FEATURE ORIENTATION AND POSITIONAL ACCURACY ASSESSMENT OF DIGITAL ORTHOPHOTO AND LINE MAP FOR LARGE SCALE MAPPING: THE CASE STUDY ON BAHIR DAR TOWN, ETHIOPIA

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ABSTRACT:

This study used in-situ GPS data to validate the accuracy of horizontal coordinates and orientation of linear features of orthophoto and line map for Bahir Dar city. GPS data is processed using GAMIT/GLOBK and Lieca GeoOfice (LGO) in a least square sense with a tie to local and regional GPS reference stations to predict horizontal coordinates at five checkpoints. Real-Time-Kinematic GPS measurement technique is used to collect the coordinates of road centerline to test the accuracy associated with the orientation of the photogrammetric line map. The accuracy of orthophoto was evaluated by comparing with in-situ GPS coordinates and it is in a good agreement with a root mean square error (RMSE) of 12.45 cm in x- and 13.97 cm in y-coordinates, on the other hand, 6.06 cm with 95% confidence level – GPS coordinates from GAMIT/GLOBK.

Whereas, the horizontal coordinates of the orthophoto are in agreement with in-situ GPS coordinates at an accuracy of 16.71 cm and 18.98 cm in x and y-directions respectively and 11.07 cm with 95% confidence level – GPS data is processed by LGO and a tie to local GPS network. Similarly, the accuracy of linear feature is in a good fit with in-situ GPS measurement. The GPS coordinates of the road centerline deviates from the corresponding coordinates of line map by a mean value of 9.18cm in x-direction and -14.96cm in y-direction. Therefore, it can be concluded that, the accuracy of the orthophoto and line map is within the national standard of error budget (~ 25cm).

1. INTRODUCTION

With the development of technology, digital photogrammetry has started to be used widely in almost all areas about mapping. Especially, digital orthophos which are photogrammetric products are being used by different sectors because of their easy interoperability. In this connection, Siriba (2009) stated that the identification of parcel boundaries using photogrammetric method has become an alternative approach to ground based surveying and has been adopted in different countries for modernizing land information registration and administration system. Photogrammetric technique provides seamless coverage of cadastral information, but the accuracy of data has to be calibrated using in-situ ground measurements to realize the production of large scale maps (ranging from 1:500 to 1:10,000) based on orthophoto and digital line map that can be reliably used for practical cadastral applications. In recent years, much technological advancement has been made in the field of photogrammetry and the process of making maps using orthophotos. However, the photogrammetric data are affected by different factors such as topographic variations, canopy, earth’s curvature and other error sources introduced by computational procedures such as rectification and digitalization.

The rectification process is affected by the accuracy and spatial distribution of the ground control points, the aerial triangulation process, and digital elevation, and the method/software used for rectification. These errors reduce the spatial accuracy of
photogrammetric data and cause geometric distortion and misorientation of linear features. Lawali and Waziri (2014) showed that orthorectification process reduces geometric errors inherent within photography and imagery. The variables contributing to geometric errors include camera and sensor orientation, systematic error associated with camera and topographic relief displacement, and earth curvature. Greenfeld (2001) also explained that orthophotos generally offer significant benefits, but all orthophotos are not generated with equal accuracy. In general, the accuracy and quality of orthophoto varies based on the accuracy of the source data. Other contributing error factors include the characteristics and calibration of equipment used for image capture such as the camera and/or scanner.

Currently, Ethiopia is involved to develop high resolution and accurate rural and urban cadastral map. So far, promising development have been made in system development, aerial photo capturing, aerial triangulation, orthophoto generation, and feature extraction and digital line map preparation for 23 towns including Bahir Dar Town. Besides, there is an increasing demand for rural and urban cadastral mapping. For example, the Ethiopian government has planned to capture aerial photo of 92 towns during the second Growth and Transformation Plan (from 2016-2020) to further improve the cadastral and land management system. Therefore, study aims to assess the accuracy of orthophoto and digital line map acquired over the entire area of Bahir Dar Town, by comparing coordinates of some selected points and linear features from orthophoto and digital line map against an independent accurate data more obtained from GNSS measurement. This study used orthophoto and digital line map acquired from aerial photogrammetric survey carried out over the whole area of Bahir Dar Town, accounting for a total area of 159 km². The photogrammetric surveying was conducted by Information Network Security Agency (INSA) in 2011/12 with standard aerial camera at 1.2,000 scale and 15cm Ground Sample Distance (GSD).

In practice, the quality of photogrammetric data can be examined by assessing the accuracy of vertical and horizontal coordinates of land parcel boundaries, point features and orientation of linear features. The positional accuracy achievable using photogrammetric methods and the scale of the final map are determined based on mapping requirements and practice (Siriba, 2009). The spatial accuracy evaluation of the orthophoto and its suitability for a given application can be performed in a number of different ways. One way to do this is to overlay it onto another reference (e.g., a vector-based graphic) information layer known to have higher accuracy. Differences or errors in feature locations between the orthophoto and reference layer are observed and quantified. The results of that error quantification are used to determine the accuracy of the orthophoto. Another way to test the spatial accuracy is by using the Global Positioning System (GPS) to determine accurate positions of features that can be easily identified on the orthophoto (Greenfeld, 2001). The accuracy in the positions of photogrammetric datasets needs to be evaluated against in-situ ground-truth datasets using positional accuracy assessment technique.

Positional accuracy assessment refers to the task of evaluating the absolute relative positions of the spatial objects on aerial photo and digital line map with respect to their true locations on the surface of the Earth.

The accuracy is usually determined for both horizontal and vertical coordinates. Horizontal positional accuracy is an estimate of accuracy of the horizontal positions of the spatial objects that can be measured in terms of latitude and longitude or local easting and northing coordinates (Kapnias, 2008). Whereas, the vertical positional accuracy refers to the uncertainty with which the vertical coordinates (ellipsoidal height/geocentric radius) of spatial objects can be measured. In general, the positional accuracy of orthophoto refers to the accuracy at which the position coordinates (latitude, longitude and ellipsoidal height) of the spatial objects that are well recognized on the orthophoto are estimated in reference to their corresponding ground-truth coordinates acquired at the same locations using an independent ground based in-situ measurement such as Global Navigation Satellite System (GNSS) observations (Congalton and Green, 2009; American Society of Photogrammetry and Remote sensing (ASPRS), 2013). In theory, the accuracy of ground based reference data used to validate the accuracy of photogrammetric data shall be at least three times more accurate than the photogrammetric data being assessed (Congalton and Green, 2009), while error in positional accuracy of photogrammetric data is the difference between the coordinates of the same selected spatial objects as acquired from photogrammetric survey when compared to coordinates measured using GNSS receivers.

Regarding with the GPS data processing for reference dataset, there are two types of GPS data processing software. The first is scientific GPS data processing software and the second is commercial GPS data processing software. It is usually believed that scientific GPS data processing software is better than commercial software, in terms of accuracy of coordinate results especially in large areas. However, continual improvements in commercial GPS data processing software may enable people to achieve the same result as the scientific software for long baseline distance (Featherstone, 2004). Scientific Institutions always develop scientific software such as Bernese, GIPSY. GAMIT, SWAG. Whereas, the commercial software developed by commercial company, an example of such software; Trimble Geomatics Office (TGO), LGO and Topcon.

In addition to point wise positional accuracy assessment of the photogrammetric products (orthophoto and its digital line map), the correctness of the orientation of linear features should be evaluated (Siriba, 2009). The utilization of points remains to be convenient and photogrammetric researchers recently focused on using high level features (linear and area feature) in various photogrammetric operations (Curitiba, 2003). In this connection, such features increase system redundancy and consequently show the geometric strength and robustness in terms of the ability to detect blunders and local anomalies (Atak, 2008). Siriba (2009) stated that linear feature (straight line and area) could be evaluated for their geometric, radiometric, and mosaicking accuracies. Besides, straight lines are valuable for
the recovery of the interior orientation parameter (IOP) of the cameras, where object space straight lines should appear as a straight lines in the image space in the absence of distortion (Habib, 2009). Due to advancement in digital photogrammetric surveying, there is a growing interest to use linear features for various development activities and this resulted in the necessity of evaluating the accuracy of linear features orientation in space.

2. METHODOLOGY

Regarding the methodological approach, the data sources for this study are the orthophoto and digital line map acquired over the whole area of Bahir Dar city during a period of 2011/12. The ground based in-situ GNSS measurements at some selected and identified spatial objects were conducted for the checkpoints establishment. The study used the best method among positional accuracy assessment techniques. GPS data acquired at selected reference points for the observation session of 72 hours in static sense are processed using Leica Geofice (LGO) and GAMIT/GLOBK software packages. The results from the two processing techniques were compared for internal self-accuracy assessment. The GPS post processing technique used Continuously Operating Reference Station (CORS) and International GNSS Service (IGS) as a reference stations. To improve the accuracy of the checkpoints’ coordinates, the Receiver Independent Exchange Format (RINEX) file and Broadcast (BRDC) file were downloaded from those stations via Internet (http://igs.bkg.bund.de/file/rinexsearch) and imported into GAMIT/GLOBK to enable the minimization of error using double differencing principle and least square sense. Regarding checkpoint sampling design and distribution, the study used the newly endorsed ASPRS and NSSDA mapping standards and Ethiopian Mapping (EMA) standards. For comparison purpose, the coordinate transformations were made because of the GPS coordinates and the coordinates extracted from orthophoto and digital line map are defined in different coordinate reference system and the whole procedures are illustrated in the figure below (See Figure 1).

![Figure 1. Positional and orientation assessment of digital orthophoto and line map schematic diagram](image)

3. RESULT

3.1. Positional Accuracy Assessment

This study explicitly examined the accuracy of orthophoto and its digital line map in terms of horizontal position and orientation of road centreline. The GPS coordinates for the five checkpoints were determined using GAMIT/GLOBK with the RMSE values ranging from 0.61cm to 1.06 cm (Table 1).

<table>
<thead>
<tr>
<th>PID</th>
<th>Grid Coordinate, Adindan UTM by GAMIT from regional GPS stations</th>
<th>Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Easting (m)</td>
<td>Northing (m)</td>
</tr>
<tr>
<td>GPS1</td>
<td>326693.6185</td>
<td>1282895.8886</td>
</tr>
<tr>
<td>GPS2</td>
<td>323211.6201</td>
<td>1282942.3193</td>
</tr>
<tr>
<td>GPS3</td>
<td>325020.2210</td>
<td>1280209.7277</td>
</tr>
<tr>
<td>GPS4</td>
<td>322080.5410</td>
<td>1282414.3735</td>
</tr>
<tr>
<td>GPS5</td>
<td>323716.1279</td>
<td>1281627.9210</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This contribution has been peer-reviewed.
Table 1. GAMIT/GLOBK derived GPS coordinates of the checkpoints with their corresponding residuals errors and GDOP values

According to the 1989 NSSDA’s standard, the equation for the average horizontal error or horizontal RMSE $h$ is calculated from the errors of the individual test sample points using equation 1.

$$RMSE_h = \sqrt{\frac{\sum_i^n ((x_{ri} - x_{mi})^2 + (y_{ri} - y_{mi})^2))}{n}}$$

(1)

The Horizontal error at the point $i = \sum_i^n ((x_{ri} - x_{mi})^2 + (y_{ri} - y_{mi})^2)$

The Horizontal error at the point $i$ in $x$ and $y$

$$\sigma_x^2 = \frac{\sum_i^n (x_{ri} - x_{mi})^2}{n}$$

$$\sigma_y^2 = \frac{\sum_i^n (y_{ri} - y_{mi})^2}{n}$$

Where, $x_i$ and $y_i$ are the reference coordinates and $x_m$ and $y_m$ are the map or image coordinates for the $i$th sample point, $\sigma_x^2, \sigma_y^2$ are second momentum or variance of the statistical distribution.

The second momentum or variance is the square root of the average of the set of squared differences between map coordinates and their corresponding in-situ coordinates. Errors in X and Y coordinates are computed separately because they are independent of each other. In theory, it is assumed that errors are normally distributed and independent of each other in the X and Y component, a factor of 2.4477 is used to compute horizontal accuracy at 95 % confidence level using equation 2 (NSSDA, 1989).

$$\text{Accuracy} = \frac{2.4477 \sqrt{\sum_i^n ((x_{ri} - x_{mi})^2 + (y_{ri} - y_{mi})^2))}{n}}{2}$$

(2)

or

$$\text{Accuracy} = \frac{2.4477 \sqrt{\sigma_x^2 + \sigma_y^2}}{2}$$

(3)

If $\sigma_x^2 = \sigma_y^2$, equations (2) and (3) can be reduced to a more simplified formula. Let

$$RMSE_h = \sqrt{2} \cdot \text{RMSE}_x - \sqrt{2} \cdot \text{RMSE}_y$$

Where

$$\text{RMSE}_x = \sqrt{\frac{\sum_i^n (x_{ri} - x_{mi})^2}{n}}$$

$$\text{RMSE}_y = \sqrt{\frac{\sum_i^n (y_{ri} - y_{mi})^2}{n}}$$

Or equivalently, the RMSE in x- and y-directions can be given as

$$\text{RMSE}_x = \sqrt{(\sum (x_{ri} - x_{mi})^2)/n}$$

$$\text{RMSE}_y = \sqrt{(\sum (y_{ri} - y_{mi})^2)/n}$$

Therefore, the horizontal accuracy can be given by:

$$\text{Accuracy} = 2.4477 \cdot \frac{\text{RMSE}_h}{2} = 1.22385 \cdot \text{RMSE}_h$$

(4)

Note that the constants 1.7308 and 1.22385 are the standard value from the x-axis of the standard normal distribution for an interval with a probability of 95%.

The RMSE of the difference between the orthophoto coordinates and in-situ GPS coordinates of the five check points in x and y-directions are 12.45 cm and 13.97 cm, respectively. The horizontal accuracy of orthophoto is determined at 6.06 cm with 95% confidence level, which means three times less than the accuracy of reference dataset (0.774 cm) (Table 1 and 2).

In addition to GAMIT/BLOBK GPS data processing software, the study used LGO software packages as well to establish checkpoints to conduct positional accuracy assessment of the given orthophoto. To do so, two scenarios were implemented regarding the use of GPS network. The first scenario was to process the GPS data of the five checkpoints with a tie to local GPS reference station (TANA CORS station was) available over short baseline distance. For this scenario, the average accuracy of GPS data are 1.748 cm and 2.47 cm in x and y-directions, respectively (Table 3).

Table 2. Comparison between GPS coordinates and orthophoto-based coordinates

<table>
<thead>
<tr>
<th>P.ID</th>
<th>Easting (m)</th>
<th>Northing (m)</th>
<th>Elevation (m)</th>
<th>Error E (m)</th>
<th>Error N (m)</th>
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</thead>
<tbody>
<tr>
<td>GPS1</td>
<td>322669.1568</td>
<td>1322049.0870</td>
<td>1700.0512</td>
<td>0.0172</td>
<td>0.0253</td>
</tr>
<tr>
<td>GPS2</td>
<td>322311.1679</td>
<td>1322427.4520</td>
<td>1700.0554</td>
<td>0.0009</td>
<td>0.0124</td>
</tr>
<tr>
<td>GPS3</td>
<td>322502.1008</td>
<td>1320204.6539</td>
<td>1702.4210</td>
<td>0.0025</td>
<td>0.0202</td>
</tr>
<tr>
<td>GPS4</td>
<td>322200.1745</td>
<td>1322414.3049</td>
<td>1703.4914</td>
<td>0.0203</td>
<td>0.0343</td>
</tr>
<tr>
<td>GPS5</td>
<td>322715.9812</td>
<td>1321268.1013</td>
<td>1703.6153</td>
<td>0.0154</td>
<td>0.0263</td>
</tr>
</tbody>
</table>

Table 3. LGO-derived GPS coordinates of the checkpoints from local GPS network
The accuracy of orthophoto as compared to the GPS data acquired from LGO processing is 16.71 cm and 18.98 cm in x and y-direction, respectively in RMSE sense (Table 4). In other words, the positional accuracy of orthophoto evaluated for five checkpoints are estimated at 11.07 cm at 95% confidence level. In this case, the baseline distance from reference station to checkpoint location was 8 km.

Table 4. Comparison between GPS coordinates from LGO and orthophoto-based coordinate of the checkpoints

<table>
<thead>
<tr>
<th>PID</th>
<th>Sx (m)</th>
<th>Sy (m)</th>
<th>Sz (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS1</td>
<td>0.04487</td>
<td>0.04681</td>
<td>0.12963</td>
</tr>
<tr>
<td>GPS2</td>
<td>0.04076</td>
<td>0.04032</td>
<td>0.11093</td>
</tr>
<tr>
<td>GPS3</td>
<td>0.04485</td>
<td>0.04672</td>
<td>0.12923</td>
</tr>
<tr>
<td>GPS4</td>
<td>0.04885</td>
<td>0.04772</td>
<td>0.13923</td>
</tr>
<tr>
<td>GPS5</td>
<td>0.04079</td>
<td>0.04030</td>
<td>0.11072</td>
</tr>
</tbody>
</table>

Table 5. Comparison between errors in position coordinates as determined from LGO and GAMIT/GLOBK

The standard deviation (Sx, Sy, and Sz) that are associated with the LGO and GAMIT/GLOBK GPS solutions as shown in Table 5 are presented in a more illustrative way using histogram. For example figure 2, 3 and 4 shows the distribution of residual errors in x, y and -components respectively as acquired from both LGO and GAMIT/GLOBK software packages.

Figure 2. Plot of residual errors in x-component as computed from LGO and GAMIT (unit is in m scaled by 100)

Figure 3. Plot of residual errors in y-component as determined from LGO and GAMIT (unit is in m scaled by 100)
3.3. Orientation of Linear Feature

The accuracy of linear features can be tested by examining variation in the orientation of the digital line map using RTK GPS surveying technique. In RTK GPS measurement, the base station (TANA CORS) sends correction for GPS error sources in real-time via radio link to the rover over 6 km on average. In this particular study, 32 coordinate values were collected along the road centerlines. The coordinate values were digitized and the digital line map (road centerline) is overlaid on top of it. The selection of digital line map (road centerline) being tested consists of straight line (A) and curved line (B) purposely, to observe how accurate the orientation change of linear features are determined from orthophoto (Fig. 6). This segment represents road centerline from Meskel square to Yetebaberut Adebabay having 800m base line length.

Table 6. Point wise comparative result between digital line map (road centerline) values and GPS survey checkpoint values in road centreline

<table>
<thead>
<tr>
<th>PID</th>
<th>GPS survey checkpoint values</th>
<th>Digital line map (road centerline) values</th>
<th>Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X (m)</td>
<td>Y (m)</td>
<td>X (m)</td>
</tr>
<tr>
<td>1</td>
<td>323253.529</td>
<td>1281126.079</td>
<td>323253.030</td>
</tr>
<tr>
<td>2</td>
<td>323230.865</td>
<td>1281114.650</td>
<td>323230.650</td>
</tr>
<tr>
<td>3</td>
<td>323210.123</td>
<td>1281166.777</td>
<td>323210.530</td>
</tr>
</tbody>
</table>

The accuracy of the orthophoto compared to GPS data is within the national standard of error budget (~25cm) in terms of position and orientation. From the result supported, the orthophoto and line map is considered as appropriate for cadastral mapping applications, utility mapping, infrastructural mapping, road network mapping ETC. Particularly for rural areas where parcel size are very large the acquired accuracy level are extremely beyond the expected accuracy. Both GAMIT/GLOBK and LGO software with baseline processing module can handle long baseline GPS data and short base line GPS data respectively to give millimeter level accuracy. However, there are also some weaknesses in LGO, the software needs compatible receiver types for baseline...
computation and it lacks to create link to precise earth rotation parameter, pole tide corrections and solid earth tide models.

5. RECOMMENDATIONS

As a way of improving beyond the scope of this study, the study recommends that future research be done in the following concepts:

➢ The accuracy of orthophoto can be checked by increasing the number of checkpoints and incorporating other towns having undulating topography.
➢ The accuracy of orthophoto can be further examined by incorporating the vertical component during line map extraction for 3D mapping applications.
➢ Design the best linear fitting model from linear features measured by GPS surveying and their corresponding coordinates digitized from aerial photos.

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