Low Cost DTM for Certain Engineering Purposes

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ABSTRACT

Digital Terrain Model (DTM) is a representation of an earth surface in the three-dimensional form. The need to study DTM is to improve its accuracy and efficiency. There are three types of DTM which are contour lines, grid model and triangulated irregular network (TIN) model where each one has its own characteristics depending on the purposes of the DTM. Total station is often used in acquisition of terrain data for the DTM due to its practicality (depending upon weather condition) and easier to use albeit labor intensive. For this study, DTM is produced based on the selected study area and the generated DTM will be used to simulate preliminary engineering practice during construction such as cut and fill and certain hydrology simulation. To generate DTM, terrain data is acquired through using Total Station. The data is used as to produce the terrain model using TIN method. The model is analysed based on several aspects. Area with major change in slope requires higher density of data to describe the feature of the slope changes. Different pattern data distribution can also be seen in different DTM with different feature requirement. Different types of terrain have different effects on the DTM production. In the end of this study the accuracy of this Low Cost DTM and its applicability for engineering purposes will be assed.

Keywords: Digital Terrain Modelling (DTM), Total Station, Geographic information system, Spatial analysis, Hydrology.

1.0 INTRODUCTION

Digital Terrain Modeling (DTM) is a representation of the earth surface in a 3D plane by using the available terrain data. Terrain data can be obtained through various techniques of data acquisition such as;

1. Photogrammetric data capture which include aerial photography and digital satellite imagery [1]
2. RADAR: RAdio Detection And Ranging which uses radio wave portion of the electromagnetic spectrum [2]
3. LIDAR: LIght Detection And Ranging which uses ultraviolet, visible and infrared region of the electromagnetic spectrum [2]
4. Ground surveying, among the most common method used

There are two main types of DTM which are grid and Triangulated Irregular Network (TIN). The regular square grid is a 2-dimensional array where each entry stores an elevation. An entry represents an area on the Earth and the stored value is the elevation of the center point of the region [7]. The TIN model represents a surface as a set of contiguous, non-overlapping triangles. Within each triangle the surface is represented by a plane. The triangles are made from a set of points called mass points. These mass points can occur at any location, the more carefully selected, the more accurate the model of the surface. TIN-based model is able to describe features very well. The TIN model is also attractive because of its simplicity and a significant alternative to the regular raster of the grid-based model [3].
The application of DTM can be divided into three major domains which are:

i) Civil Engineering

ii) Planning and Resource Management

iii) Military Applications

Since DTM are widely used for such purposes, there are many significant problems that arise. The roughness of the terrain surfaces determines the difficulty of DTM representation of terrain. Only few points need to be sampled if the terrain is simple. Alternatively, if the terrain is complex, more points need to be measured [4,5].

Hence, DTM resolution plays an important role in determining its detail. It depends on the intended application of DTM. Lower horizontal resolution DTMs produce lower slope gradients on steeper slopes and steeper slope gradients on flatter slopes. However, higher-resolution DTMs may not be necessary for generating useful soil-landscape models. Therefore, an optimal DTM resolution is needed to be determined [6,8]. Hence this study has the following objectives which are to assess the:

1. Accuracy of Low-cost DTM produced by Total Station
2. Potential use of the above Low-cost DTM for some engineering purposes.

### 2.0 MATERIALS AND METHOD

There are four phases of process involved in this study. The four phases are the selection of study area, data acquisition process, terrain representation and DTM application simulation. The details and procedures involved in each processes will be explained in subsequent section.

#### 2.1 SELECTION OF STUDY AREA

Before conducting data collection, suitable terrain area is chosen based on the following criterias:

a) strategic location (easier for the transportation and movement of equipment)

b) suitable topography to perform surveying by total station and GPS.

c) open space with less obstruction.

d) must have terrains with major change in the shape of the terrain surface (to produce visible shape on the DTM)

The area chosen for this study is the area from near the parking lot to the Pocket C and Academic Block 14 which is within the campus area of UTP.

#### 2.2 DATA ACQUISITION PROCESS

The process of collecting data began by obtaining at least one known coordinate as the first control point. The known coordinate is then used to obtain another two control points to be located at the study area. These control points are obtained by using GPS. The coordinates obtained are shown in Table 1.

<table>
<thead>
<tr>
<th>Control points</th>
<th>Ground Northing (m)</th>
<th>Ground Easting (m)</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP1</td>
<td>E718718.515</td>
<td>N484880.681</td>
<td>H26.705</td>
</tr>
<tr>
<td>CP2</td>
<td>E717828.700</td>
<td>N484819.500</td>
<td>H31.907</td>
</tr>
<tr>
<td>CP3</td>
<td>E717827.100</td>
<td>N484863.100</td>
<td>H32.399</td>
</tr>
</tbody>
</table>
These control points are then used in the collection of terrain data by using Total station. The sampling method used in collecting terrain data is composite method of the following methods:

1) Random sampling, to acquire data points for the topography purposes.
2) Progression sampling, to acquire more points at the area where curve shape is required and fewer points are collected at the area with straight line features.
3) Selected sampling, to describe the boundaries of man-made objects (such as road divider, drainage, pathway and stairs).

2.3 TERRAIN REPRESENTATION

The collected coordinates are transferred into the computer and used to generate points in the AutoCAD Land Development software. From the generated points, break lines are introduced by connecting each of the data points using the 3D polylines function in the software to establish the features in the area such as roads, drainages, pathways and stairs as shown in Figure 1.

![Figure 1: Terrain data points collected by Total station and breaklines](image)

After establishing break lines, the terrain surface in the form of Triangulated Irregular Network model is constructed by using the ArcMap software. The details of the terrain features such as wall, roads, and pathway can be generated using ArcScene software.

2.4 DTM APPLICATION SIMULATION

The simulation of various DTM applications can be generated by using the ArcMap software. However, this study focuses on the simulation of:

a) Cut-and-fill Volume
b) Hydrology Flow Direction and Flow Accumulation

2.4.1 SIMULATION OF CUT AND FILL VOLUME

The workflow of generating the cut-and-fill volume simulation using the ArcMap software is shown in Figure 2.
2.4.2 SIMULATION OF HYDROLOGY FLOW DIRECTION AND FLOW ACCUMULATION

The workflow of generating the hydrology flow direction and flow accumulation simulation using the ArcMap software is shown in Figure 3.

3.0 RESULTS AND DISCUSSION

The result of the study is represented in the form of digital terrain models and some simulations of DTM applications. The analysis of the study is also discussed in this section.
3.1 DIGITAL TERRAIN MODEL

Figure 4: The plan view of the study area (left) and the digital terrain model of the study area (right)

Figure 4 shows the generated DTM for the whole area of study from the plan view. The picture of the actual terrain shown on the right was taken from the Google Earth software from the sky view. However, the photograph can only show the terrain in two-dimensional form. Compared to the DTM, the terrain is represented in three-dimensional form and visible where different colours are used in distinguishing the differences of the terrain heights. Different tones of colours are used in distinguishing the sun shades and the amount of sun light received by the area.

Figure 5: Pictures of actual terrain and the generated DTM

Figure 5 shows the screenshots of the generated DTM with the picture of the actual feature on the terrain. The comparison made between these two pictures shows that the generated DTM is almost similar to the actual terrain. The features on the actual terrain are represented well in the DTM.

However, there are some slight differences between the generated DTM and the actual terrains as shown in the red circles in the figure. This was due to generalization during the data acquisition
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process where sampling points were only taken at certain crucial parts of the terrain features. Generalization needed to be done for optimization of data sampling.

The errors may also come from the data acquisition process whereby the person who holds the prism pole did not hold the pole correctly or the person may not change the height of prism target to the correct height. Therefore, proper data acquisition procedure should be undertaken during the process of data collection to reduce the errors in generating DTM.

Better accuracy of the DTM representation can be done if more points are collected. The breaklines produced earlier also helps in the accuracy of the DTM by forcing the construction of TINs to follow the shape of the features in generating DTM.

It was also observed that the terrain representation is better described when more data is obtained within certain area compared to less data obtained within the area. However, optimization of data sampling can be done by distinguishing the type of the terrain. Terrain with little variations in height requires less density of data compared to the terrain with more variations in height. Terrain with little variation in height is almost the same as a flat surface. Therefore, the amount of data collection for this type of terrain can be reduced which also have no effects in the accuracy of the DTM.

3.2 SIMULATION OF CUT-AND-FILL AREA

Since the study is made within the campus area of Universiti Teknologi Petronas (UTP), there is no future development that is going to be constructed here, thus, there is no data of a real project can be used as the data to generate the DTM of a new proposed area. In this case, assumptions have been made in the process of determining the height of the terrain for the proposed development area. The result of the DTM generated for the proposed construction can be seen in Figure 6.

The result for the simulation of cut-and-fill volume is shown in Figure 6 and the cut and fill area is differentiated by using blue and red colours respectively.

Figure 6: Cut-and-fill volume simulation for proposed construction
From the simulation, the volume of cut and fill is calculated by the software and is shown in Table 2.

**Table 2: Table of Cut and Fill Volume**

<table>
<thead>
<tr>
<th>Type of area</th>
<th>Volume ($m^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut</td>
<td>1,320.521289</td>
</tr>
<tr>
<td>Fill</td>
<td>9,389.182385</td>
</tr>
</tbody>
</table>

### 3.3 SIMULATION OF HYDROLOGY FLOW

Simulation result will be shown in the following section. The generated DTM has been able to show hydrologic features such as flow length and flow accumulation as in Figure 7 and 8.

#### 3.3.1 SIMULATION OF FLOW DIRECTION

Figure 7 shows the simulation of hydrology flow direction on the generated DTM. The flow direction is represented by the differences of colour values which are represented in a set of grid cells. The flow direction can be determined by finding the direction of steepest downward fall from one cell to another. This is done automatically by the software.

#### 3.3.2 SIMULATION OF FLOW ACCUMULATION

The levels of flow accumulation are established in different tones of colours as indicated in Figure 8. By distinguishing cells with high accumulated flow, a network of high-flow cells can be determined. These high-flow cells lie mostly at the drainages and lower points of terrain.

However, as shown in the figure, the high-flow cells did not lie mostly at the drainages. The water accumulated in the drainage flows to the south of the study area where the area at the south has lower elevations compared to the north area. The figure also shows that flow accumulate more at lower ground area because of the area limitations in data collection whereby there is no drainage presented in the DTM to flow the water.
4.0 CONCLUSIONS

As conclusions, from the analysis, the generated DTM is very similar to the actual terrain which DTM can be used as a representation of the earth surface for many purposes. DTM can describe the features on the actual terrain very well with the help of breaklines. Higher density of data is required at the area with major change in shape. However, optimizations of data need to be achieved by determining the type of the terrain. Terrain with little variations in height requires less density of data compared to the terrain with more variations in height. Time and energy can be saved through optimization of data sampling. Proper procedures in performing the data acquisition process are important in obtaining better representation of DTM with less error. Better planning of data sampling is needed to be done to achieve optimization and better representation of DTM.

DTM can be used to simulate cut and fill volumes for the proposed developments. The layout of a proposed development of the area is compared with the layout of the terrain before the development. The volume of cut and fill is calculated by the software after comparing the differences of heights between both layouts. DTM can also be used to simulate the hydrologic flow of a certain catchment area. The flow direction can be determined by distinguishing the elevation in each cell. The water flows from the higher level to the lower level of cells. Flow accumulation is determined after obtaining the flow directions. Network of high-flow cells can indicate high accumulation of flow which is very important in determining the drainage network of a catchment area.

5.0 REFERENCES


**Authors Biography**

Dr Abd Nasir Matori is an Associate Professor for Geomatics/Geoinformatics at the Department of Civil Engineering, Universiti Teknologi PETRONAS (UTP). He obtained his PhD from University of Newcastle upon Tyne, UK in 1996 and has been with UTP for almost ten years. To date he is research-active, and has been the recipient of IRPA and CIDB research grants.

His research interests are basically in two broad areas which are geomatics and geoinformatics as follows:

**Geomatics:**
1. To study the application of GPS precise positioning for long baseline deformation analysis in near real-time scenario
2. To study the application of terrestrial positioning for deformation analysis in real time and near real-time scenario
3. to study the application of GPS positioning for mobile application
4. To study the application RTK and virtual RTK GPS for DTM and DEM generation modeling
5. To study the application of GPS for indoor positioning

**Geoinformatics:**
1. To study the application of GIS for hazard risk zonation mapping for landslide, flood etc.
2. To study the application of GIS for suitability analysis of a project
3. To study the application of GIS for DEM and DTM modeling
4. to study the application of remote sensing for landslide deformation monitoring and oil & gas offshore exploration
Hazwani Bt Hidzir was born in Kuala Lumpur, Malaysia in March 1986. She graduated in December 2008 from Universiti Teknologi Petronas (UTP) in Bachelor of Civil Engineering, choosing “Urban Engineering” as her major. Currently she is working as a Civil/Structural Engineer in Development Division, PETRONAS CARIGALI SDN BHD, KLCC, Malaysia.

She has worked as a Civil and Structural Trainee Engineer during her 8 months of internship at KEMASEPAKAT SDN BHD, Kelana Jaya, Malaysia, a civil and structural engineering consultant company. Her final year project was on Digital Terrain Modeling with Total Station for certain engineering purposes.