Higher geometric accuracy using GPS derived ground control points for LULC analysis

Muhammad Yazrin Yasin[1,2], Jamalunlaili Abdullah[2], Norzailawati Mohd Noor[3], Nisfariza Mohd Noor[1], Mariney Mohd Yusoff[1]

1. Department of Geography, University of Malaya, Jalan Prof DiRaja Ungku Aziz, 50603 Kuala Lumpur, Malaysia

2. Faculty of Architecture, Planning, Surveying, University of Technology MARA, Jalan Ilmu, 40450, Shah Alam, Selangor Malaysia

3. Kuliyyah of Architecture and Environmental Design, International Islamic University of Malaysia, Jalan Gombak 50728 Kuala Lumpur

Abstract

Georeferencing in remote sensing imagery provides an integrated validation on the land use land cover (LULC) changes of urban growth. Geometic accuracy in georeferencing can be increased using Global Positioning System (GPS) derived ground control points (GCPs). Providing higher geometric accuracy is essential in LULC analysis especially in densed area with rapid urbanization. The geometric accuracy relies largely on accurate rectification of the remotely sensed data to produces classified thematic change maps. The study used data from Landsat TM, ETM+ and OLI TIRS. The rectification process involves two main references which are the GPS derived GCPs and the topographic map derived GCPs. GPS derived GCPs are acquired through ground measurement using Android 10.36.0 WGS84 capability smartphone. The topographic map is acquired from the Department of Survey and Mapping Malaysia with 1:50,000 scale, 25-meter countour line and rectified skew orthomophic grid projection. The study found that the GPS-derived GCPs were accurately higher with the root mean square error (RMSe) shows higher accuracy for its source points and corrections points.

Keywords: Geometric accuracy, Global Positioning System, ground control points, root mean square error

Introduction

The application of remote sensing imagery in land use land cover (LULC) change detection requires geometric correction procedures to produce higher accuracy map projection. Geometric correction increased rectification of map to locate points or regions of interest, detecting changes in multi temporal images and quantifying surface dimensions (De Leeuw *et al*., 1988, Stumpf *et* *al*., 2016). Ground control points (GCPs) are widely utilized for geometric correction by directing the GCPs on the baseline images and the corresponding map to mathematically determining coordinate reference (Nguyen 2015). The quality of GCPs and the quality of map significantly resolve the geometric accuracy. Previous scholar demonstrated a subpixel error using map-derived GCPs especially using a small scale map (Yasin *et al*., 2020).

A standard error of Landsat imagery and a topographic map with ranging scale from 1:10,000 to 1:50,000 are approximately around 0.2 to 0.9 pixel (Kardoulas *et al*., 1996). And the ranging of one pixel value to actual area are between 4 meters to 60 meters depend on the baseline images spatal resolution and computing complexity. Root mean square error (RMSe) is the difference between the reference output GCP coordinate and the actual output coordinate after completing georeferencing procedures (Chair and Draxler 2014). However RMSe do not measure the real deviation of the mesh geometry of a sensor (Yuan et al., 2020). This mean, each satellite (sensor) has different effective region RMS error. Nevertheless, satelites technology have been technologically advanced and using GPS can provide higher geometric accuracy (Wing *et al*., 2002). Furthermore, baseline maps or any other type of maps require geometric correction to ensure acquired information is realiable and dependable.

Study area

The study area is Iskandar region also named Iskandar Malaysia located from 2.785° to 1.26° North and 102.47° to 104.3° East with a total area of 230,000 hectares and the main land cover consists of urban built-up areas, vegetation, rangeland and waterbody. The population in 2006 is 1.3 million and leaped to 1.74 million in 2012 and 2.23 million in 2019 (Iskandar 2016, Kamel, 2020). Iskandar enjoys equatorial whether with temperatures are high on average, warmest month is April and December is the most wet with rainy seasons creates tropical rain forests. Cloud coverage is significantly high. Iskandar Malaysia is a regional economic corridor planned, promoted and facilitated by Iskandar Regional Development Authority (IRDA). Capital of Johor is Johor Bahru and it is also located within Iskandar region.

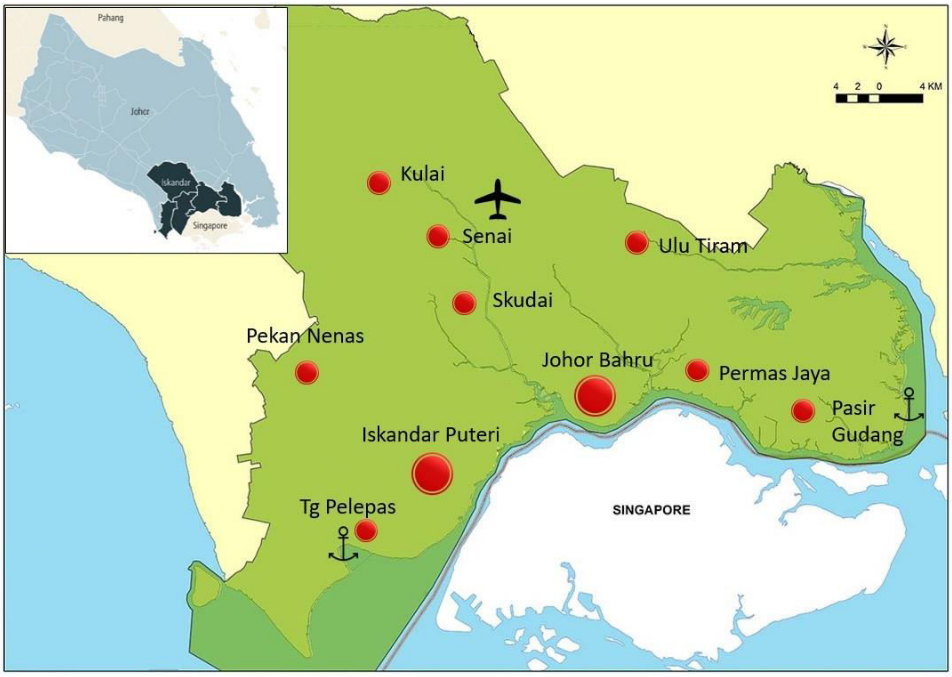

Figure 1. Iskandar Malaysia. Inset: Iskandar in the state of Johor and south of Peninsular Malaysia.

Data Sets and Material

The primary data consisting of the remote sensing imagery, topographic map and GPS-derived GCPs. The remote sensing imagery acquired for the study area Landsat Thematic Mapper (TM), Landsat Enhanced Thematic Mapper Plus (ETM+) and Landsat Operational Land Imager and Thermal Infrared Sensor (OLI TIRS). The spatial resolution for each imagery is 30-meter. The Johor thematic scale 1:50,000 and 25 meters contour line with Rectified Skew Orthomorphic Grid projection. The GPS derived GCPs is a global navigation satellite system that provides location, velocity and time synchronization acquired through ground receiver compatible device.

Table 1 Primary Data

Type of Data	Specification	Sources
Landsat TM	1991 30-meter resolution 7 bands	USGS Landsat Data Access
Landsat ETM+	2005 30-meter resolution 8 bands	USGS Landsat Data Access
Landsat OLI TIRS	2019 30-meter resolution 11 bands	USGS Landsat Data Access
Johor Bahru Topographic map	Scale 1:50,000 25 meter countour line Projection: Rectified Orthomorphic Grid	Department of Survey and Mapping Malaysia Sheet no. BG31, BG32, BG33, BG41
GPS-derived GCPs	Android 10.36.0 WGS84	Ground measurement

Landsat TM is equipped with Thematic Mapper and Multi-Spectral Scanner (MSS) has seven bands and one thermal infrared band. Landsat ETM+ has 8 bands – band 6 is thermal infrared and band 8 is panchromatic 15-meter resolution. Landsa OLI TIRS has twho thermal infrared bands – band 10 and 11 while band 8 is panchromatic. Landsat imagery are shown in Figure 1. The details of Landsat imagery acquired for this study are shown in Table 2.

Landsat TM　　Landsat ETM+　　Landsat OLI TIRS

Figure 2 Acquired remote sensing imagery

Table 2 Remote sensing imageries acquired

Sensors	Month/ day	Year	Spatial resolution (m)	Time	Path/row	Band combination
Landsat TM	05/21	1991	30m	1130	125/59	1,2,3,4,7
Landsat ETM+	06/04	2005	30m	1118	125/59	1,2,3,4,7
Landsat OLI TIRS	04/13	2019	30m	1128	125/59	2,3,4,5,7

Methodology

Ground measurement

Geo-referencing used both sources of data to test the accuracy of each GCPs provided – topographic map and GPS derived. Ground measurement with GPS receiver produced GPS derived GCPs. Rangel *et al.*, 2018 suggest using the optimal 15 GCPs for better distribution of positional accuracy. The optimal GCPs means the georeferencing has three sets of reference points – 5, 10 and 15 GCPs. GPS derived GCPs were generated throughout the area of interest by placing the device at the center of conflict point of junctions, intersections or viaduct. Figure 3 shows the distribution of the GCPs of the study area.

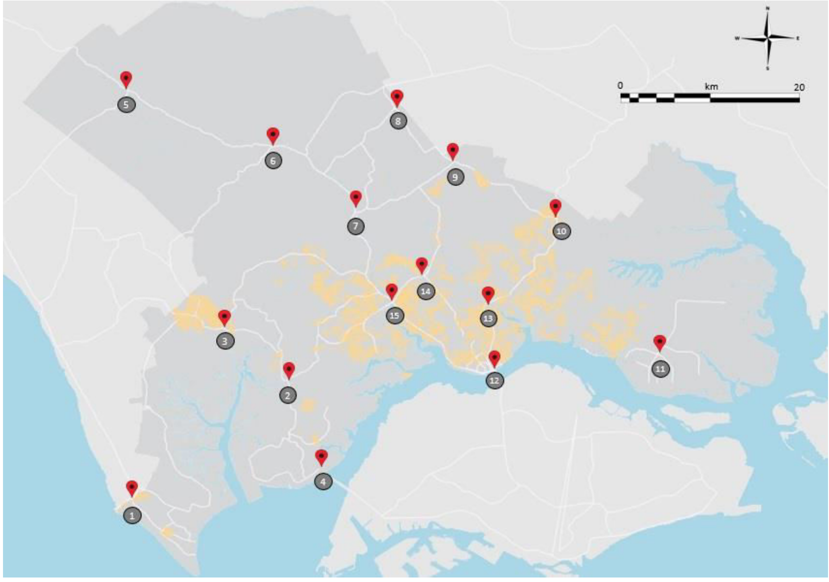

Figure 3 GPS-derived Ground Control Points of the study area

Table 3 Ground Control Points Longitude – Latitude of the study area

No.	Longitude – Latitude	Description
1.	1°24'55.9"N 103°25'27.9"E 1.415528, 103.424416	Junction Jalan Pontian – Kukup 95 and Jalan Peradin J110
2.	1°28'28.7"N 103°36'31.5"E 1.474637, 103.608756	Elevated intersection Second Link Expressway E3 and Pontian Highway 309, Gelang Patah
3.	1°28'28.7"N 103°36'31.5"E 1.474637, 103.608756	Intersection Skudai – Pontian Highway 5 and Jalan Sawah J113, Pekan Nenas
4.	1°21'48.2"N 103°36'59.8"E 1.363377, 103.616604	Jalan Tanjung Kupang J4 crossing under Second Link Expressway E3
5.	1°47'44.4"N 103°19'13.6"E 1.795660, 103.320438	Jalan Besar Benut 96 crossing above North South expressway E2
6.	2°43'36.8"N 101°43'36.5"E 2.726890, 101.726809	Jalan Parit Panjang Sedenak J107 crossing above North South expressway E2
7.	1°37'03.0"N 103°38'47.8"E 1.617508, 103.646603	Intersection Federal Road 1 and Second Link Expressway E3, Senai
8.	1°53'03.3"N 103°23'41.5"E 1.884253, 103.394846	Intersection Jalan Kluang Renggam J25 and Jalan Renggam J26
9.	1°48'01.1"N 103°29'51.0"E 1.800307, 103.497486	Intersection Jalan Kota Tinggi Kluang 91 and Jalan Kota Tinggi Kluang 93
10.	1°34'59.5"N 103°49'06.4"E 1.583202, 103.818431	Intersection South Desaru Expressway E22 and Jalan Kota Tinggi 3

11.	1°27'51.4"N 103°53'18.3"E 1.464265, 103.888414	Intersection Pasir Gudang Highway 17 and JB East Coast Highway/ Jalan Pasir Gudang 35
12.	1°27'33.7"N 103°46'02.7"E 1.459366, 103.767418	Jalan Tanjung Putri 52 crossing under Johor Bahru Causeway AH2
13.	1°31'18.6"N 103°45'49.9"E 1.521842, 103.763855	Elevated Intersection Tebrau Highway 3 and Eastern Dispersal Link Expressway AH2
14.	1°34'38.1"N 103°39'28.2"E 1.577239, 103.657844	Intersection North South Expressway E2/ Eastern Dispersal Link Expressway AH2, Federal Road 1
15.	1°32'53.2"N 103°39'25.2"E 1.548107, 103.657002	Intersection Skudai-Pontian Highway 5 and Federal Road 1

Geometric correction

Performing geometric correction to the baseline images involved rectifying the imagery to accurately located ground control points (GCPs). To register the baseline images and minimize geometric errors, the study used a dataset of well distributed 15 GCPs of Johor topographic map with 1:50,000 scale and the same GCPs created from ground measurement throughout Iskandar using a device equipped with GPS enabled Android 10.36.0 WGS84. The GCPs were tipped at strategic location such as crossroads that are visible in the baseline images and the topographic map. The baseline images were then calibrated to the GPS-derived GCPs and topographic map derived GCPs. The equation for geometric error is:

$$RMS_e = \sqrt{\frac{\sum_{i-1}^{n}[\,(x_i - x_j)^2 + (y_i - y_j\,)^2]}{n}} \qquad \text{(Eq. 1)}$$

where x_i and y_i are the easting and northing projections of the transformed point, x_{ij} and y_j are the easting and northing projections of the corresponding GCP, and n is the number of points used in the process.

To get the optimum number of reference point, the study used a well distributed minimum (5 points), medium (10 points) and maximum (15 points) of GCPs to the baseline images. It means although 15 GCPs were created, not all dataset produced the best result at maximum point. Zhao *et al.*, (2016) suggest, to support the geometric correction and because of the least number of GCPs being used, the second order polynomial is used because it equally calculating the least-squares solution throughout the baseline images. The second order polynomial equation are:

$$x + \Delta x = a^0 + a^1X + a^2Y + a^3XY + a^4X^2 + a^5Y^2 \quad \text{(Eq. 2)}$$
$$y + \Delta y = b^0 + b^1X + b^2Y + b^3XY + b^4X^2 + b^5Y^2$$

where x and y are image coordinates, Δx and Δy are the distortions in $x-$ and $y-$ directions, *X* and *Y* are plane coordinates, while $a^{0,1\ldots5}$ are the coefficients.

The most suitable band for the operation is infrared for Landsat TM and ETM+ due to the high contrast of vegetation and built-up areas. For Landsat OLI TIRS however, false composite image or RGB is the most suitable band while the panchromatic image is most suitable for SPOT because of its resolution. The study had chosen SPOT 5 for the operation because the study used the most scene from it.

Results

An error distribution or the RMS_{xy} in the geometry were detected for all the Landsat imagery due to the RMSe gives errors with larger absolute values more weight than errors with smaller absolute values. The study use format rectification accuracies of RMS_{xy} between 0.23± to 0.70± to examine the relative accuracy of the control point, source point and correction point using second order polynomials. The results shows that GPS-derived errors for Landsat TM is ±0.23 compares to map-derived is ±0.27. For Landsat ETM+ also shows GPS-derived errors is ±0.60 compares to map-derived is 0.64. Landsat OLI TIRS shows smaller differences between GPS-derived ±0.29 and map-derived ±0.30. Thus the overall results are GPS-derived GCPs has higher accuracy than the topographic map-derived GCPs.

Table 4 The Root-Mean-Square error ($RMSe_{xy}$) of the control point, source point and correction point using GPS and 1:50,000 scale topographic map

Imagery	Reference point	No.	Control Point $RMSE_{xy}$	Source point $RMSE_{xy}$	Correction Point $RMSE_{xy}$
Landsat TM	GPS	5	± 0.10	± 0.29	± 0.25
		10	± 0.16	± 0.26	± 0.24
		15	± 0.19	± 0.25	± 0.23
Landsat ETM +	GPS	5	± 0.45	± 0.79	± 0.65
		10	± 0.48	± 0.63	± 0.61
		15	± 0.52	± 0.63	± 0.60
Landsat OLI TIRS	GPS	5	± 0.24	± 0.35	± 0.29
		10	± 0.26	± 0.34	± 0.30
		15	± 0.28	± 0.34	± 0.31
Landsat TM	topo map	5	± 0.22	± 0.31	± 0.29
		10	± 0.25	± 0.30	± 0.28
		15	± 0.28	± 0.27	± 0.27
Landsat ETM +	topo map	5	± 0.46	± 0.73	± 0.70
		10	± 0.56	± 0.72	± 0.68
		15	± 0.61	± 0.67	± 0.64
Landsat OLI TIRS	topo map	5	± 0.24	± 0.38	± 0.30
		10	± 0.30	± 0.37	± 0.35
		15	± 0.32	± 0.35	± 0.34

Analysis of number of GCPs shows both Landsat TM and Landsat ETM+ utilizing 15 GCPs for higher accuracy whle Landsat OLI TIRS utilizing only 5 GCPs to get higher accuracy. This shows the geometric correction procedure do not necessary utilizing more GCPs for higher accuracy. Another important note is Landsat ETM+ has higher RMS error than the other two Landsat sensors. This has been explain earlier where each satellite (sensor) has different effective region RMS error. The actual differences on the ground for Landsat TM, ETM+ and OLI TIRS are 2.9 meters, 1.1 meters and 0.7 meters consecutively.

Conclusions

All GPS-derived GCPs shows higher accuracy compare to map-derived GCPs in the geometric correction procedure perfomed. However, the differences are between 0.01 pixel and 0.04 pixel, or 0.7 meters to 2.9 meters in the ground. This is because the GPS nominal accuracy is 4-meter RMSe with 95% confidence interval, higher than the coarse resolution of Landsat TM, ETM+ and OLI TIRS. However, the small differences in RMSe could contribute to larger differences in LULC analysis. The study use three multitempotal images between 2006 and 2019 and it was vastly growing from 2006 to 2019 with rapid LULC changes. Georeferencing or coordinate transformation on LULC change detection with a multitemporal imagery in some way would produce errors. Geometric correction assists in reducing that error.

References

[1] A.J. De Leeuw, L.M. Veugen and H.T.C. Van Stokkom 1988 Geometric correction of remotely sensed imagery using ground control points and orthogonal polynomials. International Journal of Remoe Sensing, 9, 10-11, 1751-1759

[2] N.G. Kardoulas, A.C. Bird, A.I. Lawan 1996 Geometric correction of SPOT and Landsat Imagery: A comparison of Map- dan GPS-Derived Control Points

[3] Michael G. Wing, Aaron Eklund, Loren D. Kellogg 2005 Consumer-Grade Global Positioning System (GPS) Accuracy and Reliability *Journal of Forestry*, Volume 103, Issue 4, June 2005, Pages 169–173,

[4] Thanh Nguyen 2015 Optimal ground control points for geometric correction using genetic algorithm with global accuracy. European Journal of Remote Sensing. 48. 101-120

[5] Andre Tumpf, Jean-Phillippe Malet, Anne Puisaant, Julien Travelleti 2016 Monitoring of earth surface motion and geomorphologic process by optical image correlation Book Land surface remote sensing editor Nicolas Baghdadi, Mehrez Zribi. ScienceDirect

[6] Sichen Yuan, Bingen Yang, Houfei Fang 2020 Direct root-mean-square error for surface accuracy evaluation of large deployable mesh reflectors AIAA Scitecg 2020 Forum

[7] T. Chai, R. R. Draxler 2014 Root mean square error (RMSE) or mean absolute error (MAE)? – Arguments agains avoiding RMSE in the literature Geoscientific Model Development Copernicus Publication

[8] Engku Ahmad Kamel 2020 Iskandar Malaysia Updates Iskandar Regional Development Authority https://www.mdbc.com.my/wp-content/uploads/2020/09/MDBC-Johor-State-Briefing-Interchamber-IRDA.pdf

[9] Muhammad Yazrin Yasin, Norzailawati Mohd Noor, Mariney Mohd Yusoff, Jamalunlaili Abdullah 2020 The geometric correction procedure using topographic map versus GPS-derived ground control points for LULC analysis. 41st Asian Conference on Remote Sensing-ACRS2020. Deqing County, Zhejiang Province, China from November 9th -11th , 2020