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Development of Digital Elevation Model (DEM) from Aerial photographs using Photogrammetry Technique

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ABSTRACT

Digital Elevation Model (DEM) is the three dimensional representation of the Earth surface. Digital Elevation Model is based on higher number of points with X, Y, Z coordinates of bare earth. DEM is the input for many applications in the real world. It is essential to generate the DEM fast and accurately. There are different techniques such as terrestrial, aerial based, satellite based and Airborne Laser Terrain techniques are available in the markets. Based on the accuracy of the DEM, the selection of the techniques may vary. Aerial based photography was taken here as input and Photogrammetry techniques were used for the generation of DEM. In this study, Different Photogrammetry software's are involved for generation of DEM. Accuracy of the DEM is based on numerous parameters, some of the important parameters are resolution of aerial photography, Accuracy of the Aerial Triangulation results, and also the terrain conditions. The accuracy achieved by the aerial photography DEM was in the centimetre level. Especially, horizontal accuracy is better than vertical accuracy. It was compared with ground based GCPs values for analysing the accuracy of the DEM. Horizontal accuracy between 3 to 15 centimetres and the vertical accuracy between 10 to 22 centimetres and also DEM generated in the flat terrain is better than the undulated terrain.

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INTRODUCTION

Development of technology, ease the generation of DEM. Nowadays, DEM is the primary sources for the different application areas such as Urban planning, land slide analysis, soil erosion studies, slope mapping, volume calculation and so on. For the generation of DEM, we do need two or more images showing the same images with different location. Though terrestrial surveying instruments are also available for generating the DEM manually, automated generation of DEM is the recent trends. Invention of computers and the development of image processing techniques are influencing the automatic DEM generation. Automatic image matching is carried out between the two or more overlapping aerial photography and matches the common features. Matching of common feature is the basics of generation of DEM. Different Photogrammetry software's are available for generation of DEM.

Another different types terrain representation models are Digital Terrain Model (DTM), and Digital Surface Models (DSM). These two terms are confused with Digital Elevation Model. DTM is considered as continuous usually smooth surface which, in addition to height values also contains other element that describes a Topographic surface, slope, aspect, gradient, and others. Like Digital Terrain Models, Digital Surface Models contain the spatial elevation data of the terrain in digital format which is usually represented as a grid with natural and artificial features such as vegetation and building, etc.

DEM can generate from the terrestrial surveying, Aerial photographs, and Satellite images and also from Airborne Laser Terrain Mapping methods. Selection of the techniques and the input requirements are based on the application. Terrestrial methods provide the input elevation information for the generation of DEM, but it is very time consuming and also difficult to access the inaccessible areas.

Some Satellite is capable of providing the stereo images, which is the essential input for the DEM generation. The advantage of satellite based stereo images is, the area coverage, receiving the satellite images in the regular interval, easy to access the

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inaccessible areas, no prior permission from the Government to purchase the satellite images. But the vertical accuracy is above a metre in the satellite based generated DEM. Though it is useful for so many applications, some detailed mapping is not carried out using the satellite based DEM data.

Selection of Aerial photographs and the Photogrammetry techniques is very important for generating DEM in the centimetre accuracy and also the application of large scale and detailed mapping.

1. Need for the study:

DEM is the essential input for the different application and the various mapping products. Especially the Orthophoto production, soil erosion, land slide, watershed delineation, urban planning, and etc. The need for the DEM is very essential for the above mentioned application, and also important for other application which is not mentioned here. Though terrestrial techniques are provide the high accurate terrain model for the Earth surface, it is very time consuming and also some time very difficult to access the private property and high undulated mountains. In order to reduce the timing and also generated terrain model for inaccessible areas, the Aerial based, Satellite based and Airborne Laser Terrain mapping was essential for the generation of DEM. The above mentioned three different methods are providing the different accuracy for the DEM. Satellite based DEM can cover the large area of terrain model, but the vertical accuracy is not enough for large scale mapping and detailed mapping. But the advantage is taking satellite data in the regular interval. Aerial photograph based DEM can provide the accuracy in the centimetre level. It is good for the large scale and detailed mapping. Photogrammetry is the much known technique, which is work with stereo images for generation of 3 dimensional earth surfaces. In this study, Aerial photograph based DEM is useful for generating the contour in 50 cm interval, and also for delineating drainage pattern.

MATERIALS AND METHODS

Data:

The study area is Queensland from Australia. Only two overlapping aerial photograph was taken as input for carrying out this study.DEM input is the output of the Aerial Triangulation (AT) results. DEM is generation is carried out after completion of the Aerial Triangulation (AT). It is clear that AT result is very important for DEM accuracy concern. There are three important inputs are required for completion of the Aerial Triangulation, such as camera calibration, Ground Control Point (GCP) and Aerial photography.

Aerial photos taken from the aircraft, the flying height is 1145 meter above the ground level. The scanning resolution of the Aerial photo is 15 microns.

Camera information:

Camera calibration certificate providing the information's about number of fiducials, fiducial coordinates, calibrated focal length, principal point and lens distortion also. The above mentioned camera calibration information's necessary to carry out the project set up and interior orientation process. There are four corners fiducial in this camera. Fiducial coordinates are given in the table 1.

Calibrated focal length, photo scale, and the principal point information's are given below.

Calibrated focal length = 152.980 mm, Photo scale = 1:7,485,

Principal Point X (mm) = -0.002, Y (mm) = 0.005

Ground Control Pints (GCP):

Ground Control Point (GCP) is the important information to relate the image coordinate system into real world coordinate systems. GCP's are collected from the field using terrestrial surveying instruments. Global Positioning System may be used for collecting the GCP's from the field.GCP accuracy and distribution should be good in order to get the better results of the Aerial Triangulation. Number of GCP measured for this sample project was five, also the GCP are well distributed over project areas. All the GCP are considered as full GCP. Full GCP consists of both Horizontal and vertical coordinates values. The GCP used for this sample project mentioned in the table 2. Aerial Triangulation result is based on the images measurements and the accuracy of the Ground Control Points.

Aerial Triangulation:

Aerial triangulation (AT) or aero triangulation is the photogrammetric term meant for densifying the ground control points. It is determining the XYZ values of points on the ground by means of measurements taken from the stereo images.

Photogrammetry products are referring to the object space, for example, maps, Orthophoto, Digital Elevation Model. Aerial Triangulation is the prerequisite for this process and request as much as information for doing so. Ideally the result of aerial triangulation should include completely reconstructed surface, both in terms of geometry and radiometry.

One of the most fundamental processes in Photogrammetry is identifying and measuring the conjugate points between two or more overlapping photographs. In analytical aerial triangulation the identification of conjugate points is performed by human. In the digital aerial triangulation, once attempts to solve the problem automatically – a process known as image matching.

AT can process either interactive method or automatic method. In the interactive AT method, human is required to completing the tasks. In the case of Digital or Automatic AT method, very little effort of human work is required. A more recent development began in the AT after introducing the Global Positioning System (GPS) and Inertial Measurement Unit (IMU)during the flying.GPS and IMU are providing the exterior orientation parameters (X, Y, Z, omega, phi, kappa), which is important for the initial approximation of the block set up and also reducing the control point requirement for the project.

AT is consists of important three steps such as Interior orientation, Relative orientation and Absolute orientation. Interior orientation (IO) is not required when the Aerial photographs are taken with digital camera, because digital camera is not having the fiducial marks. Generally interior orientation is carried out for relating the pixel system with fiducial system. Relative orientation (RO) is carrying out for connecting the adjacent photographs and strips to stabilize the blocks by means of image measurements. Absolute orientation (AO) is generally done for levelling and scaling the model. It is mainly for transferring the image coordinate system to object space coordinate system.

Project setup:

Initial settings are done in the project set up such as, camera focal length, camera fiducial coordinates, aerial photo location, and photo pixel size and principal point, also added in the project setup.

Interior Orientation (IO):

Interior orientation is carried out for relating the pixel coordinate system into image coordinate system. Fiducial marks are reference mark for transforming the pixel system into image system. After the project set up, interior orientation needs to be carried out using the inpho software. IO can be carried out manually as well as automatically using the software. Since the number of aerial frame is very less, manual interior orientation was performed for this project. In the manual Interior orientation, the each fiducial mark is measured manually on the aerial photographs. In the automatic interior orientation, the template was designed for the fiducials, in the template, fiducial size, shape of the fiducial are mentioned. After designing the templates, only one aerial photographs fiducials are needed to be measured. Then remaining photographs fiducials are measured automatically using the option available on the software. Automatic Interior orientation work well where the more number of aerial photographs in the projects and also all the photographs taken using the same camera. Maximum 8 fiducial marks can be measured in the IO. In this study, four fiducial mark aerial photographs were used. The figure 1 shows the fiducial mark position on the aerial photos. Only four fiducial coordinates are given in the camera file. After measuring the fiducial on the fiducial locations, the accuracy can be estimated based on the RMS value and sigma naught values present on the IO log file.

Relative orientation (RO):

Relative orientation is essential task to connect the adjacent photographs and adjacent strips to stabilize the block. Adjacent photographs and strips are connected by so called tie points. The tie point is the conjugate point between adjacent aerial photo and adjacent strips. Relative orientation and point transfer in aerial triangulation is part of one image are matched with part of other images in order to generate the tie points. Relative orientation does not require the recognition of specific features. The measure conjugate points only have to be geometrically well distributed in the model area. Relative orientation is the pre requisite for providing the parallax free stereo image for the photogrammetric data collection, and interpretation purposes. In the relative orientation process, the tie points can be measured manually and also by automatic process. Either automatic or manual, the concept is to match conjugate features between two or more overlapping aerial photographs. It is good to measure the tie points on the van Gruber locationto enhance the image measurement accuracy. And also that tie point should be sufficient and well distributed throughout the model area to produce the parallax free stereo images. It is good to avoid measuring tie points on the tree top, building top, shadow areas, movable objects, and temporary features, to reduce the image measurement errors and also reduce parallax. More erroneous tie points are leads to the wrong Aerial triangulation results and also reduce the efficiency of the block stability.

Absolute Orientation (AO):

Absolute orientation is transformation of stereo model coordinates or image coordinate system into object space coordinate system through a scaling and levelling. Ground control points (GCP) are required to transforming the image coordinate system in to object space coordinate system. GCP's are collected from the field by using Global Positioning System (GPS). GCP's is one of the essential inputs to determine the Aerial Triangulation result. Nowadays in the software domain, there is no rule that AO need to be performing after the RO. We can measure the GCP before measuring tie points on the overlapping aerial photographs. The reason is the block is having initial approximation exterior orientation parameters from GPS and IMU during the flying. Minimum three control points are required for completing the AO process. But in order to get higher accuracy, it is better to have more GCP's on the block and also GCP's should be distributed on the block.

Digital Elevation Model (DEM):

Digital Elevation Model is 3 dimensional terrain representations. DEM is generated after the AT results were attained the expected accuracy. Digital Elevation Model was generated using the Leica Photogrammetry Suite 9.2 (LPS). LPS is having the DTM extraction module, which is useful for generating the DEM.

DEM editing:

DEM editing is carried out using the DT master from the Inpho software. Generated output file format was Shape file. It can be imported to DT master using import vector data option. The additional instruments required for DEM editing is 3d mouse and 3d stereo class. Both the instruments should attach to the computer before start the editing. The layers creation was done for the break line and mass points in the DT master itself. Break line is representing the discontinuity or sudden changes in the Earth surface. Break line is necessary to draw where ever the discontinuity is high in the terrain. Generally break line is draw to represent the drainage pattern, abrupt slope, and also to represent the ridges and valleys. A mass point is required to fill the gap in the generated DEM and also to correct the wrong generated mass points. Automatically generated DEM mass point is based on the terrain conditions and the AT results. Automatic generated DEM is good in flat terrain except the flat terrain with buildings and trees. The percentage of erroneous point is more in the undulated terrain compared to the flat terrain. It is necessary to correct the wrong mass point in those areas. The figure 1: shows the DT master user interface for the DEM editing. Yellow points are indicating the mass points, and red line indicates the break line. Contour map can be generated using the DT Master interface. The figure 2 shows the contour map generated in DT master. Contour map is very useful option to edit the terrain effectively. Especially in the undulated terrain, the editing can be carried out effectively using the contour option in the DT master.

RESULTS AND DISCUSSION

Digital Elevation Model is important input for different applications, such as Orthophoto generation, urban planning, soil erosion studies, watershed delineation and land slide analysis. There are various techniques are available for generating Digital Elevation Model, such as terrestrial survey, GPS survey, Aerial survey, Satellite survey and Airborne Laser Terrain Mapping. In this study, Photogrammetry technique was used for generating the DEM. Digital Photogrammetry is the recent development in the Photogrammetry techniques. High speed processing computer, software, and hardware are used for the generation of DEM in the Digital Photogrammetry techniques. Most of the process in Digital Photogrammetry is automated, such as Interior orientation, Relative orientation, DEM generation, Orthophoto generation and Mosaicking. Accuracy of the DEM, derived from the Photogrammetry techniques is based on the various factors such as flying height, camera focal length, scanning resolution of the aerial photography, weather condition during the fly and skilled person. Generally, photogrammetric technique is suggested when the output is required in the centimetre accuracy and also for detailed mapping. In the Photogrammetry, Horizontal accuracy is better than the vertical accuracy.

The figure 3 shows Triangulated Irregular Network (TIN) representation of the Digital Elevation Model. TIN is one type of representation of the DEM based on the Elevation information. TIN is essential for the purpose of editing the DEM in the accurate way. If the TIN triangle comprises equally spaced triangles and small triangles, then it can be concluded that the DEM editing has been carried out well. The figure 3 depicts the equally spaced and small triangles, except the edges of the model and forest areas. In this study area, forest area is very dense, so mass points are kept where ever the terrain is visible. In the model edges, the parallax may be more and more over the edges is not required for our study.

The figure 4 represents the Z colour coding of the terrain. Z colour coding is done based on the elevation information on the mass point data. Elevation is classified based on the colour. Based on this approach, drainage pattern of the study area was clearly delineated.

The figure 5 shows the Digital Elevation model by interpolation method using GIS software. Interpolation is done based on the Elevation data. DEM are generated for the elevation data using GIS software. From the elevation information, it was clear that most of the terrain is the combination of both, flat and undulated terrain. But undulated terrain is very small portion compared to the flat terrain. Undulated terrain elevation is above 100 meter above the mean sea level. From the figure 5 it was clear that terrain elevation lies the range 26 to 110 metre.

The table 3 shows the accuracy of the GCP's between the original and measured on the aerial photography. From the table, it was clear that Z accuracy lower than X, Y accuracy.XY accuracy lies between 3 to 16 centimetres and vertical accuracy lie between 10 to 23 centimetres. It was necessary to analyse the GCP's accuracy before going for the DEM generation and Topographical mapping.GCP analysis was carried out between the GCP's measured on the field using GPS and GCP's measured on the aerial photograph after the completion of the AT. Accuracy of the satellite based generated DEM is discussed below.

K.Jacobsen et al has described about SPOT satellite which is viewing across the earth orbit. It

takes at least few days to imaging the same location from different orbit. If the weather condition is not good, the time interval may be larger. If the object is changing meanwhile, an image matching may be degraded or even impossible. If the object is not changing between the imaging periods, a vertical accuracy of 5 to 10 meter is possible in open and more flat areas. He has also described about MOMS-sensor which was viewing forward, to the nadir and backward, so a DEM generation is possible with images taken with just few seconds time interval. The three view direction can be used together for common intersection, improving not only the direction and also the reliability. MOMS' vertical accuracy in urban area is 7.9 meter, but in the forest area is 17.2 meter.

K.Jacobsen et al has discussed about the flexible viewing of IKONOS enables stereo view with the base length of just 90 km or 12 seconds time difference. The automatic matching for the area taken with same orbit causes no problem. It achieves accuracy in z is +- 1.7 meter. But the accuracy will degrade when the combination of two scenes taken in the different timing. If it is taken in the different timing, the accuracy is +-5.8 meter in the height. Elasker (2009) reviewed the different studies of accuracy assessment of IKONOS, for instance, the mapping accuracy of the stereo images with GCPs was reported as 1.32 meter RMSE in horizontal direction and 1.82 meter in vertical direction. However earlier it was in the range 6.2 meter in horizontal direction and 10.1 meter in vertical direction (Dial 2000).

K.Jacobsen et al has described about the Quick bird images which achieves the accuracy in x, y direction of 1 meter, but the accuracy in z is +/- 5 meter. Cheng and Chappel (2006), extracted DEM of Quickbird stereo images showed an average difference of 3 meter for gentle and moderate terrain and up to 30 meter for rugged terrain in vertical values.

Cartosat-1 accuracy was evaluated by Evan et al (2008) using the ENVI and PCI Geomatic. The generated DEM vertical accuracy was compared to NED, ASTER, and SRTM DEMs while the horizontal accuracy was compared with the Digital Orthophoto Quad data. The result showed the most accurate DEM generated by PCI with Mean vertical error was slightly less than 4 meter, and the standard deviations were less than 10 meters with horizontal accuracy of 5 meters x-y.

V.K Singh et al (2010) observed that while using only RPC information for Cartosat – 1 stereo data, the error in height was in the range of 124 - 126 metre. However, after use of GCPs and triangulation adjustment, the Cartosat-1 DEM image becomes smooth and the error in height was reduced from 3 to 18 m.

It was clear from the above discussion that the DEM generated from the aerial photography yields better results than the satellite based DEM. Though higher resolution satellites such as IKONOS, Quickbird, Worldview - 1, 2provided spatial resolution in centimetre, it was not able to produce DEM in the centimetre accuracy. Therefore it's not possible to use satellite based DEM for highly accurate and detailed mapping. In addition, the accuracy of the aerial photography based DEM vary based on the flying height, GCPs measurement from the field and also scanning resolution of the aerial photography and focal length of the aerial camera used.

Table 1: Fiducial coordinates of aerial photographs

ID	X (mm)	Y (mm)
1	-105.990	-106.0030
2	105.9950	-106.0090
3	106.0010	106.0090
4	-106.0010	106.003

Table 2: Ground control points (GCPs)

ID	X (m)	Y (m)	Z (m)
25	365693.971	8116214.038	27.702
26	364974.013	8116056.69	42.543
27	364556.849	8115982.108	62.429
28	365826.386	8115566.011	35.517
29	365278.008	8115352.692	48.767

Table 3: Ground control point residuals

	GCP measured on the field			GCP measured on the stereo pair			Residuals		
ID	X (m)	Y(m)	Z (m)	X (m)	Y(m)	Z (m)	Vx(m)	Vy(m)	Vz(m)
25	365693.971	8116214.038	27.702	365693.93	8116214.06	27.57	-0.037	0.019	-0.137
26	364974.013	8116056.69	42.543	364974.11	8116056.82	42.69	0.096	0.125	0.146
27	364556.849	8115982.108	62.429	364556.84	8115982.12	62.56	0.005	0.015	0.129
28	365826.386	8115566.011	35.517	365826.24	8115566.01	35.75	0.145	0.003	0.229
29	365278.008	8115352.692	48.767	365278.10	8115352.53	48.66	0.092	0.161	0.107

Fig. 1: DEM editing - DT Master

Fig. 2: Contour Interval

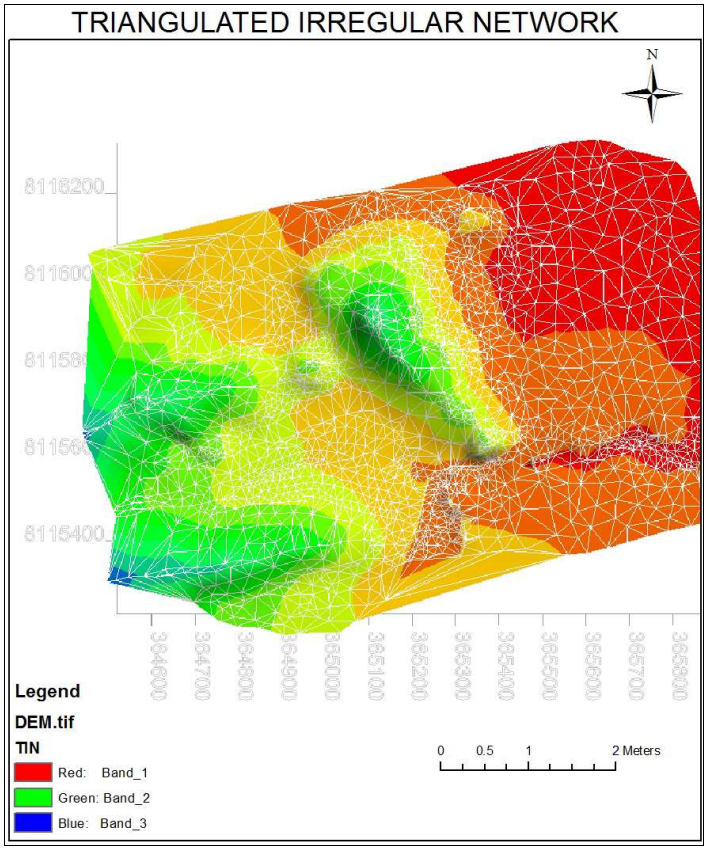


Fig. 3: TIN Representation of DEM

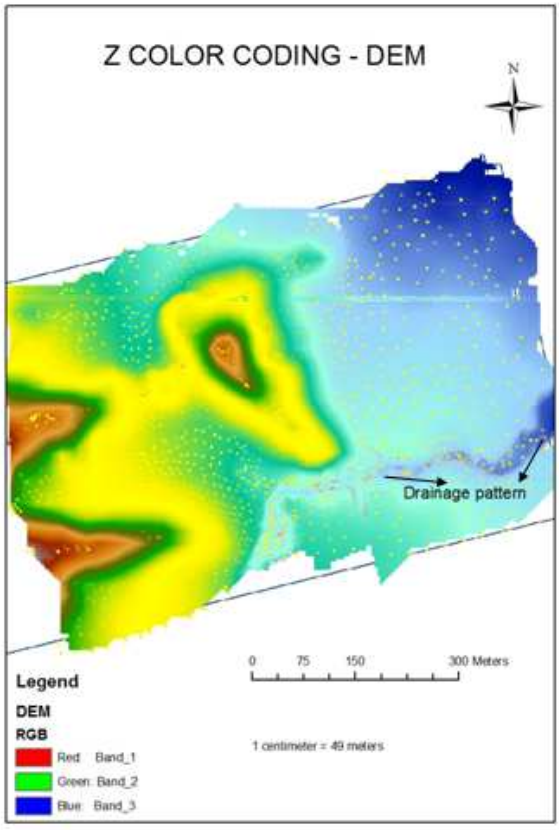


Fig. 4: Z Color coding for representing drainage pattern

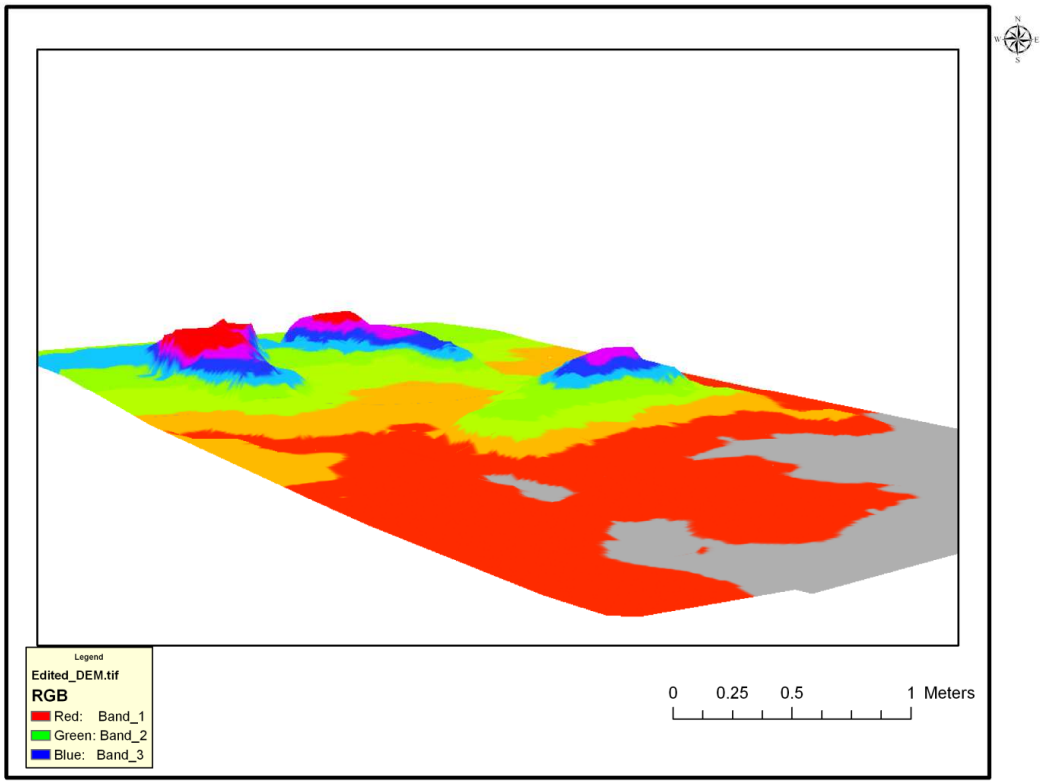
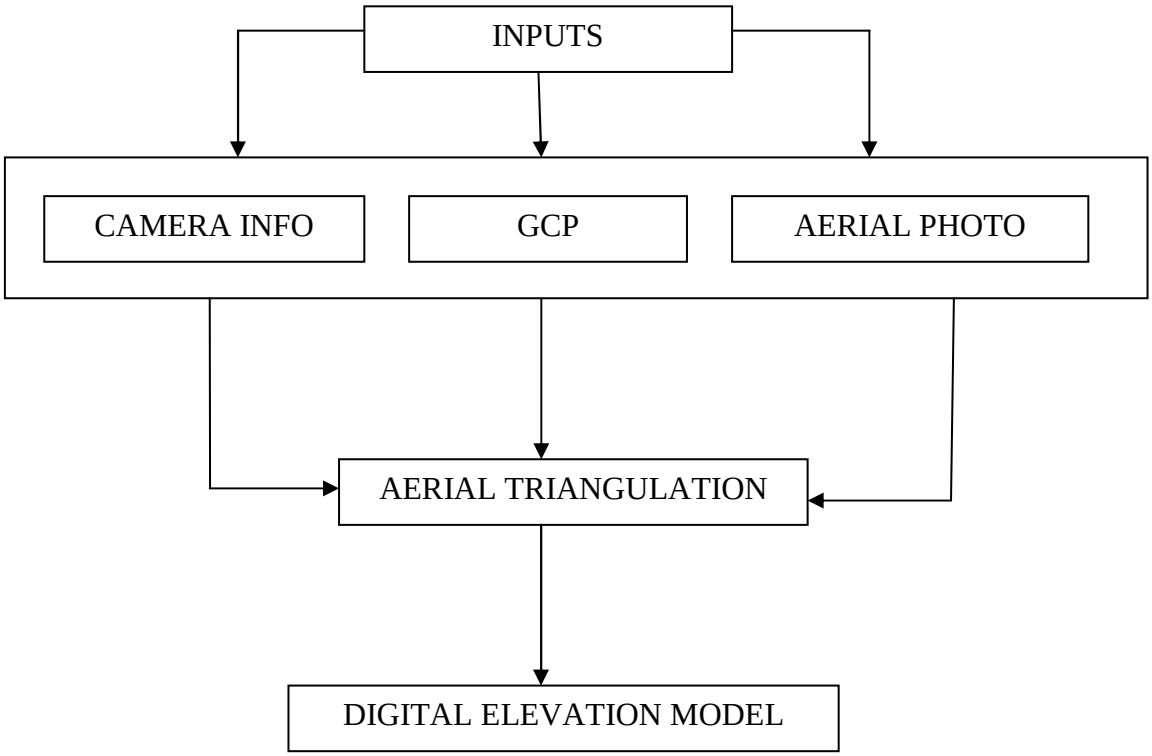


Fig. 5: Digital Elevation Model - Interpolation Method



Flowchart 1: DEM generation methodology

Conclusion:

DEM generation is essential because it is important input for different applications. Various sources are available for the generation of DEM, such as terrestrial techniques collected elevation data, Aerial photography, Satellite images, and Airborne Laser Terrain Mapping collected elevation data. And also different techniques are available such as Photogrammetry, Geographical Information System and Image processing. DEM accuracy relies on different factors; one of the main criteria is the source of the data. In this study, it was concluded that the Aerial based generated DEM was better than Satellite images generated DEM. Photogrammetry software is capable of handling the Aerial and Satellite images for the generation of the DEM. The Aerial photograph provides the centimetre accuracy, whereas the Satellite image confers the accuracy in the metre level. In this study, horizontal accuracy is better than vertical accuracy. Horizontal accuracy achieved in this study is 3 to 15 centimetres and the vertical accuracy is 10 to 22 centimetres. Aerial photograph based generated DEM is an important inputs for various applications, especially for the large scale and detailed mapping. DEM generated in this study was used for creating the contours, and delineating the drainage pattern.

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