Comparison of Digital Elevation Models Based on High Resolution Satellite Stereo Imagery

Abdul Qayyum, Aamir Saeed Malik, Muhammad Naufal Bin muhammad Saad

Electrical and Electronics Engineering Department
Universiti Teknologi PETRONAS Tronoh, Perak, Malaysia

engr.qayyum@gmail.com

Abstract— **In this paper, we analysed and compared the digital elevation model (DEM) based on high resolution QuickBird and Pleiades satellite stereo images. 3D maps were generated for objects like trees near poles of power transmission lines using satellite stereo images. This study was very challenging due to weather condition, hilly and non-uniform terrain at Kota kina balu in East Malaysia. First we require the geometric accuracy of these two sensors for 3D mapping of the area of interest. Also we require accurate Digital elevation model for better height calculation of vegetation/trees near power poles. For these purposes, we evaluated the accuracy of DEM using high resolution satellite stereo imagery. The comparison was made based on RPC coefficients and ground control point's measurement (GCP). Results shown that the Pleiades satellite sensor is feasible for generating the elevation model for small area. This shows that Pleiades sensor can be used for monitoring the vegetation near poles of high transmission power lines based on the satellite stereo images.**

Keywords— **Pleiades Satellite Sensor, QuickBird Sensor, DEM, RPC, and GCP.**

I. INTRODUCTION

The Pleiades satellite has been launched on 17 December 2011 and within one year another Pleiades satellite sensor has been launched on December 2 2012 [1].The Pleiades consisting of high resolution optical sensors with 0.7 meter panchromatic resolution and 2.8 multispectral resolution capabilities. It covers the swath about 20 km. It provides low cost solution with minimum area scan 100 km and has low weight. The main characteristics of Pleiades satellite is stereo data can be attained during one pass using forward and backward sensor capability as compared to the other very high resolution satellite sensors like IKONOS, QuickBird, GeoEye and Worldview [2].

The excellent feature of the Pleiades is taken three stereo images in a single pass in the same orbit. The Pleiades satellite sensor 1A and1B are almost identical in their features but Pleiades 1A has more accuracy in their geometric model based on rational polynomial coefficients. The Pleiades system is accurately dual-purpose optical observation system. The Pleiades system is fulfil the requirements of the dual system which has large application in agriculture, resource management, geology survey, forestry mapping and risk management for the commercial and scientific and institutional customers. It has large field of view in a long track and across track. In photogrammetry the fundamental parameter is the ratio between distance of flight height and two separating acquisition is called baseline ratio.

For measuring good 3D height, we need low baseline ratio value which incorporate low occlusion. The B/H ratio has a range between 0.7 to 1 for good 3D mapping applications. Many methods can be deployed to monitor the vegetation growth, and more importantly to estimate the height of the vegetation within the danger zone.

Traditional method of manual line patrol or inspection on foot lack accuracy primarily due to human judgmental errors. Moreover, this traditional method consumes a long time, and can be dangerous; essentially due to bad weather, or sometime exposes human to wild and vicious animal. Aerial inspection of power lines using a helicopter, or airborne imaging sensors are very expensive and trivially feasible in a non-uniform terrain [3]. In comparison with the manual visual inspection method, the aerial inspection can cover a larger area in a lesser time but incorporates excessive costs. The latter method is also prone to error introduced by camera shaking, and target location ambiguity, especially for non-uniform terrain.

Videography or aerial multispectral imaging utilizing computer vision techniques are better than the previous two methods. This method also uses the helicopter or balloon or airborne vehicle to capture the aerial images of vegetation. This method has a better accuracy as compared to visual or video surveillance, but more time consuming due to the low altitude of the airborne vehicle and its accuracy is dependent upon the multispectral resolution.

The method of satellite stereo imaging can provide a cost effective solution, with lesser involvement of human resources and manual judgment. The time required to monitor a particular danger zone is less, since the images are captured using satellite. The use of satellite stereo images has many advantages over visual inspection on foot and airplane based technique. The satellite images cover a wide area; have cost effective and easier access to restricted areas [4].

In this paper, we developed the DEM based on rational polynomial coefficients (RPC) and further used GCP to compare the performance of both Pleiades and QuickBird satellite sensors. We can enhance the performance of digital elevation model based on geometric model using Pleiades satellite sensors and also we choose the model which appropriate gave the accuracy of the DEM. We required the accurate DEM for measuring the height of trees near power poles based on Pleiades as well as QuickBird satellite sensors. We measured the performance of DEM with or without GCP.

Pleiades satellite sensor used without GCP and QuickBird Satellite used GCP. This paper presents algorithms to process the stereo images obtained via Pleiades satellite sensors, and carry out the required calculation to monitor the vegetation, followed by performance comparison with Pleiades stereo images based on RPC and GCP model.

The background or related work of stereo matching algorithms is discussed in Section II. The proposed technique is explained in Section III. Section 1V presents the simulation results. The conclusion and future research directions are presented in Section V.

II. RELATED WORK

The Pleiades satellite has the capability to acquire stereo imagery in one pass with the few second differences. It has also ability to provide stereo pairs color images of 20 km swath and 70cm resolution obtained with base-to height ratio from 0.15 to 2.The Pleiades has been placed on the same sun-synchronous orbit at 694km [1]. It has been acquiring the panchromatic stereo images with resolution of 50 cm and multi-spectral images with resolution 200cm and also in bundle form 50cm black and white and 200cm multispectral. The Pleiades satellite has high resolution and low weight and also low cost for acquiring the images of small area [5]. Digital Elevation Model comprises the elevation of terrains surface for specified area in topographic area and it has many applications such as Geographic Information Systems (GIS), Natural hazards, mass movement modelling of water flow, formation of relief maps and much more. There are many techniques based on aerial images and terrestrial surveying were used for the generation of DEM for a decades [5].

The development of Global positioning System (GPS) helped the conventional techniques, however, there are many difficulties are involved such as time-consuming, reaching into impenetrable areas, high expenses, are still remaining. To conclude, the opportunity comes into sight by using satellites stereo images for generation of DEM data was began with the launch of the first of SPOT series satellites in 1986 [6].There are many advantages. There are many experiments have been conducted to calculate remote sensing data as new alternative for producing DEM [7]. Using very high resolution satellite images have the range of base-to-height ratio between 0.5 to 1 make the generation of DEM and 3D mapping very accurately [8], with the development of the satellite sensors, there is a need to improve and redesign the rigorous model .There are many software tool such as Erdas, ENVI, digital mapper ArcGIS, PCI Geomatics are used in commercial level to generate and extract the DEM. There is a need to choose best stereo images and techniques for generation of DEM are essential and all assessment is based on the specification of very high resolution satellite images.

There are basically three models used for geometric correction to generate the true orthorectification of imagery and DEM [9]. The rational Polynomial coefficients used ground control points, Rigorous model and third one is also based on RPC provided by vendor. The third approach may not use Ground control points, first two methods used above 30 Ground control points for the true correction of the model [10].

III. METHODOLOGY

A. Proposed framework

The proposed depth measurement method was applied on satellite stereo imagery of Pleiades satellite. The Pleiades have GSD 0.7m for panchromatic images and 2.25 m for multispectral images. The images of Pleiades were cropped due to memory constraints of the processing system. After acquisition of stereo images and completing the pre-processing, we can set the physical parameter for mapping the image points with ground points. We need two types of models, first is the rigorous geometric model and second one is the rational polynomial model. RPC model was used for measuring the accuracy of the digital elevation model. We required the correct RPC model for mapping the 3D height of the object on the ground. The ground control points are used to measure the accuracy of DEM in QuickBird Satellite sensor. The GCP points are very useful for measuring the geometric correction of the stereo images.

The stereo matching algorithms have very important rule in the accuracy of the digital elevation model. There are many stereo matching algorithms are existing based on area based and feature based. We used correlation method based on desired area for finding correspondence between two stereo images.

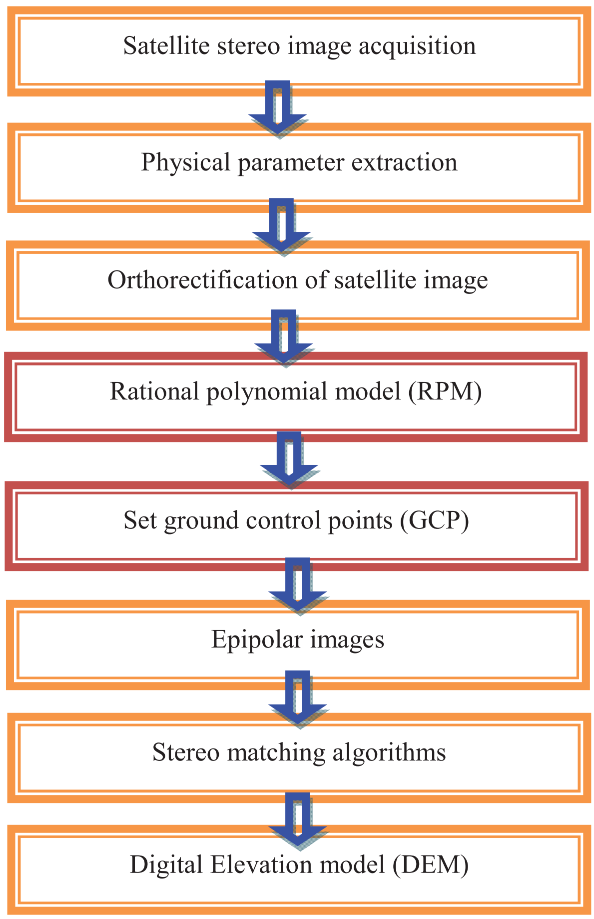

Fig. 1. Proposed framework for evaluation of digital elevation model (DEM) by incorporating RPC model and ground control points

B. Analytical Model or Rational polynomial Coefficient Model

The geometric modelling is defined the relationship of the raw image pixels and geographic coordinated on the ground. There are two geometric model are used on sensor level and can be delivered. These are:

a. A rigorous sensor model

b. A rational function model

The results are very comparable when we are going to using these two models.

The rigorous model is composed of complete set of parameters of the acquired image.

1) Focal plane properties and alignment.

2) Time stamp image

3) Ephemeris time tagged and smoothed attitude

The preference given to rigorous model is easy to use in photogrammetric pro-cessing in block adjustments due to clear separation between different physical parameters. The RFM (Rational function model) is the approximation of the rigorous sensor model. This model takes the ratio of polynomial based on senor geo location. This ratio is a very simple relationship of raw pixel image and ground coordinates. This model has very high accuracy as compared to the original rigorous sensor model. This model can be used to generate the sensor level product and helped out to reduce the high distortion. RFM can be used as a good senor model for elevation the accuracy of the DEM [11].

RPC is extracted from the physical camera model of Pleiades sensors. RPC model are used to transform 3D object space coordinate into 2D image space coordinate system. RPC model can be used for the orthorectifcation of the stereo images, feature extraction and terrain extraction task. It provides the accurate and feasible solution for communicating the camera object with image object relationship from vendor to end user.

The rational polynomial coefficient model is an analytical model which gives a relationship between

- Image coordinates + altitude and ground coordinates (Direct model: image to ground).
- Ground coordinates + altitude and image coordinates (Inverse Model: Ground to image).

Ground coordinates used by inverse model or calculated by direct model are (longitude, latitude) in the WGS84 geodetic system, the “altitude” used is a height above ellipsoid [9].

1) Direct Localization Algorithm.

$$X = \frac{\sum_{i=1}^{20} c_i \cdot p_i(x,y,Z)}{\sum_{i=1}^{20} d_i \cdot p_i(x,y,Z)} \quad (1)$$

$$Y = \frac{\sum_{i=1}^{20} c_i' \cdot p_i(x,y,Z)}{\sum_{i=1}^{20} d_i' \cdot p_i(x,y,Z)} \quad (2)$$

2) Inverse localization Algorithm.

$$x = \frac{\sum_{i=1}^{20} c_i \cdot p_i(X,Y,Z)}{\sum_{i=1}^{20} d_i \cdot p_i(X,Y,Z)} \quad (3)$$

$$y = \frac{\sum_{i=1}^{20} c_i' \cdot p_i(X,Y,Z)}{\sum_{i=1}^{20} d_i' \cdot p_i(X,Y,Z)} \quad (4)$$

Where (X,Y) are ground coordinates, (x,y) are image coordinates, (Z) =altitude coordinate, c,d,c',d' are nominator and denominator coefficients of rational polynomial coefficients.

$$\begin{aligned}\sum_{i=1}^{20} c_i \cdot p_i(x,y,Z) &= c_1 + c_2 x + c_3 y + c_4 Z + c_5 xy \\ &+ c_6 xZ + c_7 yZ + c_8 x^2 + c_9 y^2 + c_{10} Z^2 \\ &+ c_{11} xyZ + c_{12} x^3 + c_{13} xy^2 + c_{14} xZ^2 + c_{15} x^2 y \\ &+ c_{16} y^3 + c_{17} yZ^2 + c_{18} x^2 Z + c_{19} y^2 Z + c_{20} Z^3\end{aligned} \quad (5)$$

$$\begin{aligned}\sum_{i=1}^{20} c_i \cdot p_i(X,Y,Z) &= c_1 + c_2 X + c_3 Y + c_4 Z + c_5 XY \\ &+ c_6 XZ + c_7 YZ + c_8 X^2 + c_9 Y^2 + c_{10} Z^2 \\ &+ c_{11} XYZ + c_{12} Y^3 + c_{13} YZ^2 + c_{14} XZ^2 + c_{15} Y^2 Z \\ &+ c_{16} X^3 + c_{17} XZ^2 + c_{18} Y^2 Z + c_{19} X^2 Z + c_{20} Z^3\end{aligned} \quad (6)$$

The maximum power of each term is three. These functions are easy to use and have the benefit of low computational complexity and wide support in existing soft-ware. They allow a very simple relationship between raw pixels in an image (2D) and geographic coordinates (3D).They provide very high accuracy with respect to the rigorous model. The RF model is generated by using the rigorous model.

IV. EXPERIMENTAL RESULTS

We used the Pleiades & QuickBird satellite stereo images for generation of digital elevation model based on the rational polynomial function model and GCP. We used physical parameter and coefficient length is equal to 20 for this particular experiment. We have taken the Pleiades satellite stereo images (1A & 1B sensor) of area of interest at 27-June-2014 and 5-September-2014 of Kota kina balu in East Malaysia and for acquired QuickBird Satellite sensor images from Digital Globe website for comparison purpose. The extraction of digital elevation model based on stereo images depends on the rational polynomial coefficients of the RFM as well as set ground control points (GCPs). If the RPC has good value it means that the accuracy of DEM is feasible and further GCPs point help out the accuracy more in DEM generation. Our proposed framework was applied on stereo images of Pleiades & QuickBird Satellite sensors. Results are shown in Fig. 2 and Fig. 3.

It is evident from these two figures that DEM generated from images acquired from Pleiades Satellite sensor 1A produced better results as compared to Pleiades satellite sensor 1B sensor. The circle marked in Fig. 2 and Fig. 3 shows that more object heights were extracted in case of Fig. 2 as compared to Fig. 3. It means that DEM computed using Pleiades Satellite sensor 1A is more accurate as compared to the DEM extract from the Pleiades satellite sensor 1B. To illustrate the results more significantly, we have also reconstructed the 3D model of DEM for both sensors as shown in Fig. 4 and Fig. 5. The square marked area in Fig. 4 and Fig. 5 justify our results in term of object height extraction. Fig. 4 shows more object heights as compared to Fig. 5. It means that Pleiades Satellite sensor 1A based DEM extraction is more accurate as compared to the Pleiades satellite sensor 1B based DEM extraction without measuring the ground control points.

Now in second case the QuickBird satellite images are used for the extraction of DEM with the help of ground control points. The external measurement of ground control points is helpful to enhance the accuracy of the DEM. The quickBird Satellite stereo imagery has a resolution 0.7 ground sample distance (GSD) for panchromatic and 4.5 for multispectral images and these images are taken from urban area and used to build the digital elevation model. The Images contain building, stadium and river roads etc.

The DEM is generated from the QuickBird Satellite stereo image as shown in Fig. 6. You can see that the roads and some buildings are clearly extracted where we have small illumination and noise which incorporated through satellite sensors. The extracted part is shown in yellow box. The 3D model has been clearly indicated the height of building as shown in the below figure.in yellow box. This model clearly shows the height of building and some small objects as shown in the figure. The accuracy of digital elevation model (DEM) depends on the ground control points (GCP). The GCP have the major role for the true rectification of DEM and accuracy depends also the rectification of DEM. We also investigate the tie point between two satellite images and shown in the summery in the table. The tie point between two stereo images has the average success rate is 96 precent which is sufficient for the generation of elevation model based on satellite stereo imagery. The ground control points are shown in Table .1.

Fig. 2. Digital Elevation Model (DEM) Using Pleiades Satellite 1A sensor

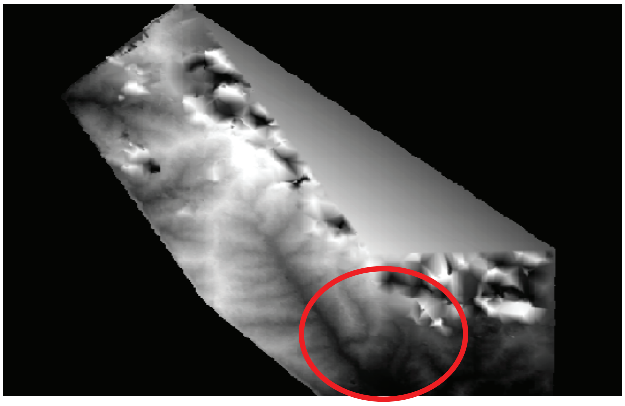

Fig. 3. Digital Elevation Model (DEM) using Pleiades Satellite Sensor 1B

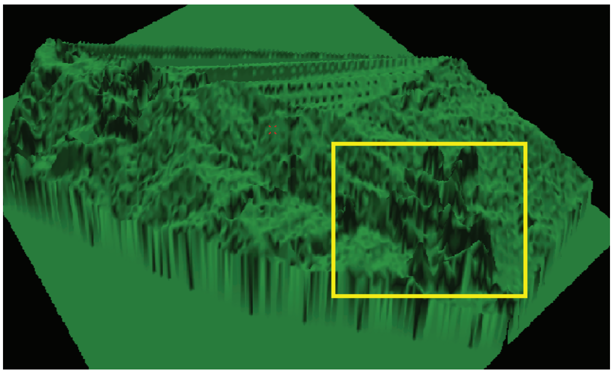

Fig. 4. 3D model of Pleiades Satellite sensor 1A

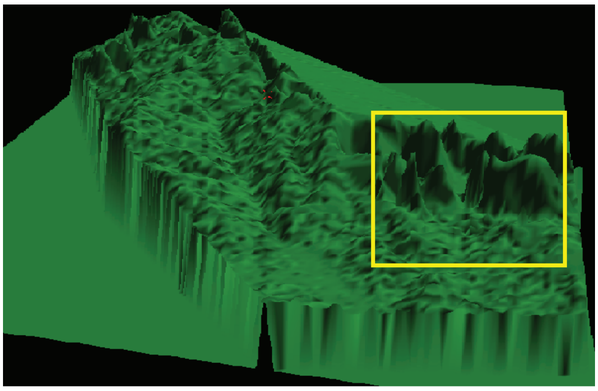

Fig. 5. 3D model of Pleiades satellite sensor 1B

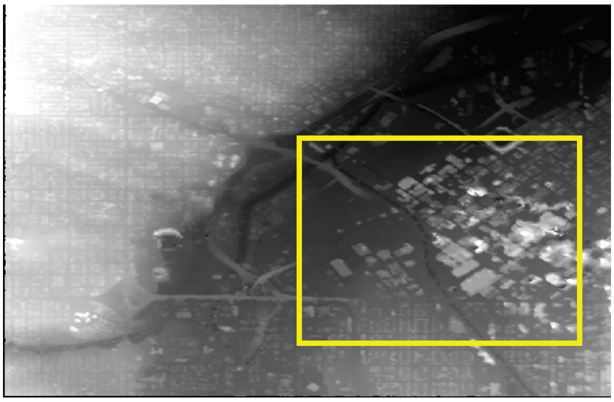

Fig. 6. Digital Elevation Model (DEM) using QuickBird Satellite Stereo images.

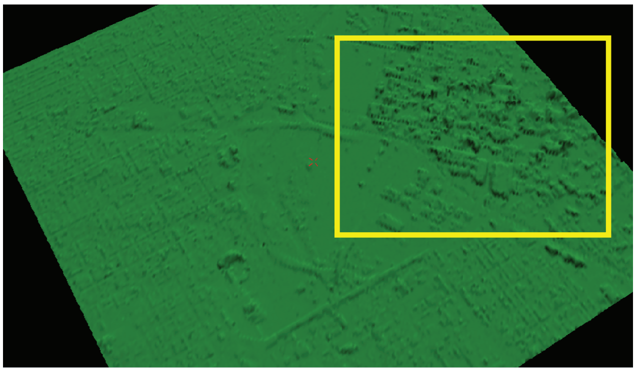

Fig. 7. 3D model of QuickBird satellite stereo images

In the next step, we have compared the RPC coefficients up to order of 20 between Pleiades 1A satellite sensor and Pleiades satellite sensor 1B as shown in the Fig. 8 and Fig. 9 using direct rational functional model. This comparison is also repeated on inverse rational functional model as shown in Fig. 10 and Fig. 11.

It is clear from the Fig. 8 and Fig. 9 that RPC coefficient up to order 20 have less values for Pleiades 1A sensor as compared to Pleiades 1B sensor for images acquired on 26 June 2014. In Fig. 7, the result is the same as previous one in Fig. 8. Similarly, RPC coefficients comparison results using inverse rational functional model was shown in Fig. 10 and Fig. 11. For both figures comparison, we can see that RPC coefficients have fewer values for Pleiades 1A sensor in comparison to Pleiades 1B sensor. These small values of RPC coefficients also produce better 3D mapping and object height extraction.

In conclusion, the Pleiades satellite sensor 1A provide more accurate DEM based on the rational polynomial coefficients as compared to Pleiades satellite sensor 1B. Therefore, we can select Pleiades 1A sensor for monitoring the vegetation or trees near power poles based on the satellite stereo images of the area of the interest.

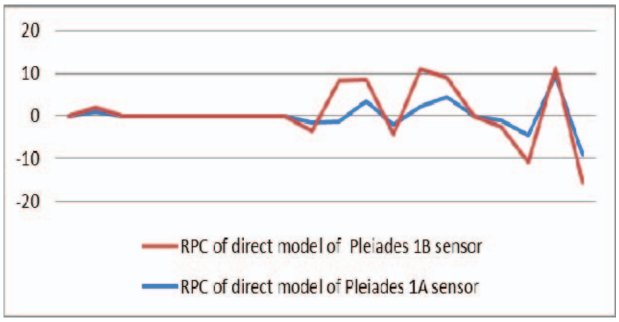

Fig. 8. RPC of direct functional model for Pleiades satellite stereo images acquired at 27-June-2014

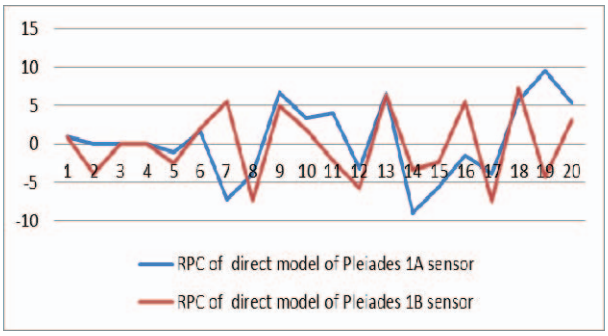

Fig. 9. RPC of direct functional model for Pleiades satellite stereo images acquired at 5-September-2014

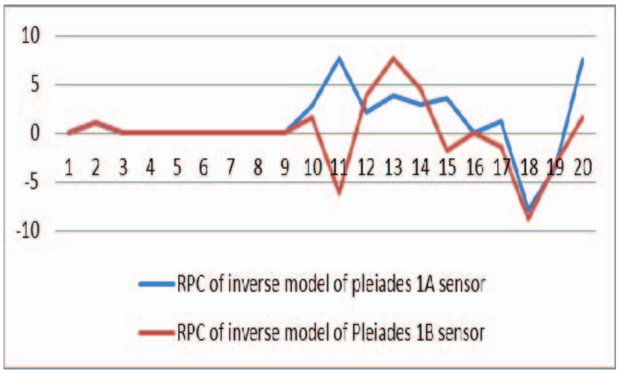

Fig. 10. RPC of inverse functional model for Pleiades satellite stereo images acquired at 27-June-2014

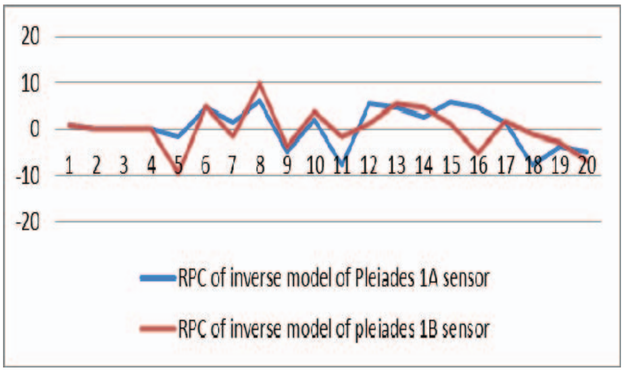

Fig. 11. RPC of inverse functional model for Pleiades satellite stereo images acquired at 3-September-2014.

Table.1. Ground control points using in QuickBird satellite stereo images.

Satellite Sensors	Ground Control Points (GCP)
QuickBird Stereo image #1	496154.954, 494839.642, 500989.864, 490913.572, 4400522.662, 4398837.024, 4397630.735, 1619.704, 1630.846, 1590.692, 1668.642, 1768.642, 1968.642, 2068.642, 2268.642.
QuickBird Stereo image #2	516154.954, 504839.642, 520989.864, 480913.572, 4400522.662, 4498837.024, 4397630.735, 1619.704, 1630.846, 1790.692, 1668.642, 1868.642, 2068.642, 2268.642, 2468.642.

V. CONCLUSION AND FUTURE DIRECTION

In this paper, we implemented the digital elevation model based Pleiades and QuickBird satellite sensors 1A and 1B using geometric model and ground control points (GCP). The accuracy of DEM depends upon the resolution of Pleiades 1A sensor & Pleiades 1B sensor and RPC model. We compared he performance of both sensors 1A and 1B and also compare with the QuickBird satellite sensor and results showed that Pleiades 1A satellite senor produces more accurate digital elevation model as compared to the Pleiades 1B satellite sensor without ground control points. The QuickBird satellite sensor produce more accurate result by using ground control points as compared the Pleiades satellite sensor even though the Pleiades satellite has good charterictics for scanning small area. It means that we can use Pleiades 1A sensor for monitoring the vegetation and trees near poles of high transmission power lines based on the satellite stereo images for the area of the interest.

In future, we can also compare the digital elevation model based on the RPC with other available sensors. Further, we can use ground control points to improve the accuracy of DEM for object height extraction.

ACKNOWLEDGMENT

This research is sponsored by Ministry of Energy, Green Technology and Water, Malaysia (KeTTHA), Malaysia.

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