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PHOTOGRAMMETRIC MAPPING FROM HIGH-RESOLUTION STEREO IMAGERY AND COMPARATIVE ANALYSIS USING EXISTING DATA

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Abstract— The launch of the very high resolution (VHR) sensor satellites has paved the way for further exploitation of the capabilities of stereo satellite imagery for many applications and most importantly in the extraction of topographical details. Advances in digital technologies in the photogrammetric technique provide more accurate and up to date topographic representation, while traditional methods of topographic mapping are time-consuming and require large technical support. This paper explores the methods of production and an analysis of the capabilities of the high-resolution stereo imaging system for the extraction of features (topographic map) and generation of digital elevation model (DEM). This study uses high-resolution GeoEye-1 stereo pair images. For qualitative assessment, topographic features were extracted by digitizing the georeferenced stereo pair images and overlapped to form a DEM and orthophoto within the Summit Evolution software. Georeferencing was carried out using the existing Ground Control Points (GCPs) and Check Points (CPs) established using Real-Time Kinematic Global Navigation Satellite System (RTK-GNSS) technique. For quantitative assessment, a total of 7 existing GCPs were considered suitable for use and 5 CPs were established as a check for accuracy of the output. The accuracy of the CPs was evaluated by computing Root Mean Square Error (RMSE). The average horizontal RMSE for the left image and right image were 1.17150098m and 0.819334672m respectively and the average vertical RMSE was 1.605898565m. Additionally, the standard deviation for elevation data from generated DEM using photogrammetric technique and existing elevation data of RTK-GNSS technique were computed, which resulted in 15.91286667 and 16.59529228 respectively. The accuracy was evaluated by comparing the results of the data extracted using stereo satellite images and those extracted from ground measurement techniques (Total station and RTK-GNSS). The comparative analysis showed that stereo pair images provide a viable alternative to other ground mapping techniques providing results within the acceptable range. Based on error estimation and analysis, it concludes that, if strict photogrammetric processing model and ground control points are employed, high-resolution satellite imagery can be used for the accurate generation and update of the topographic maps, DEM and digital orthophotos, which can be further be used as a reference for comparative analysis applications.

Keywords— photogrammetric techniques, VHR stereo satellite imagery, topography, DEM, orthophoto, Georeferencing, GCP, CP, RMSE, standard deviation.

I. INTRODUCTION

Photogrammetry comprises techniques concerned with making measurements of real-world objects and terrain features from images. Applications include the measuring of coordinates, quantification of distances, heights, areas and volumes, topographic mapping, generation of digital elevation models and orthophotographs [1]. Photogrammetry is the art, science and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomenon [2]. With the advances in space sensor technology, greater availability of high-resolution satellite images and advancement in digital photogrammetry, the creation of maps and conducting analysis has become more convenient and effective.

Topographic maps are a detailed, and accurate graphical representation of geographical feature that occurs on the earth's surface [3]. The objective of carrying out the topographic survey was to generate accurate topographic maps using digital photogrammetric mapping technique from high-resolution stereo satellite imagery to update existing maps and to perform comparative study in terms of the cartographic feature attributes and its accuracy assessment by considering the importance of topographic mapping. The stereo imagery used for the topographic mapping is of 0.5-meter (50 cm) resolution and the satellite sensor is the GeoEye-1. The GeoEye-1 satellite sensor features the most sophisticated technology ever used in a commercial remote sensing system [4]. The stereo imagery for the generation of topographic map is of the year 2013 which covers the whole of Samdrup Jongkhar district.

Topographic maps are very important, and there are no updated versions of maps produced with photogrammetric mapping from high-resolution stereo satellite imagery and no comparative study has been done in terms of the cartographic feature attributes and its accuracy assessment. Therefore, the objectives of the study are to assess the level of details that can be extracted from stereo satellite imagery and compare the extracted features with the existing vector data. The study will also assess the quality and accuracy of DEM generated using stereo satellite imagery and establish a production line for mapping. An analysis is in terms of cost, time, accuracy and advantages of photogrammetric mapping over other mapping techniques such as the use of Total Station, GPS, etc.

The Jigme Namgyel Engineering College campus which is situated at around 800 meters (2600 ft) above sea level located at 18 kilometers from Samdrup Jongkhar in eastern Bhutan was selected as the study area.

II. BODY (METHODOLOGY)

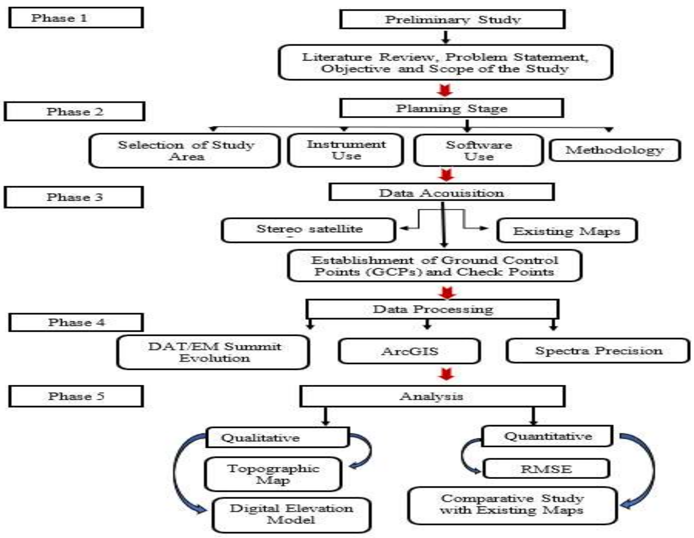

Fig. 1. Methodology Flowchart

2.1 Materials and Software

The general flowchart used for carrying out photogrammetric mapping for this study is shown in Fig.1. The materials used for the study are Digital Photogrammetric Workstations (DPWs), 3D mouse, Stereo Compilation (3D) Glasses. and RTK (real-time kinematic) Spectra Precision 60. A stereo display (also 3D display) is a display device capable of conveying depth perception to the viewer. The basic technique of stereo display is to present offset images that are displayed separately to the left and right eye, overlaying the two images gives 3D perception. For the project, the stereo display hardware used is NVIDIA workstation. The 3D Mouse is a high-performance 3D hand controller. The stereo compilation glasses are used in photogrammetry for the purpose of viewing the images in a 3D model when the pair of images are being superimposed on one another [5]. Without the use of 3D glasses, it would be difficult and almost impossible for viewing the images stereoscopically.
The basic concept behind RTK is that a base station receiver is set on a known point around the project site and the base station receiver sends correction data to the survey receiver (Rover). The correction data is typically sent via UHF Radio link or Bluetooth connection [6]. A topographic survey can be done very efficiently with the RTK.

DAT/EM Summit Evolution software provides a set of powerful tools for discovering and capturing 3D information from stereo data. The software includes CAD and GIS interfaces, 3D stereo vector superimposition, automated feature editing, contour generation and many more tools [7]. It also supports the generation of orthophoto, terrain visualization, contour generation, DEM collection and topographical feature extraction. An ArcGIS is a geographical information system (GIS) software that allows handling and analyzing geographical information by visualizing geographical statistics through layers [8]. Spectra precision survey office is an office software ideal for processing and analyzing optical survey data and GNSS data recorded in the field [9]. It allows processing and generating reports of RTK, Static, Fast static, and stop-and-go Kinematic data.

2.2 Data Acquisition

Stereo satellite images also called stereoscopy or 3D imaging is a photography technique originally developed for creating the illusion of depth in an image or set of images. Two images of an area are taken from slightly different angles allowing for depth to be perceived when viewing the images [10]. The workflow of data acquisition and processing to analysis the results to update the existing topographic maps of using photogrammetric mapping techniques is shown in Fig.2.

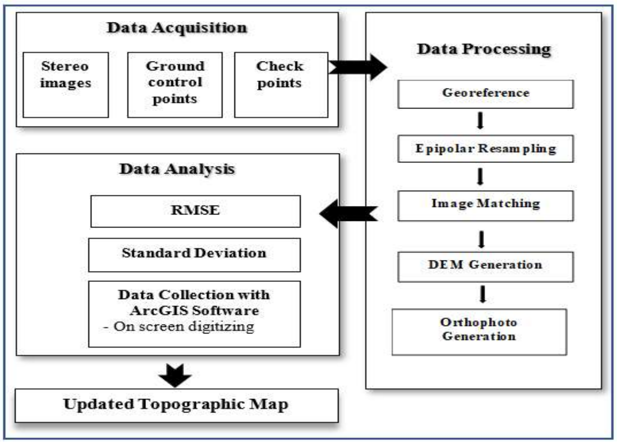

Fig. 2. Data acquisition work flow

The stereo satellite image used for the project was acquired from National Land Commission Secretariat (NLCS) covering the whole of Samdrup Jongkhar District with a resolution of 0.5 meters. The stereo pairs were both in panchromatic and multispectral mode and for this study the multispectral imagery was used. The data were collected at 11 bits per pixel and were in Geographic map projection, WGS84 datum.

GCPs with known coordinates defining horizontal position and the altitude coordinate are used to georeferenced satellite images [11]. A check point with unknown ground coordinates is visually recognizable in the overlap area between multiple images and are used for quality assessment [12]. Their coordinates are obtained with RTK survey. Georeferencing is the process of taking a digital image and adding geographic information to the image so that the image is positioned correctively relative to real-world or ground position [13]. GCPs and CPs provides accurate positional data, required to align or to georeferenced the satellite image (raster data) to a map coordinate system. A total of seven existing GCP coordinates and five new CPs were considered as shown is Table 1 and Table 2.

TABLE 1. List of existing ground control points used as reference points and for georeferencing in the study.

		Coordinates Obtained from RTK		
SI. No.	**Station**	**Easting(m)**	**Northing(m)**	**Elevation(m)**
1	GCP03	395577.318	2972944.29	855.694
2	GCP05	395393.073	2973005.107	869.204
3	GCP06	395251.519	2972977.758	874.07
4	GCP07	395414.673	2972876.4	849.283
5	GCP13	394996.446	2972588.824	873.41
6	GCP16	394727.746	2972679.228	891.85
7	GCP17	394599.108	2972658.551	881.142

TABLE 2. List of check points collected using RTK-GNSS technique to check for the accuracy of the generated results.

		RTK-GNSS observation		
SI. No.	**CP Identifier**	**Easting (m)**	**Northing (m)**	**Elevation (m)**
1	CP01	395608.924	2973045.868	848.439
2	CP02	395447.488	2972959.063	865.657
3	CP03	394926.07	2972629.992	888.968
4	CP04	394733.573	2972648.992	882.743
5	CP05	394647.524	2972753.116	881.128

2.3 Data Processing

2.3.1 Creating stereo project

Created a project file that organizes the images and other project files in submit evolution software. Loaded an image in SMTI format and perform georeferencing. Import GCPs and surveyed CPs data and set the coordinate system applicable to the study area location (DRUKREF 03 Bhutan National Grid and EGM2008 coordinate systems). Finally, open two partially overlapping stereo images in submit evolution software as shown in Fig.3.

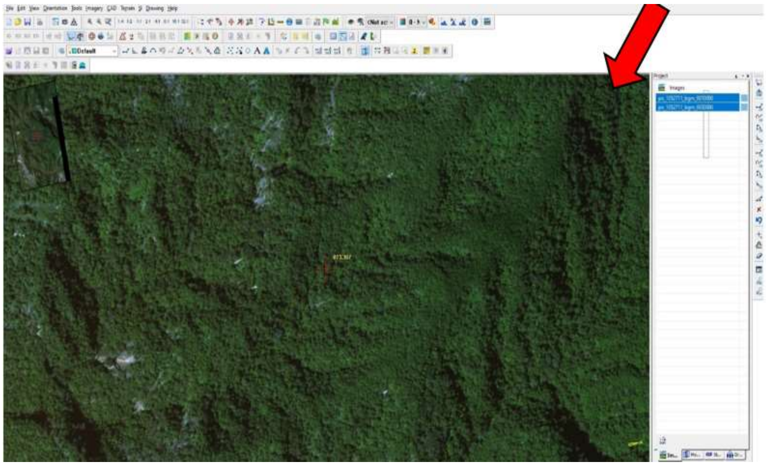

Fig. 3. Partially overlapping stereo images

2.3.2 DEM generation

Image point measurement of GCPs and CPs are collected using RTK-GNSS and adjusted for DEM generation. To validate the image geo-positioning accuracy, seven GCPs and five CPs evenly distributed in an overlapping area of the stereo-images were used. To generate the DEM, initially created epi-polar images from each stereo-pair and resampled them to eliminate vertical disparity (Y-parallaxes) between stereo images [14]. Then, created a polygon covering the entire study area so that the DEM can only be generated inside the polygon. The breakpoints collected for DEM generation should be evenly distributed and the DEM generated so is shown in Fig.4 which was used in creating contour maps.

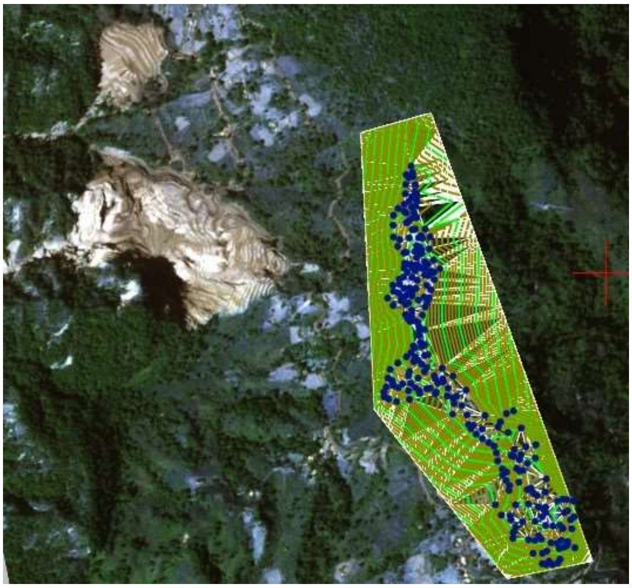

Fig. 4. DEM generated in summit evolution

2.3.3 Topographic map generation

After orienting and generating DEM, the topographic map was created in ArcMap using Cad Up feature. Created layers for the different features to be extracted through the photogrammetric mapping. Features such as roads and buildings were collected using the editor in the summit evolution and subsequently mapped in ArcMap as shown in Fig.5.

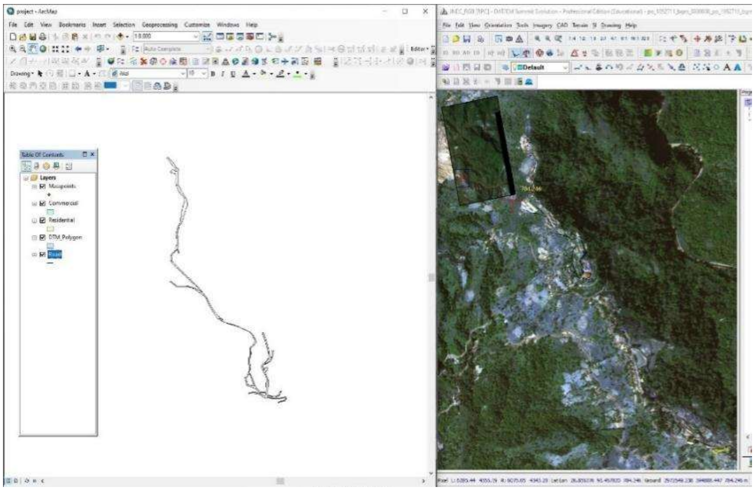

Fig. 5. Extraction of geographical features using photogrammetric mapping technique and simultaneously mapped in ArcMap.

2.3.4 *Orthophoto Project*

Created a project file that organizes the images. Open an orthophoto image in summit evolution and loaded a DEM file to be used with the terrain. Activated superimposition in ArcMap to view objects superimposed over the summit evolution image and finally digitize objects in ArcMap.

2.4 Results and Discussion

2.4.1. *Results*

The accuracy of the CPs was assessed by computing the root mean square error (RMSE).

$$RMSE = \sqrt{\frac{\sum (N_i - N_j)^2}{n}} \quad (1)$$

Where N_i is the observed values, N_j is the reference values and n is the number of points.

Table 3. summarizes the relevant statistical values about the sensitivity and accuracy of the CPs collected using the photogrammetry and RTK-GNSS techniques. The RMSE of the data should be as low as possible for increasing the accuracy of the final outcomes. For the five CPs used the average RMSE in the Left image was computed to be 1.17150098 m, for the Right image the RMSE was 0.819334672 m and for elevation, it was computed to be 1.605898565 m. The consideration for the CPs was made since the RMSE computed for the above three parameters were considerable low (higher accuracy) for a 0.5-meter resolution stereo image.

TABLE 3. Computed RMSE for the checkpoints in terms of the horizontal coordinates (X, Y) and vertical coordinate (Z) of both the stereo images.

	Residuals in Left and Right Image								Difference in Elevation	
CheckPoint	X Residual Left	Squared Residual X	Y Residual Left	Squared Residual Y	X Residual Right	Squared Residual X	Y Residual Right	Squared Resiudal Y	Δ Z	Squared Residual Z
CP01	1.2668	1.60478224	0.9332	0.87086224	1.4646	2.14505316	1.0643	1.13273449	0.321	0.103041
CP02	-1.7455	3.04677025	-1.2785	1.63456225	-1.9376	3.75429376	-1.3652	1.86377104	0.916	0.839056
CP03	0.9715	0.94381225	0.676	0.456976	0.6376	0.40653376	0.2233	0.04986289	3.267	10.673289
CP04	-1.0866	1.18069956	-0.7404	0.54819216	-0.4573	0.20912329	0.0402	0.00161604	0.843	0.710649
CP05	0.5937	0.35247969	0.4097	0.16785409	0.2927	0.08567329	0.0374	0.00139876	0.754	0.568516
Sum		7.12854399		3.67844674		6.60067726		3.04938322		12.894551
RMSE		1.194030485		0.857723352		1.148971476		0.780945993		1.605898565
Average RMSE in Left Image		1.17150098								
Average RMSE in Right Image		0.819334672								
RMSE in Elevation		1.605898565								

2.4.2. *Topographic Map Accuracy*

The topographic map generated using stereo satellite imagery consists of geographical features such as roads, buildings and playing fields. Since the stereo image was captured in the year 2013, the new features are not incorporated in the map generated using the photogrammetric mapping as shown in Fig.6.

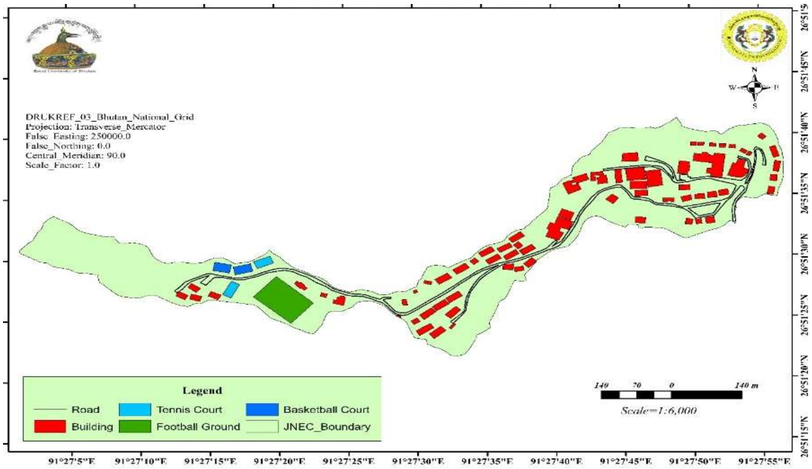

Fig. 6. Buildings and road map from stereo satellite images using photogrammetric technique.

The comparative map used for the qualitative analysis was created using RTK-GNSS technique. The existing map was generated during the year 2018-2019. The map consists of all the new features and infrastructures which were built in recent years as shown in Fig.7.

From the comparison map as shown in Fig.8, it is concluded that there are some offsets in the horizontal distance and horizontal coordinates (longitude and latitude) of the photogrammetrically extracted features when overlaid onto the existing map. Change in the land use proportion can also be visually analyzed which has occurred due to infrastructural development in recent years. The difference in the horizontal position of the features (buildings, roads and playing fields) may be due to the incorrect orientation of the images and there might have been some errors in the collected GCPs and CPs.

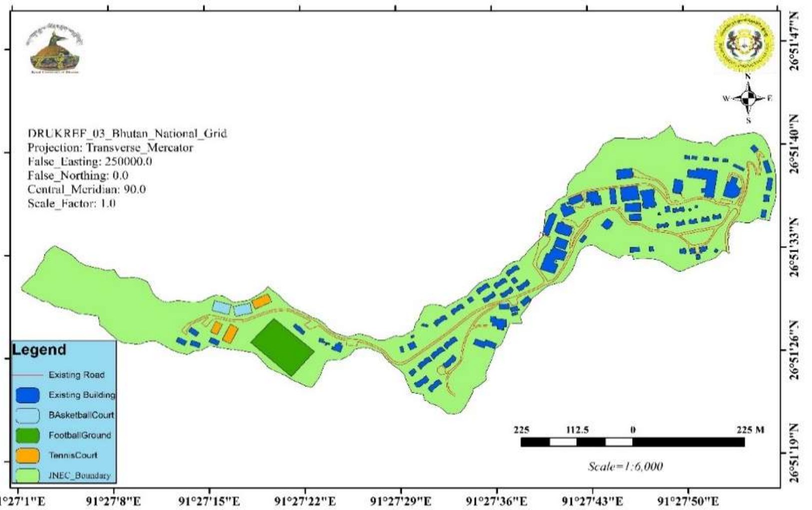

Fig. 7. Existing buildings and road map (comparative map) generated using the data surveyed using RTK-GNSS.

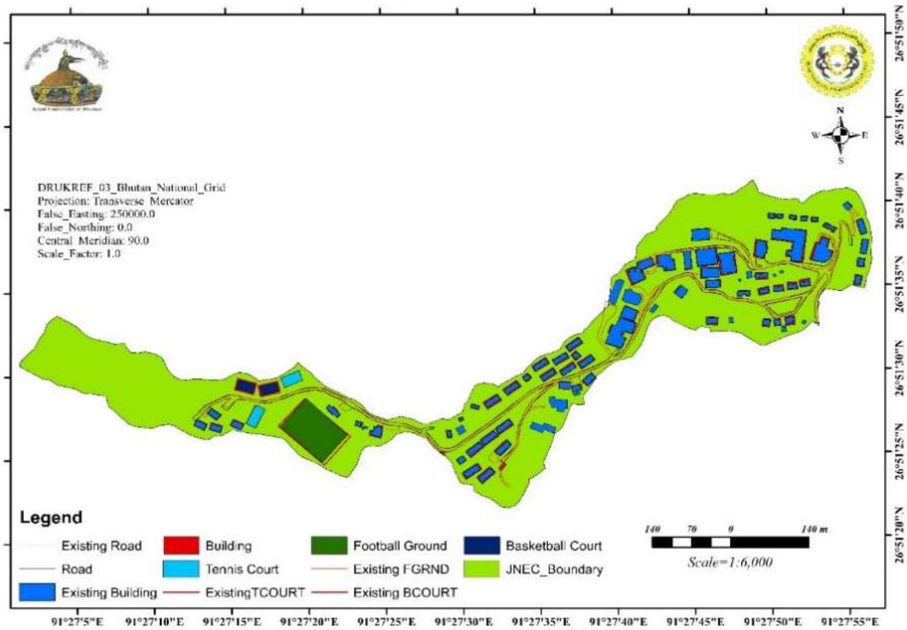

Fig. 8. Comparison Map created by overlaying features extracted using photogrammetric mapping over the existing map created using RTK-GNSS techniques.

2.4.3. Digital Elevation Model Accuracy

The qualitative analysis of the generated DEM was executed by comparing to existing data. The existing data used for the comparative analysis is the elevation data collected using RTK-GNSS technique.

From the elevation data used, the maximum and minimum elevation points collected using photogrammetric techniques were 893 meters and 830 meters respectively with a mean elevation of 868.182 meters. For the elevation data used from the RTK-GNSS technique, the maximum and minimum elevation were 894 meters and 827 meters respectively and a mean elevation of 868.056 meters. From the observed elevation data, it is concluded that the difference in the mean elevation of the elevations collected using the two techniques is computed to be 0.126 meters. The mean elevation difference as shown in Table 4 and illustrated in Fig.9 is within the acceptable range since the difference is less than a meter. The computed standard deviation shows a minimal dispersion of the elevations since the standard deviation for photogrammetric and RTK-GNSS methods are 15.91286667 and 16.59529228 respectively. Therefore, it is concluded that the DEM generated using the elevation data collected using the photogrammetric technique is accurate.

TABLE 4. Elevation differences and standard deviations were computed for the elevation data extracted from photogrammetry and RTK-GNSS methods to determine the accuracy of the generated DEM.

Statistics	Photogrammetry Elevation data (m)	RTK-GNSS Elevation data (m)
Minimum	830	827
Maximum	893	894
Mean	868.1824818	868.0566038
Standard Deviation	15.91286667	16.59529228

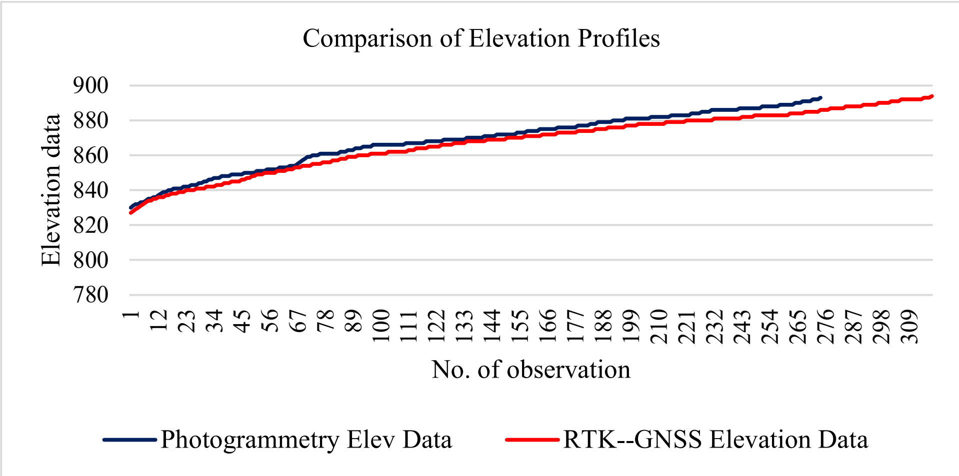

Fig. 9. Distribution of elevation data of the elevations computed by photogrammetric and RTK-GNSS techniques.

A total of 274 points were collected in the stereo image used for the DEM generation using the summit evolution software and a total of 318 points were used from the already existing contour data. With the positive conclusion drawn, the contour maps were generated and a confirmed topographic map was created as shown in Fig.9. A contour map is a map illustrated with contour lines and represents relief of the land [15]. Contour maps help individuals to determine and visualise the changes in elevation.

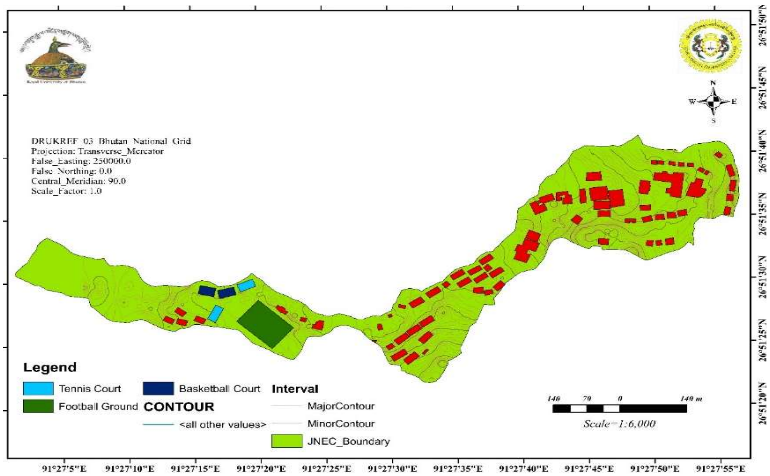

Fig. 10. Topographic Map using the high-resolution stereo imagery by photogrammetric mapping technique

2.5 Discussion

Based on the results obtained in this project, the accuracy for the checkpoints used for the DEM generation has shown that the average RMSE for both the left and right image is 0.997172236 m (where RMSE of left image = 1.17150098 m and RMSE of right image = 0.819334672 m). The average RMSE in elevation data for the CPs was calculated as 1.605898565 m. Once the RMSE in checkpoints were computed to a desirable value the DEM was generated in reference to those adjusted CPs.

The accuracy and the level of features that can be extracted using photogrammetry is dependent on the resolution of the captured image. If the visibility of the features present in the image is low there is every chance that the data captured for those particular points is less accurate and also some features present will be left out during the digitization. For accurate results of the topographic map, it is necessary to have high-resolution stereo satellite imagery.

For the accuracy of the DEM generation, it depends on the accuracy of GCPs and CPs used for the georeferencing of the stereo image during the initial stage of the photogrammetric mapping technique. If the RMSE for the GCPs and CPs are larger than the accuracy cannot be maintained, so for greater accuracy in the generation DEM and contours the RMSE should be as minimum as possible. Once the minimum RMSE is obtained the GCPs and CPs can be used in the DEM generation.

In the case of the orthophoto accuracy, since it is an image-like map the accuracy of the orthophoto will be high as long as the accuracy of the DEM is high.

Overall, the results obtained in this project indicate that higher accuracy in the outputs can be achieved and many analyses can be made if the procedures for the photogrammetric mapping technique are followed strictly. Developments in data acquisition and processing software in photogrammetry, it allows the reuse and enhancement of historical data for DEM generation, feature extraction and orthophoto generation, leading to better and faster results.

III. CONCLUSION

This study describes the generation of a topographic map, DEM, and orthophoto and their accuracy assessments by using photogrammetric mapping technique from high-resolution stereo satellite imagery. The checkpoints collected using RTK-GNSS technique were used as a check for accuracy control.

According to the results achieved, it is possible to state that the generated DEM and topographic map can be used for comparing it with existing data maps and make conclusions in terms of the cartographic features extracted and elevation data.

This work has evaluated the accuracy that can be achieved by using high-resolution stereo satellite images for different applications involving feature extraction, DEM and orthophoto generation. The extraction of digital elevation models and 3D features was performed after georeferencing the image using GCPs and CPs. The 3D information extracted from the stereo satellite images was compared to that of the existing maps. In addition, the maps produced from the stereo satellite imagery were transformed into knowledge-based components, such as the computation of RMSE for the horizontal and vertical coordinates of the stereo images used, comparison of the extracted features and computation of standard deviations of the elevation data for conducting comparative study and analyzing the results for its accuracy assessments.

The comparative analysis showed that stereo satellite images now provide a viable alternative to other ground mapping techniques providing values within the acceptable range. The use of photogrammetric mapping provides with a wider range of advantages which includes, an integrated stereo workflow capable of performing multi-tasks (using both Summit Evolution software and ArcGIS software side by side), supports multiple data sources and collects stereo features directly into ArcMap window. Photogrammetric mapping technique can be expensive during its initial stage as the cost of photogrammetric workstations and acquisition of VHR satellite image is reasonably expensive, but the time consumed for mapping works is very less as compared to other ground measurement techniques and higher accuracy outputs can also be achieved.

The stereo images acquired by VHR satellite sensors play an important role in topography and DEM generation applications, provided that all the processing steps follow strict procedures and the result of each step is carefully assessed. Lastly, the outputs and analyses produced using the photogrammetric mapping technique using VHR stereo satellite imagery can be used as a reference to do comparative analysis.

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