used which are 3D surface view and shaded relief view. Based on the views, the diferences between output of two filters were recognized. For the pair which looked slightly different from each other, the output is not carried forward for the next comparison stage. If there is no obvious differences detected or the pair looked similar in naked eyes, then the output is carried forward for the second comparison process whereby the output from ALDPAT is overlapped simultaneously with DTM by TerraScan.

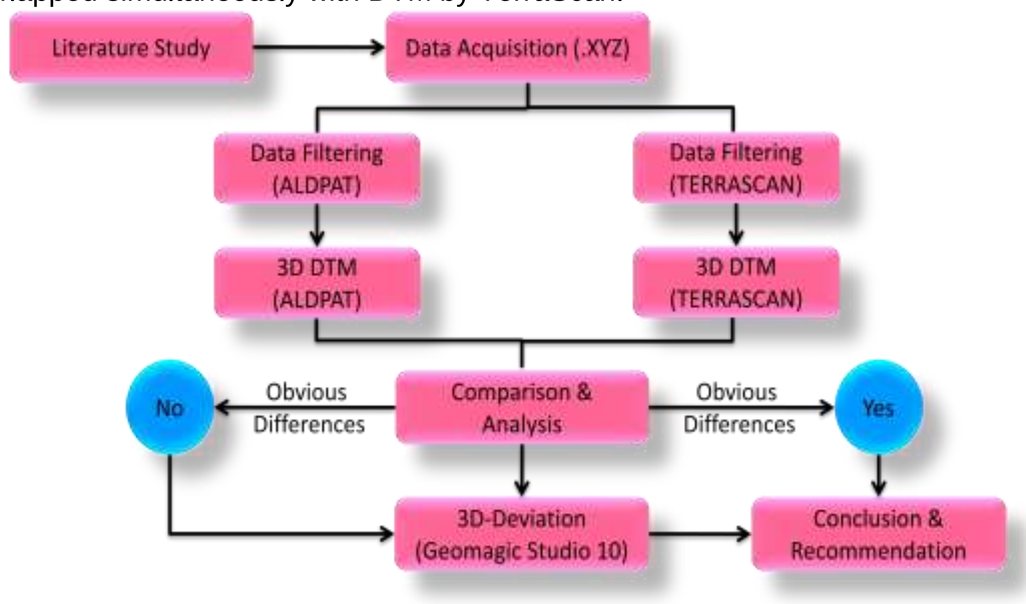

Figure 3: Process involved in the research.

After the first stage of comparison which is only based on the display of the output, the next stage of comparison is done using Geomagic software. The method used in this software to detect the differences between two surfaces is called 3D-deviation. A deviation spectrum is used as an indicator to evaluate the best DTM produced by filtering algorithms in ALDPAT. Last but not least, conclusion and recommendations are made.

3.2 Airborne LiDAR Data Processing and Analysis Tools (ALDPAT)

There are numbers of OS software developed to process LiDAR data such as ALDPAT, Dielmo Open LiDAR and GRASS. Currently, Dielmo Open LiDAR 2.0 has the capability to access, visualization and analysis of the original LiDAR data that allows to manage big volumes of data and do automatic quality control of LiDAR flights, measuring the point density, height accuracy, flown areas, areas without data, area covered by each flight line, overlap between flight and height differences between flight lines. On the other hand, GRASS is focusing on handling massive LiDAR data sets in geographic information system (GIS) particularly to compute high resolution DTM and conduct topographic analysis. Nonetheless, this research is concentrated on ALDPAT software which is developed by the International Hurricane Research Center, Department of Environmental Studies from Florida International University, USA (Zhang and Cui, 2007). It provides a set of transparent and automatic filtering algorithms to classify ground and non-ground LIDAR measurements and a series of auxiliary tools such as thinning, tiling and gridding the point data set to assist the LIDAR data analysis. Instead of filtering LiDAR data, ALDPAT also provides other services related to processing LiDAR data sets. The services are separate first and last stop measurements, convert ellipsoid to orthometric height, compute strip boundary merge boundary files and create shape file. However, this research only focused on the filtering process of LiDAR data. There are several filtering algorithm provided in this software such as Elevation Threshold with Expand Window (ETEW), Progressive Morphology (Morph Filter), Maximum Local Slope (Slope Filter), Iterative Polynomial Fitting (Polynomial Filter), and Adaptive TIN. Each of the filtering algorithms has their own filtering parameter. Hence, user needs to explore every single parameter involved in the filtering process.

3.2.1 Filtering Methods in ALDPAT

The capability of each filtering algorithms in ALDPAT depend on the topography of the data itself. Every filtering algorithm in ALDPAT has its own specification as stated below:-

a) Adaptive TIN (ATIN) Filter

Adaptive TIN uses the distance of point on the surface of a TIN to select ground points from LiDAR data sets. This filter will select a few low points that are most likely a terrain surface. The points are then triangulated to yield TIN. The main strength of this algorithm lies in its ability to handle surfaces with discontinuities, which is particularly useful characteristic in urban areas (Axelsson, 2000). In every iteration, point are tested and added to the TIN if they are below the thresholds (**Figure 4**). The parameters of the threshold are the angle points that make the TIN facets and the distance to nearby facet nodes. At the end of each iteration the TIN and the data derived thresholds are recomputed (newly identified ground points are included in the computations). New thresholds are computed based on the median values estimated from the histograms of each iteration. The iterative process ends when no more points are below the threshold.

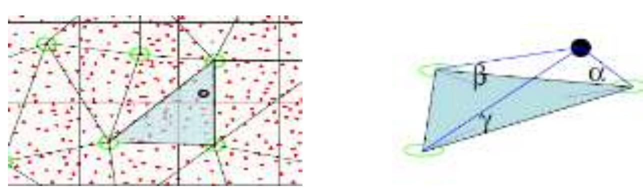

Figure 4: Point selection in ATIN filter is based on angle (α,β,γ) and distance (Pfeifer, 2007)

b) Elevation Threshold with Expand Window (ETEW) Filter

ETEW filter is based on elevation differences between neighbourhoods (**Figure 5**). It used an expanding search window to identify and remove non-ground points such as buildings, trees and vegetation. According to Whitman *et. al.* (2003), neighbouring ground measurements are usually distinct from those between the ground and objects in an area of limited size. Therefore, elevation differences in a certain area can be used to separate ground and non-ground LiDAR measurements. ETEW filter will subdivided the data set into an array of square cells and all points except the minimum elevation are discarded. There will be several iterations and every *i+1* iteration, the size of the cells will increase. The iteration will stop until there is no points are eliminated from the previous iteration. This filter sometimes can create abrupt elevation changes of preserved ground measurements near cell boundaries because minimum elevations are different for each cell. Hence, the people who develop this filtering algorithm had come for a solution. To minimize this effect, the cell array is shifted by one half-cell size in the *x* and *y* directions and the filtering process are repeated for each iteration. Only points that satisfy the thresholds of the original and shifted cells are selected in each iteration.

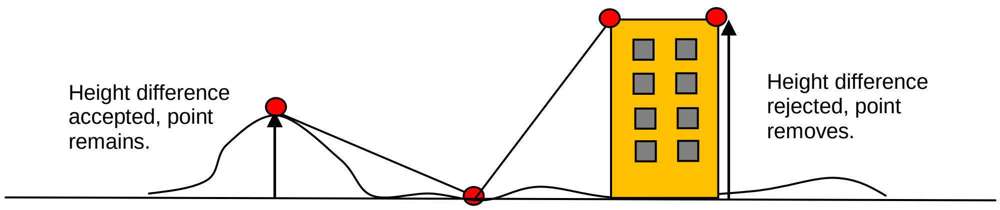

Figure 5: ETEW will remove points based on height differences between neighbourhood points.

c) Progressive Morphology (Morph) Filter

Morph filter is also included in ALDPAT whereby it is a mathematical morphology and used operations based on sets of theory to extract features from the data (Zhang and Whitman, 2005). The filtering is carried out by selecting the window size and setting the elevation difference thresholds. Measurements for different size non-ground objects will be removed while the ground data is preserved.

Most point measurements for terrain are removed and only a filtered surface is available if the opening operation is performed to the LIDAR data directly. As a result, Morph filter is good to remove non-ground points but as the window size increased, the points removed will also contain ground points (**Figure 6**). Thus, when interpolation is made, the surface created is not a true ground surface.

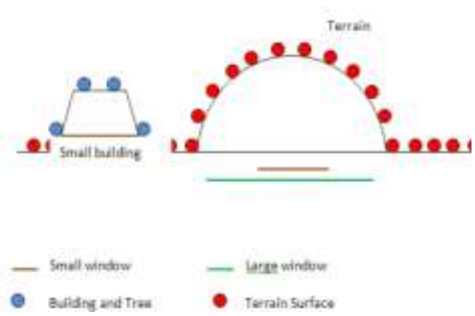

Figure 6: How Morph filters work.

d) Iterative Polynomial Fitting (Polynomial)

Polynomial algorithm adopts a principle of classifying ground and objects by selecting ground measurements iteratively from the original data set. The filter works by performing a polynomial fit of predetermined order for each frame of data points. This is done by determining which polynomial best represents the set of points in the frame. One example is a first order polynomial (a tilted plane) and the other is a numeric average (zero order). Best fit polynomials are obtained directly from the local moments. The value of the polynomial at the sample point is taken as the corresponding output sample value. **Figure 7** shows how polynomial filters work where *I* is an image, sampled at unit intervals, *W (m)* is a window function with its center at m = 0. Since a moment value is defined centered at each sample point *Ip* is called a *moment image.*

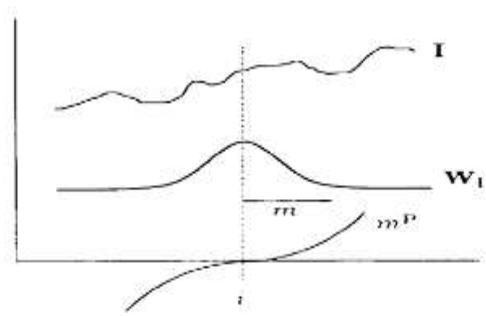

Figure 7: Functions used in the computation of local moments with respect to point *i* (Burt, 1998).

e) Maximum Local Slope (Slope)
Slope of a terrain is usually different from those between the ground and the tops of trees (Vosselman, 2000). The main parameter of the slope-based filter is the gradient of the cone's generators. Adjusting this gradient has the effect of moving the *cutoff* plane up or down (Sithole, 2001). This filter used a cone shape and a plane to determine which point to be removed. However, it did not work well under all circumstances because it removed points based on predefined threshold. Thus, to overcome this limitation, the filter was modified so that the threshold varies with respect to the slope of the terrain (**Figure 8**).

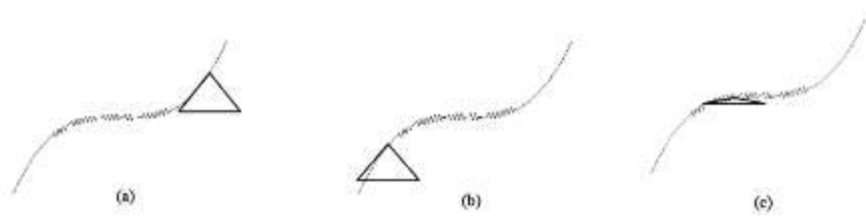

Figure 8: Mechanics of the modified filter; the slope of the cone's lateral surface adjusts to the slope of the terrain. If the slope of the cone's lateral surface is set equal to the slope of the terrain, the filter fails in cases b and c.

3.2.2 Filtering Procedures in ALDPAT

ALDPAT cannot read raw laser data format which is .LAS. If a data came in the format of .LAS, it needs to be converted into .XYZ format data. One of OS software which can convert the data from .LAS to .XYZ or .txt is LAS Utility software. Basically, ALDPAT shown a simple interface once user open the application. User may view raw data by using *Open file* functions in the main window of ALDPAT. Nonetheless, it only can view a 2D visualization of the point clouds. Other software such as Point Cloud 1.0.1 had the capability of viewing 3D visualization of the dense point clouds.

Worksheet window is opened to start the filtering process. **Figure 9** shows all the settings involved when processing LiDAR data using ALDPAT. There are 5 filtering methods provided by ALDPAT which is ETEW, Morph, Slope, Polynomial and Adaptive TIN filter. Only one filter is chosen for each processing task.

Figure 9: Setting in a worksheet before process is run.

After all of the information in the Worksheet is filled up, the Run Job button is clicked. Once the filtering process finished, a message stated ‘Success’ will appeared. The output is viewed using Point Cloud 1.0.1 software for 3D point clouds visualization. In addition, Surfer 8 is used to generate 3D surface of the filtered data. The same process is carried out upon the same data but using other four filters.

3.3 Filtering Procedures in TerraScan (Commercial Software)

TerraSolid Suite is the most complete, advanced and powerful software available for the manipulation, processing and analysis of LiDAR data (Fernandez *et.al*, 2007). The full suite comprises of four main modules: TerraModeler, TerraScan, TerraPhoto and TerraMatch. TerraScan software is used by the Department of Surveying and Mapping Malaysia (DSMM) to classiffy LiDAR data into ground surface, vegetations and buidings. It used advance ATIN (aATIN) filter to clasify ground points. Nonetheless, according to TerraScan official website, aATIN in TerraScan has been improved whereby the classification process undergoes two phases; firstly, search initial points and builds an initial temporary TIN model and secondly, lift the model upwards by iteratively adds new laser points to it. Terra applications need MicroStation V8 as a graphical interface. The applications are loaded using *Utilities* menu from Microstation window. *MDL Application* window appeared and the applications needed are chosen. TerraScan application is used to carry out the classification process while TerraModeler application for viewing the results in 3D shaded surface. Main tool box for TerraScan appeared in MicroStation V8 interface while the rest of application can be achieved under the *Application* menu.

TerraScan has the capability to import LiDAR data either in .LAS format or in .XYZ format. By using TerraModeler application, the data may be viewed in the form of 3D point clouds and 3D shaded surface. Classification process is conducted whereby points are classified into ground surface. Initially, a project file is created before the classification process is carried out. *Import Points into Project* menu is selected as to import LiDAR data into the application. A report is provided to inform total points that have been successfully imported. For classification task, user can add and specified the classification required as shown in **Figure 10**. A report on the number of points successfully classified is stated once the task is completed. Using Display Mode in TerraScan main window (**Figure 11**), the classified point can be shown according to their class as needed by user. Points which have been registered and classified as Ground class only will appear when Ground surface menu is chosen.

Figure 10: Classification information.

Figure 11: Display Mode in TerraScan

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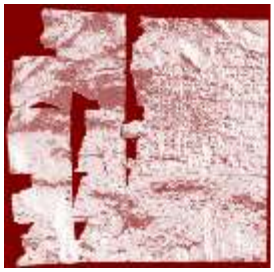
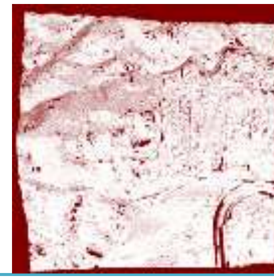
4.0 RESULTS AND ANALYSIS

Five filters in ALDPAT are used in this research while for TerraScan, one filter is used which is aATIN. DTM yield from TerraScan is determined to be highly accurate especially for elevation. It is proved in the previous study done by Samsul Farhan (2008) that the difference in elevation between GPS observation and DTM generated by TerraScan is ± 0.144m. Hence, DTM from TerraScan is used as a standard model to evaluate the best DTMs acquired by filtering algorithms in OS software. **Table 1** shows the results of the filtering process done by filtering algorithms in ALDPAT.

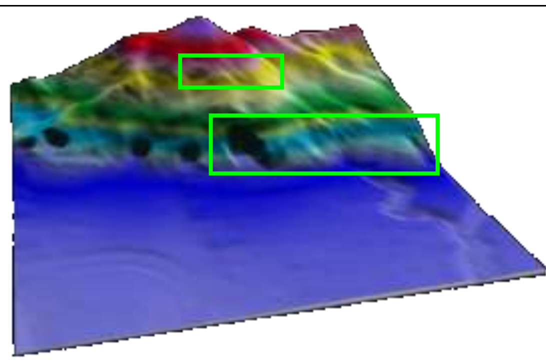
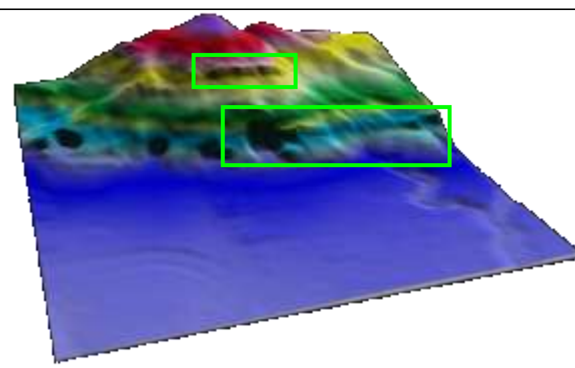
Table 1: Results from filtering process using ALDPAT.

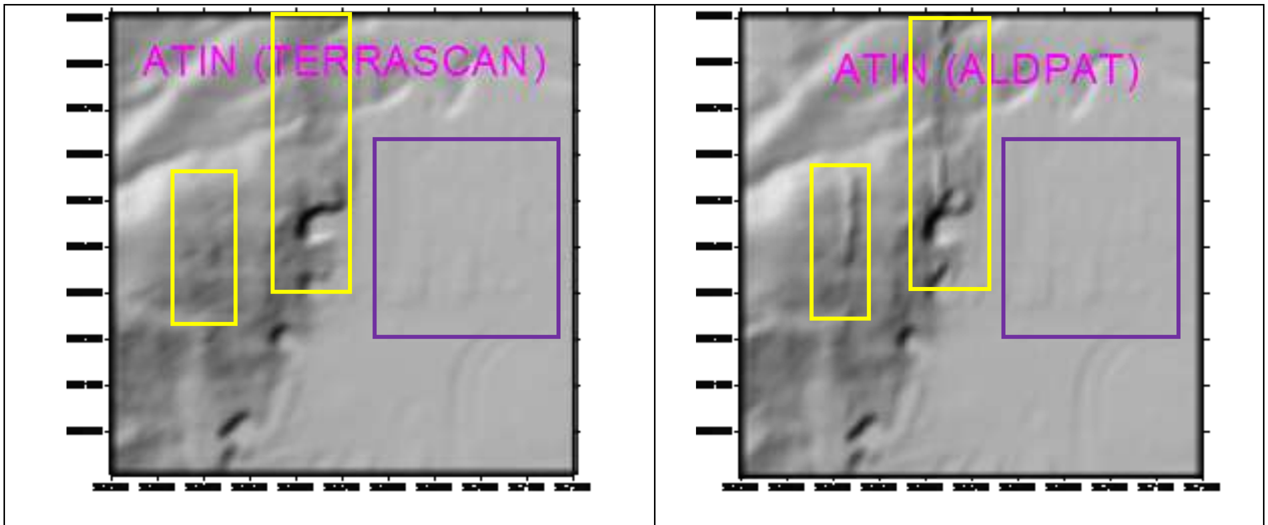
Point Cloud View	
Raw Data 	Morph Filter 
Raw = 1 001 893	Point left = 61 692 % Filter = 93.84

ATIN Filter 	Polynomial Filter 
Point left = 906 781 % Filter = 9.49	Point left = 754 080 % Filter = 24.73
ETEW Filter 	Slope Filter 
Point left = 994 064 % Filter = 0.78	Point left = 999 892 % Filter = 0.20

4.1 Results and Analysis for Adaptive TIN Filter.

Based on **Table 1**, ATIN in ALDPAT has removed 9.49% of the points in raw data. **Figure 12** shows the differences (green boxes) in 3D view that can be detected easily between aATIN and ATIN.

	
3D DTM (aATIN)	3D DTM (ATIN)



Shaded Relief View (aATIN)	Shaded Relief View (ATIN)

Figure 12: aATIN (TerraScan) and ATIN (ALDPAT)

From **Figure 12**, it shows that there are differences especially at the terrain area which means that this filtering algorithm is not suitable for the data containing the terrain surfaces. On the other hand, it does perform well at the ground surface which comprises of building or neighborhood area. It is good in detecting and removing macro objects such as buildings, vegetation on slopes, typically exists on the riverbanks (purple boxes in **Figure 12** shown the neighborhood area is well removed). Nonetheless, the removing of objects is not so smooth that it can affect the accuracy of the DTM (yellow boxes in **Figure 12**). In addition, this method does not have the capability of removing bridges and flyover. From the result obtained, the surface is not reliable as it has some obvious differences between DTM from TerraScan. Hence, the result is not carried out to the 3D-deviation process.

4.2 Results and Analysis for ETEW Filter.

This method is in fact has the same operation module with Morph filter. ETEW filter increased search window in every iteration and points are eliminated according to certain criteria. According to **Table 1**, about 0.78% of the points are removed by this filter. It is quite a small amount but generally the filter managed to perform well in both terrain and plane surface area. What makes it different than Morph filter is that it has been improved its capability in filtering point clouds. Initially, it can create abrupt elevation changes of preserved ground measurements near cell boundaries because minimum elevations are different for each cell. Hence, the cell array is shifted by one half-cell size in the *x* and *y* directions and the filtering process are repeated for each iteration. Only points that satisfy the thresholds of the original and shifted cells are selected in each iteration.

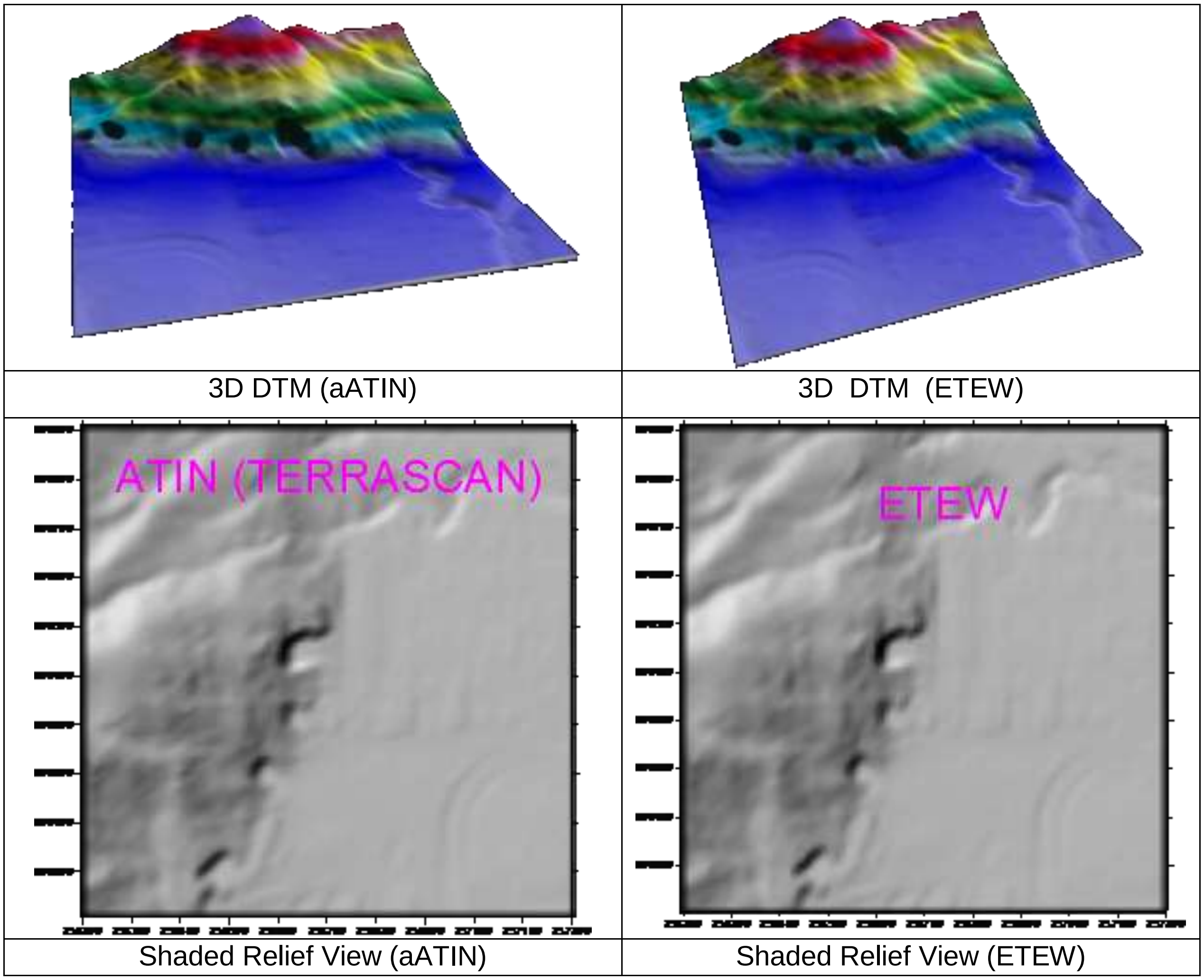
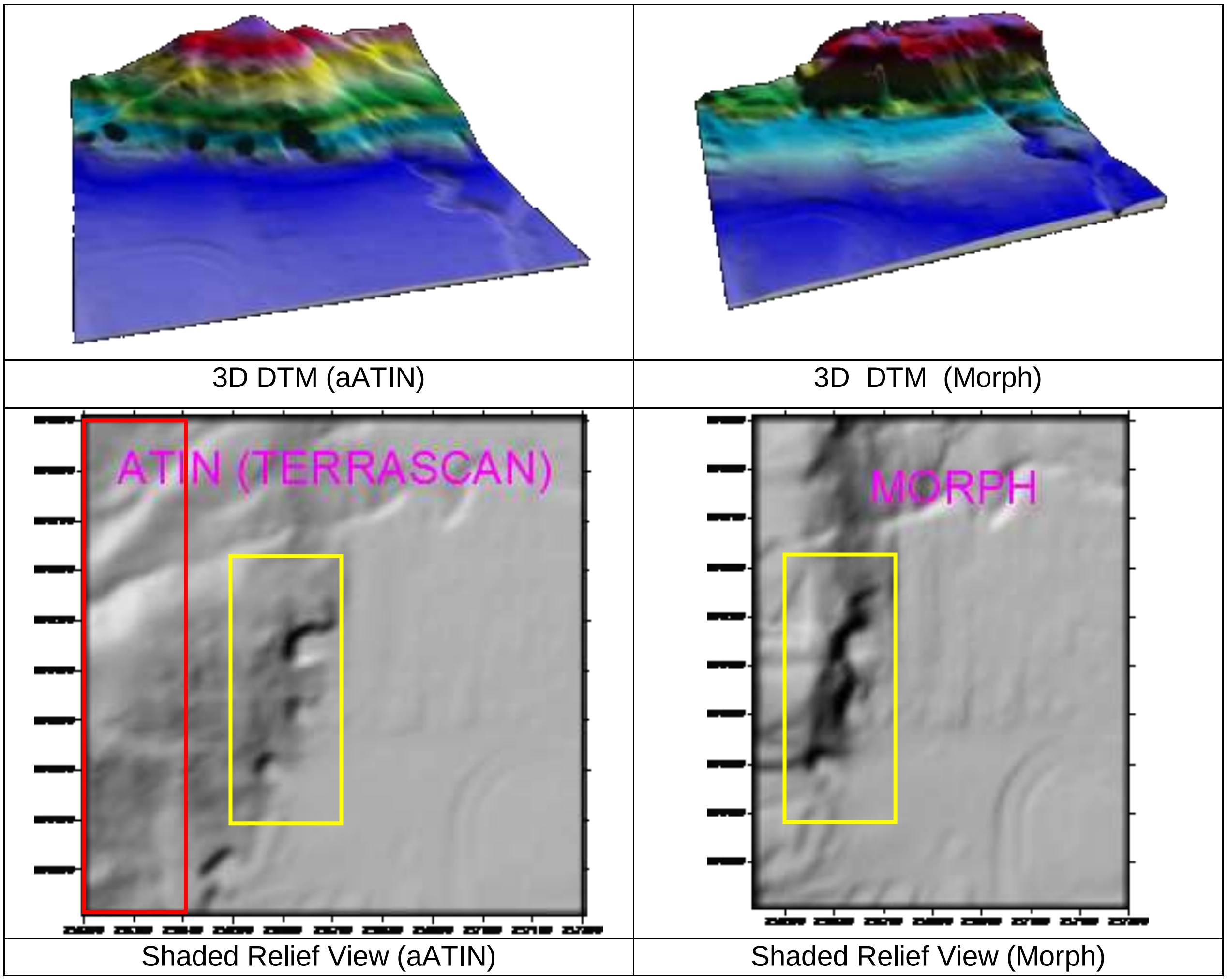


Figure 13: ATIN (TerraScan) and ETEW Filter (ALDPAT)

As a result, this filtering algorithm has produced quite significant surface which we can see from **Figure 13**. The surface is almost the same as DTM produce by TerraScan and any differences cannot be detected by naked – eyes. Hence, this result is carried forward to undergo the 3D-deviation process in Geomagic Studio 10 software.

4.3 Results and Analysis for Progressive Morphology Filter.

According to **Table 1**, Morph filter has removed 93.84% of the total points in the data. As a result, it has filtered quite a big number of points (red box in **Figure 14**). This indicates that Morph filter is totally not good in handling points in the terrain area. However, it can remove buildings and trees at various sizes from a LIDAR data set. Unfortunately, it tends to produce a surface which lies below the terrain measurements, leading to incorrect removal of the measurements at the top of high-relief terrain (yellow box in **Figure 14**). Even in the flat ground areas, the filtered surface is usually lower than the original measurements.



3D DTM (aATIN) | 3D DTM (Morph)

Shaded Relief View (aATIN) | Shaded Relief View (Morph)

Figure 14: ATIN (TerraScan) and Morph Filter (ALDPAT)

The critical part when using Morph filter is the selection of window size and the distribution of the buildings and trees in a specific area. If the window size is small, the ground points are preserved, while only a few non-ground points will be eliminated such as cars and trees. For a large building which is larger than the size of the window, the objects will be preserved. Hence, a wider window needs to apply to eliminate the big building. Consequently, the filter tends to over remove the ground points and more worst when a mountain is 'chopped off'. Since the differences are obvious, this result is not carried forward for 3D-deviation process.

4.4 Results and Analysis on Iterative Polynomial Fitting Filter.

This filter has the capability to remove vegetation on slopes and capture ramps. However, it is not much being used since the main purpose of this filter is to assess spatial outlier whereby it is computed by individual departure from the fitted polynomial trend surface. A spatial outlier is defined as an observation which is unusual with respect to its neighboring value.

From **Table 1**, it shows that Polynomial filter has removed 24.73% of the LiDAR points. But as displayed in **Figure 15**, both views is similar in naked eyes hence the differences cannot be detected. However, when refering to the point cloud view (result for Polynomial) in **Table 1**, either at the terrain or the flat surface, there are ground points that have been removed which indicates by the holes existed in the point cloud view.

Since the output of surface generated by polynomial filter is almost the same as the one generated by TerraScan, hence, the 3D model of the output is then compared by using Geomagic Studio 10 software. The deviation can be shown after 3D comparison process is carried out.

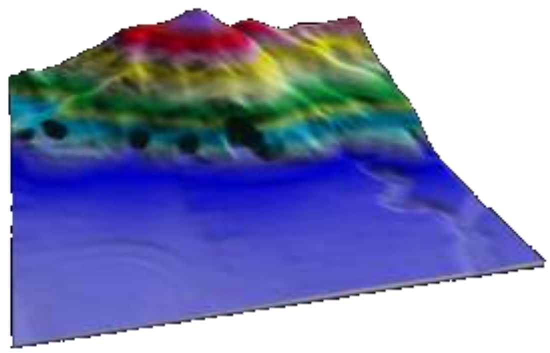
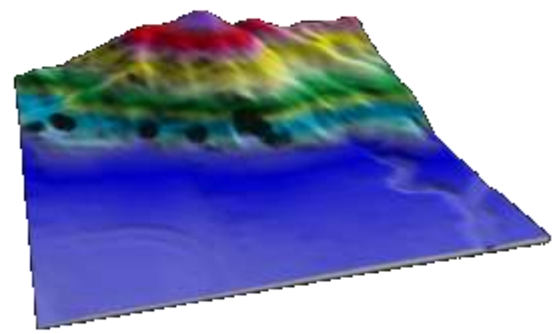
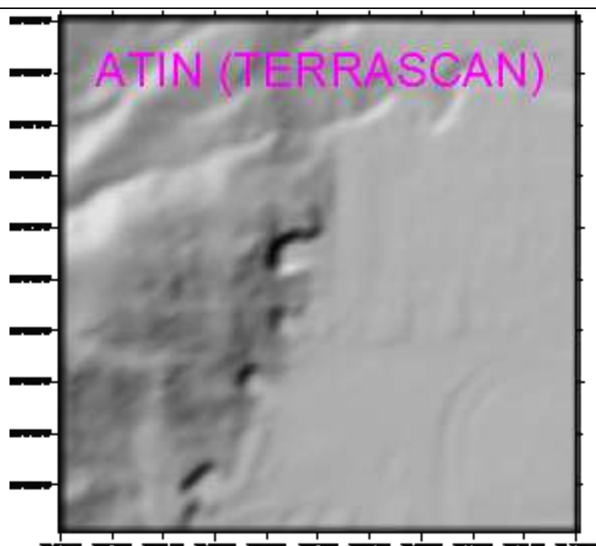
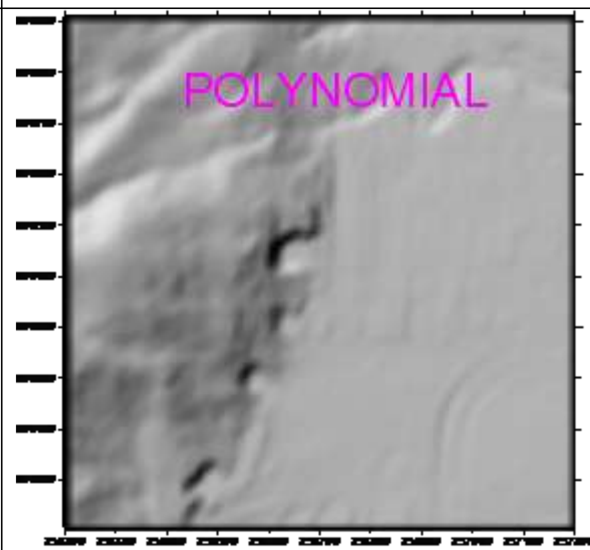
	
3D DTM (aATIN)	3D DTM (Polynomial Filter)
	
Shaded Relief View (aATIN)	Shaded Relief View (Polynomial)

Figure 15: ATIN (TerraScan) and Polynomial Filter (ALDPAT)

4.5 Results and Analysis of Maximum Local Slope Filter.

Slope filter is the filter which reduced the smallest amount of points which is 0.20% as stated in **Table 1**. The point cloud view in **Table 1** also shows the similarity between surfaces generated by Slope filter and ETEW filter. Based on the output gained, an initial conclusion is made which is the performance of Slope filter is quite good at terrain area and plane area. **Figure 16** shows that there is similarity in term of visual between DTM from TerraScan and DTM generated from Slope filter in ALDPAT.

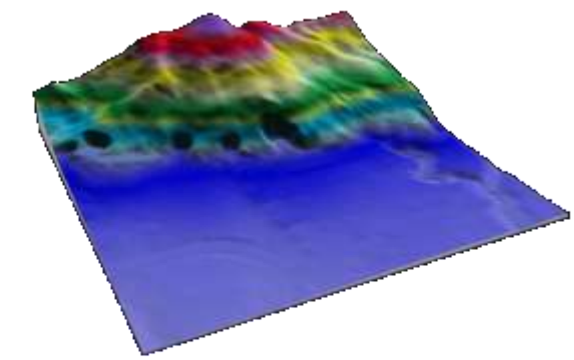
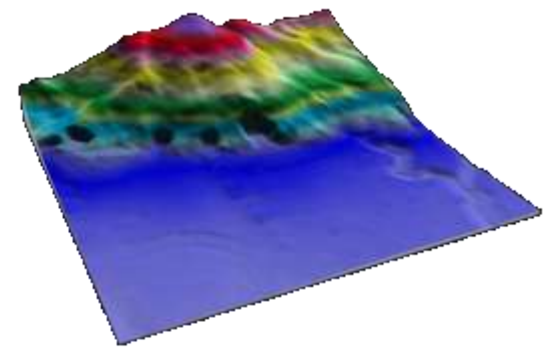
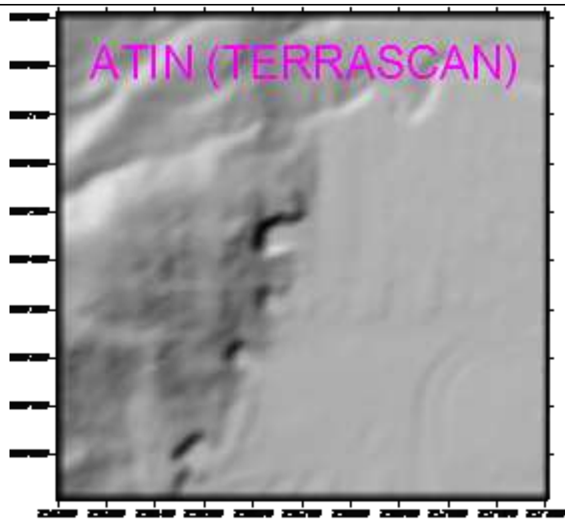
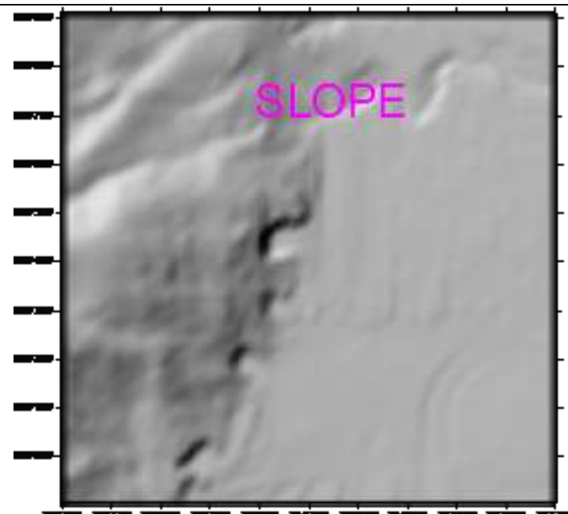
	
3D DTM (aATIN)	3D DTM (Slope Filter)
	
Shaded Relief View (aATIN)	Shaded Relief View (Slope)

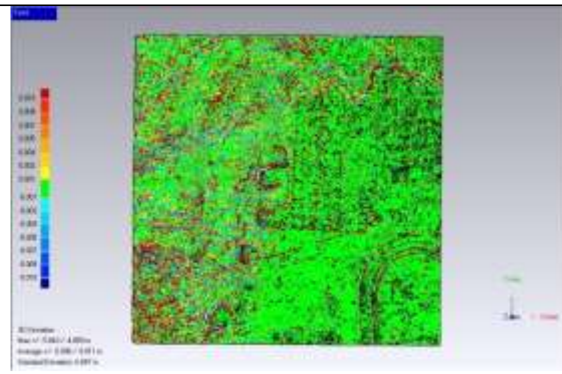
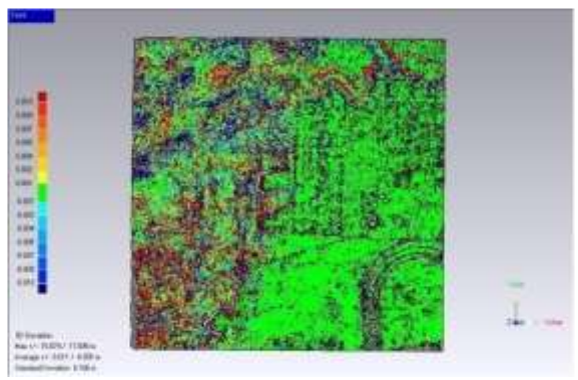
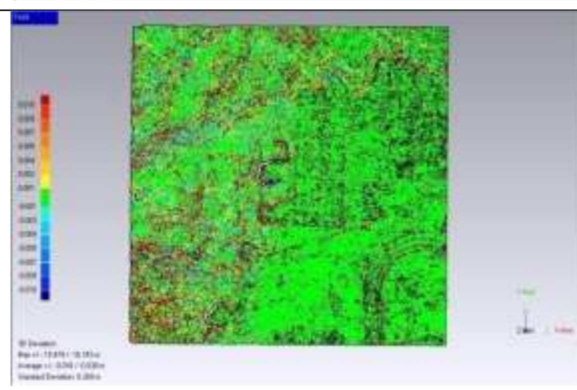
Figure 16: ATIN (TerraScan) and Slope Filter (ALDPAT)

The size of the operator in Slope filter is tuned to the size of the largest buildings in the landscape. The steps are repeated once more, with a strict parameter i.e. size of local operator, local slope, coefficients of variance propagation, and threshold value; are employed. As a result, the DTM generated from Slope filter is almost the same as the one generated by TerraScan either in shaded relief view or in 3D view. Thus, this result needs to undergo 3D – deviation process in Geomagic Studio 10 software to evaluate whether it can give the best DTM or not.

4.6 3D – Deviation Process Using Geomagic Studio 10

A 3D-deviation process is a process of overlapping two surfaces concurrently in order to determine the differences between the two surfaces. Deviation analysis in statistics refers to measuring the difference, especially the absolute difference, between one number in a set and the mean of the set. In this study, two surfaces comprise of DTM from TerraScan and DTM from ALDPAT are compared. The largest deviation is shown in term of deviation spectrum. Analysis is made based on the spectrum and standard deviation provided by Geomagic Studio 10 software. This software can support data from 3D digitizers, cameras, and scanners in XYZ or ASCII format. **Table 2** shows the results of the deviation process which has been successfully conducted.

Table 2: Result of 3D-deviation process

Standard Deviation	Result Display
3D DTM - aATIN overlap with ETEW **Standard deviation = 0.047m**	
3D DTM – aATIN overlap with Polynomial **Standard deviation = 0.186m**	
3D DTM - aATIN overlap with Slope **Standard deviation = 0.269m**	

Among five filters in ALDPAT which used in this study, only three of them produced so-called the ground surface. The criteria of choosing filter which produced the nearest DTM surfaces are based on the comparison made in the previous analysis (**Figure 12 until Figure 16**). The three filtering algorithms are the Polynomial, Slope and ETEW filters. Thus, each of them is compared with DTM generated by TerraScan by overlapping both surfaces concurrently such as DTM (TerraScan) overlapped with DTM (ETEW), followed by DTM (TerraScan) overlapped with DTM (Polynomial) and finally, DTM (TerraScan) overlapped with DTM (Slope). Before the process is proceed, the deviation spectrum is set up in the range from 0.010m to-0.010m. Hence, from the spectrum, maximum deviation can be extracted from the given visual and interpretation can be made. **Table 2** shows the results of 3D-deviation in graphical view and standard deviation.

From the results, the suitable filter in ALDPAT that can produce DTM which is almost the same as DTM yield by TerraScan is determined. From **Table 2**, 3D-deviation process towards three filtering algorithms has shown very significant results. More green color in the diagram means the data is nearest to the DTM created by TerraScan. While blue and red color shows that the deviation is in maximum state. Hence, the diagram with more blue and red color is not the best DTM. In Polynomial 3D-deviation result, some grey color seems to appear at certain spots. These grey colors mean that the point is out of the range as stated in the deviation spectrum. However, there are similarity in the deviation created by Slope filter and ETEW filter. Thus, this software provided extra information to ease user in decision making process. There is standard deviation information provided at the bottom left corner of the window. From the results, standard deviation for ETEW is 0.047m while for Slope filter is 0.269m. The suitable filter is the filter which has minimum standard deviation value. In a nutshell, from the process and the results given, the best filtering algorithm in ALDPAT that can give the best DTM is ETEW filter.

5.0 CONCLUSION

While airborne laser scanning systems have come a long way, the choice of appropriate data processing techniques for particular applications is still being researched. ALDPAT, which is one of the OSS, offers several filtering algorithms. All of them run the classification process in automated way. Nevertheless, these filtering algorithms have their own strengths and weaknesses. Sometimes the process fails to completely classify or filter out features such as vegetation or structures. When these “artifacts” remain in the data set, they degrade the resulting DTM by assimilating these features into the earth’s surface. The best DTM can be obtained if user knows how to manipulate the parameter of each filtering algorithms so that it is suitable with the condition of the area of studies whether it is an urban area or forestry area. In addition, all they have not been tested extensively for different earth surfaces such as vegetated mountains, building-dominated urban areas, and coastal barrier islands. Moreover, the capability of filtering algorithms in ALDPAT varies according to what type of data it processed such as more high building, more forestry or others. Thus, user needs to know every filter’s strengths and weaknesses. There were three filters which obtain almost the same DTM like the DTM produced by TerraScan. However, Elevation Threshold with Expand Window (ETEW) filter generated the most nearest surface to the surface produced by TerraScan. Several enhancements need to be carried out to improve the quality of ETEW filter since deviation is about ±0.010m from the surface created in TerraScan. It is believed, that ALDPAT have a bright future to compete with commercial software. Strictly remind that this study area involve forestry area and just a little neighborhood area. For an urban area, it is suggested to use Adaptive TIN in ALDPAT because it has the ability to handle surfaces with discontinuities.

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