The Impact of Different International Terrestrial Reference Frames (ITRFs) on Positioning and Mapping in Malaysia

Nur Adilla Zulkifli, Ami Hassan Md Din and Abdullah Hisam Omar

Abstract In Malaysia, Geocentric Datum of Malaysia 2000 (GDM2000) is connected to the International Terrestrial Reference Frame 2000 (ITRF2000). In comparison with the previous models, ITRF2014 represents a significant improvement in datum definition and realization. Nevertheless, the improvement causes a frame difference between ITRF2000, ITRF2008 and ITRF2014. Due to earthquakes that hit Sumatra region of Indonesia in the years 2004, 2005 and 2007 followed by post-seismic and co-seismic activities, Malaysia no longer lies on a stable continent. The movement on tectonic plate caused a shifting in geodetic datum of Malaysia to become non-geocentric. Thus, this factor gives impacts on positioning and mapping in Malaysia particularly in the realm of cadastral. Therefore, to measure the effect, the coordinates for positioning and mapping based on different International Terrestrial Reference Frames were analysed. To achieve the aim, this study is categorized into three phases. In the first phase, Global Positioning System (GPS) data was processed with respect to different reference frames (ITRF2000, ITRF2008 and ITRF2014) by Precise Point Positioning (PPP) Waypoint software. The result derived from the first phase was then be used

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in the next phase, where the coordinate was analysed based on different reference frames. In the third phase, the reliability of coordinate with different ITRFs was assessed specifically for cadastral purposes. In order to analyse the coordinates, a point at helipad of Universiti Teknologi Malaysia (UTM) was observed by using GPS static technique, and the data was processed differently according to the frames by PPP. The coordinates processed were used as a base station for fast static GPS observation. To process the data, Trimble Total Control (TTC) software was used resulting in three different coordinates of each point observed. The coordinates were assessed with respect to the existing Cassini-Soldner geocentric coordinates and coordinates derived from network-based Real-Time Kinematic (RTK) observation. The results show that ITRF2014 has small value of standard deviations with the mean of 0.0010, 0.0003 and 0.0020 m for latitude, longitude and height for point positioning. Whereas for mapping, the differences between coordinates from PA 40225—ITRF2000, PA 40225—ITRF2008 and PA 40225—ITRF2014 in general range from −0.277 to −0.209 m for northing and from 0.424 to 0.515 m for easting. In conclusion, GDM2000 has to be revised frequently with respect to the latest version of ITRF in order to give a better positional accuracy, and a fix geocentric mapping datum needs to be opted for cadastral integrated purposes in Malaysia.

Keywords International terrestrial reference frames · Geocentric datum of Malaysia · Datum · Positioning and mapping

1 Introduction

Malaysia is using datum GDM2000, and it is connected to ITRF2000. ITRF2000 is a combination of unconstrained space geodesy solutions free from any tectonic plate model. It was the most accurate that has been established by 800 stations located at about 500 sites with better distributions around the world compared to the previous ITRF models. However, due to the dynamic Earth, ITRF2000 is no longer reliable to use especially with the realization of other reference frames such as ITRF2008 and ITRF2014. There may occur differences in frames between those models that gives impacts on positioning and mapping in Malaysia especially in the field of cadastral. According to Wei et al. [1], there is a frame difference between ITRF2000 and ITRF2005 models, which may impact GNSS data processing, and it is considered more accurate to adopt the latest ITRF and to align old GNSS results into the latest frame. Meanwhile, Kang [2] also mentioned that some problem might occur when considering distinct characteristics of old cadastral surveying like a reinstatement using WGS (World Geodetic System) if there are republished national control points related to ITRF version and tectonic deformation, etc. Thus, to manage the cadastral data based on WGS in Korea, Kang suggested on developing nationwide mathematical model by installing it in GPS receiver firmware to calibrate the differences between old and new coordinates automatically.

Furthermore, from the study conducted by Satirapod et al. [3], there is also significant diversion when comparing coordinates results between different ITRFs in north and east components. Hence, due to widespread deformation and other expected post-seismic motion, they recommended updating the Thai coordinate reference frame to ITRF2005. Globally, over the past 15 years, there have been four major earthquakes that hit Sumatra region of Indonesia in the years 2004, 2005, 2007 and 2012 affected GDM2000 to no longer be geocentric. The motion of most of Sundaland has also been moved towards the west [4]. Thus, it is inevitable that this aspect affects many applications particularly on positioning and mapping purpose in Malaysia, which require accurate coordinates in accordance with the latest ITRF. Therefore, Gill [5] conducted a study to develop a datum transformation model in relation to the tectonic motion in Malaysia in order to maintain the geocentric element of GDM2000 with respect to time.

Based on previous studies conducted in China, Korea, Thailand and also Malaysia, these differences affected the coordinate systems of countries and it is compulsory to update the systems with respect to the latest global frame. Hence, this research presents an effort to analyse the coordinates particularly for positioning and mapping in Malaysia with respect to different International Terrestrial Reference Frames. The frames chosen were ITRF2000, ITRF2008 and ITRF2014, where observations were conducted to specifically study the impact on a certain point positioning and cadastral mapping in Johor Bahru.

1.1 GDM2000

Geodetic datum is a framework that enables us to define geodetic coordinates system. It includes the ellipsoid and the three-dimensional Cartesian system consists of *X*-axis, *Y*-axis and *Z*-axis as well as their translation, rotation and scale parameters. In order to describe positions on Earth accurately, a geocentric datum is required where the origin is at the mass centre of the Earth. In Malaysia, GDM2000 was adopted by the Department of Survey and Mapping Malaysia (DSMM) to establish a global and standardized coordinate system countrywide [6] where it was realized with respect to ITRF2000 at epoch 1st January 2000.

GDM2000 was realized through a permanent network of active GPS stations known as Malaysia Active GPS System (MASS) stations. In the year 1998, 15 MASS stations were established and operated where eight of the stations are located in Peninsular Malaysia and the other seven are in Sabah and Sarawak. Figure 1 shows the distribution of MASS stations across Malaysia.

GDM2000 was realized by the long baseline connection between MASS stations and 11 IGS stations from nearby regions. Four years span GPS data of 15 MASS stations and 11 IGS stations were used in the Bernese GPS processing software to determine the MASS stations coordinate on International Terrestrial Reference Frame (ITRF) [7]. In addition, according to Kadir et al. [7], GDM2000 is defined on ITRF2000 at 1–2 cm accuracy level. However, all sites coordinates used to realize

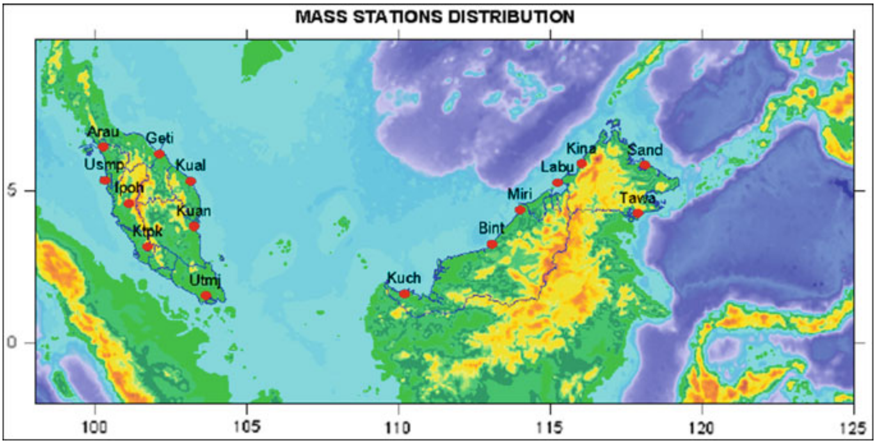

Fig. 1 Distribution of MASS stations throughout Malaysia in 1998 [7]

GDM2000 are assumed unchanged with time opposite to the fact that Earth is actually dynamic with the motion of plate tectonic.

Currently, MASS stations have been upgraded to Malaysian Real-Time Kinematic GNSS network (MyRTKnet) stations. MyRTKnet stations are the Continuously Operating Reference Station (CORS) established in Malaysia and they are broadly used in numerous positioning applications such as surveying, navigation, engineering, geodynamic and scientific studies. With the existing of MyRTKnet stations, the reliability of GDM2000 can be assessed by analysing the datum shifts via the displacements of the MyRTKnet stations caused by tectonic movements as well as the displacement induced by reference frame effects [6]. Due to earthquake that hits Sumatra region in the year 2004, a revision of GDM2000 was conducted in epoch 2006 known as GDM2000 (2006). The coordinates of four reference stations were fixed in the final local combined adjustment with respect to the original GDM2000 [8].

1.2 International Terrestrial Reference Frame (ITRF)

International Terrestrial Reference Frame (ITRF) is a set of points located on the Earth surface with their three-dimensional Cartesian coordinates and point's velocities that realize an ideal reference system. It can be used to measure plate tectonics and to represent the Earth when measuring its motion. Presently, there are 13 ITRF models realized with the aim to obtain a homogeneous reference frame for all geodetic and Earth scientific activities and applications starting with ITRF89 and ending with ITRF2014.

The combinations of space-based geodetic techniques such as Very Long Baseline Interferometry (VLBI), GPS, Satellite Lase Ranging (SLR) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) have become a common practice to determine the global reference frames. Basically, the three ITRFs used the same techniques to define origin, scale and orientation. ITRF2000 combines unconstrained space geodesy solutions free from any tectonic motion model where the network consists of 800 stations located about 500 sites [9]; meanwhile, ITRF2008 is defined based on the reprocessed solutions of VLBI, SLR, GPS and DORIS spanning 29, 26, 12.5 and 16 years observation, respectively. This network comprises 934 stations located at 580 sites in northern and southern hemisphere [10]. According to Altamimi et al. [11], ITRF2014 is generated with an enhanced in modelling of nonlinear station motion including seasonal signals of station positions and post-seismic deformation for certain sites. It is defined by using VLBI, SLR, Global Navigation Satellite System (GNSS) and DORIS by using reprocessed time series weekly from SLR and DORIS, daily from GNSS and 24 h session-wise from VLBI. With an advance in technology, the reference frames are gradually improved in time giving a better accuracy to user.

1.3 Cadastral System in Malaysia

Previously, cadastral work and topographic mapping in Peninsular Malaysia were carried out by using Cassini-Soldner (Cassini) and Rectified Skew Orthomorphic (RSO) projection system, respectively. Besides, there are ten state Cassini-coordinate systems, and the northing and easting of the origins are not referred to a single triangulation system [7]. Figure 2 shows the origins of Cassini throughout Peninsular Malaysia.

Therefore, a homogeneous coordinate system with referenced to the global datum is required to accommodate future requirements in cadastral and mapping integrated purposes [12]. Currently, Peninsular Malaysia is adopting National Digital Cadastral Database (NDCDB) through a Coordinated Cadastral System project. As the datum origin is at the mass centre of the Earth, data integration can be done globally. However, the datum used which is GDM2000 is connected to ITRF2000. A non-geocentric datum will affect positioning and mapping specifically in the realm of cadastral. Hence, a fix geocentric mapping datum is required for cadastral purposes in Malaysia.

2 Data and Methods

2.1 Research Area Identification

The areas of study involved in this research have been narrowed down to the helipad area of Universiti Teknologi Malaysia (UTM) and Kampung Pasir, Johor

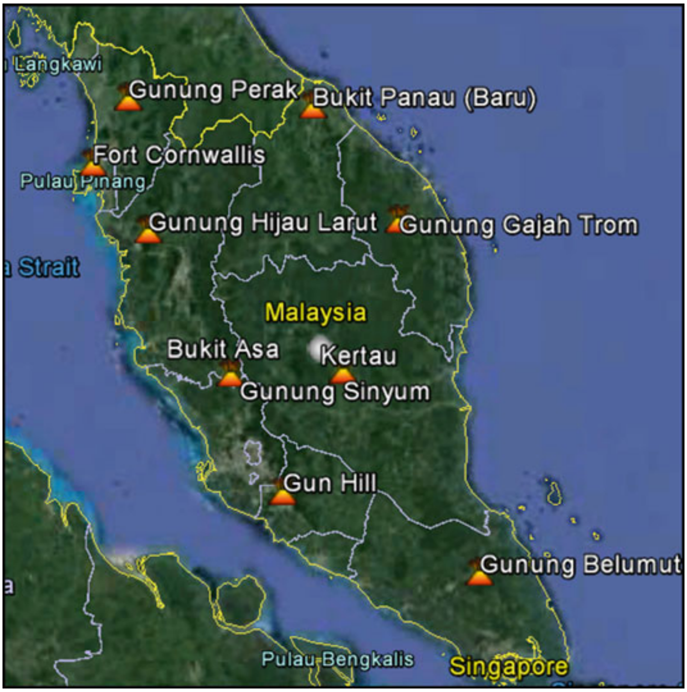

Fig. 2 Origins of Cassini across Peninsular Malaysia

Bahru where GPS static, fast static and network-based RTK observations were done, respectively. The GPS fast static observation was conducted on a point at helipad in order to do the analysis on point positioning. Meanwhile, the technique of GPS fast static and network-based RTK were implemented on cadastral lot, Lot 4199, Kampung Pasir, Mukim Pulai, Daerah Johor Bahru for the assessment in cadastral mapping.

2.2 Data Acquisition and Processing

Point Positioning. In this phase, 10 hours of GPS static observation on a point at helipad of Universiti Teknologi Malaysia (UTM) was carried out for 3 days to generate daily solution. The data was collected by using Topcon GR-5 and the data obtained was in Receiver Independent Exchange Format (RINEX) file containing Observation (O) and Navigation (N) files. The gathered data were then used for processing by using Waypoint software and Australian Surveying and Land Information Group (AUSLIG) Online GPS Processing System (AUSPOS).

The input data in Waypoint Processing Program is divided into two main parts. They are RINEX files and precise satellite orbit and clock data. The processing

Table 1 Processing parameters and models for GPS data processing by using Waypoint

Processing parameter	Processing strategy
Elevation mask angle	10°
Processing interval	1 s
Orbits/clock	Precise orbit and clock
Reference frames	ITRF2000, ITRF2008 and ITRF2014
Ionosphere	Double difference ionosphere-free linear combination
Tropospheric	Kalman filter (medium)
Processing method	PPP (multipass)
Type of solution	Float

mode used to process the data collected was Precise Point Positioning (PPP). PPP is an autonomous positioning method which does not use base station data. As no base station data was used to reduce correlated errors such as tropospheric delay, it was solved within Kalman filter whereas the ionospheric error was reduced by using linear combination (ionosphere-free) of L1 and L2. The format of input data used by Waypoint software is Waypoint Raw GNSS Data (.gpb). By using GNSS Data Converter, the data collected in RINEX format were converted into Waypoint's own format. In the meantime, precise orbit and clock data were automatically downloaded by GrafNav while running the program from ftp server of cddis.gsfc.nasa.gov. The 3 days of GPS static data were processed according to chosen reference frames (ITRF2000, ITRF2008 and ITRF2014), and the average of each coordinate was calculated. Table 1 shows the summary of processing parameters and models for GPS data processing by using Waypoint.

AUSPOS is a free online GPS data processing facility provided by Geoscience Australia [13]. The input data format for AUSPOS is in RINEX format which it only needs observation file. In order for AUSPOS to do the processing, it needs more than 1 hour data. AUSPOS follows the computation system in Bernese GNSS Software Version 5.2, which is double difference for baselines processing as well as the IGS orbits and IGS network stations. The reference stations chosen as fiducial stations are IGS and Asia-Pacific Reference Frame (APREF) stations. The coordinates computed are based on the IGS realization of the ITRF2008 reference frame and all the coordinates refer to a mean epoch of the site observation data. The 3 days data were processed by AUSPOS using different reference stations for each day, and the mean coordinates of 3 days data were calculated. Table 2 shows the summary of processing parameters and models for GPS data processing by using AUSPOS.

Mapping Purposes. In this part, fast static GPS and network-based RTK observations were conducted on five boundary stones at Lot 4199, Kampung Pasir. GPS fast static observation was carried out for 30 min with a base station established on the point at helipad whereas network-based RTK observation was carried out three times for every 10 epochs on each stone, respectively.

Table 2 Processing parameters and models for GPS data processing by using AUSPOS

Processing parameter	Processing strategy
Elevation cut-off angle	7°
Sampling rate	30 s
Orbits/EOP	IGS final orbits and EOP (Earth Orientation Parameter)
Reference frame	ITRF2008
Ground antenna phase centre calibration	IGS08 absolute phase centre variation model
Atmospheric loading	Applied
Ionosphere	Double difference ionosphere-free linear combination
Tropospheric model	GMF mapped with DRY-GMF
Tropospheric estimation	WET-GMF mapping function in 2 h interval
Tropospheric mapping function	GMF
Ambiguity solution	Code-based strategy for 180–6000 km baselines, phase-based L5/L3 strategy for 18–200 km baselines, Quasi-Ionosphere-Free (QIF) strategy for 18–2000 km baselines and direct L1/L2 strategy for 0–20 km baselines

In order to process the fast static data, TTC software was used. GPS import data of TTC are parted into two categories. They are the GPS data of base station and rover station in RINEX format. Coordinates of the base station were derived from the processing program of Waypoint based on ITRF2000, ITRF2008 and ITRF2014. Meanwhile, to attain the coordinates of rover stations, the fixed baseline processing and three-dimensional (3D) adjustment were done individually for each boundary stone. The coordinates obtained from network-based RTK were taken as average for assessment with other coordinates. Table 3 shows the summary of processing parameters and models for GPS data processing by using TTC.

Table 3 Processing parameters and models for GPS data processing by using TTC

Processing parameter	Processing strategy
GPS cut-off angle	10° and 20°
Processing interval	1 and 10 s
Orbits	Broadcast orbit
Ionosphere	Double difference ionosphere-free linear combination (more than 5 km baseline)
Atmospheric model	MSIS90
Tropospheric delay model	Saastamoinen

3 Results and Discussion

3.1 Coordinates of Point at Helipad by Precise Point Positioning (PPP)

From the Waypoint processing software, the coordinates of the point at helipad for 3 days data were derived in ITRF2000, ITRF2008 and ITRF2014. The mean for each reference frame was also calculated. The Standard Deviation (STD) for coordinates of 3 days data based on different reference frames is in mm level where the standard deviation of horizontal components is within 1 and 2 mm for vertical component. The result for vertical component is acceptable for 2 mm of standard deviation as according to Berber et al. [14], the height information in a GPS measurement is determined two to three times worse than the horizontal coordinate information, and this is because satellite configuration is more appropriate for horizontal coordinate determination. The coordinates of the point at helipad in different frames for 3 days data with their means are tabulated in Table 4 followed by the time series plot of residual coordinates for 3 days data based on three different reference frames in Fig. 3. The residual throughout the three different frames typically ranges from −0.0057 to 0.0135 mm for horizontal component (latitude and longitude) and −0.006 to 0.007 mm for vertical component (up).

From the coordinate derived based on different reference frames, the mean of horizontal and vertical coordinates between ITRF2014 and ITRF2008 shows a small difference compared to ITRF2000. This could probably tell that the earthquake that hits Sumatra region of Indonesia in the years 2004, 2005 and 2007

Table 4 Coordinates of the point at helipad with respect to ITRF2000, ITRF2008 and ITRF2014

	Latitude	STD (m)	Longitude	STD (m)	Height (m)	STD (m)
ITRF2000						
Day 1	1 33 29.59578	0.001	103 38 13.36570	0.000	42.256	0.002
Day 2	1 33 29.59536	0.001	103 38 13.36670	0.001	42.251	0.002
Day 3	1 33 29.59550	0.001	103 38 13.36637	0.000	42.263	0.002
Mean	1 33 29.59554		103 38 13.36626		42.257	
ITRF2008						
Day 1	1 33 29.59712	0.001	103 38 13.36570	0.000	42.239	0.002
Day 2	1 33 29.59670	0.001	103 38 13.36670	0.001	42.235	0.002
Day 3	1 33 29.59685	0.001	103 38 13.36636	0.000	42.247	0.002
Mean	1 33 29.59689		103 38 13.36625		42.240	
ITRF2014						
Day 1	1 33 29.59707	0.001	103 38 13.36576	0.000	42.237	0.002
Day 2	1 33 29.59664	0.001	103 38 13.36676	0.001	42.232	0.002
Day 3	1 33 29.59679	0.001	103 38 13.36642	0.000	42.244	0.002
Mean	1 33 29.59683		103 38 13.36631		42.238	

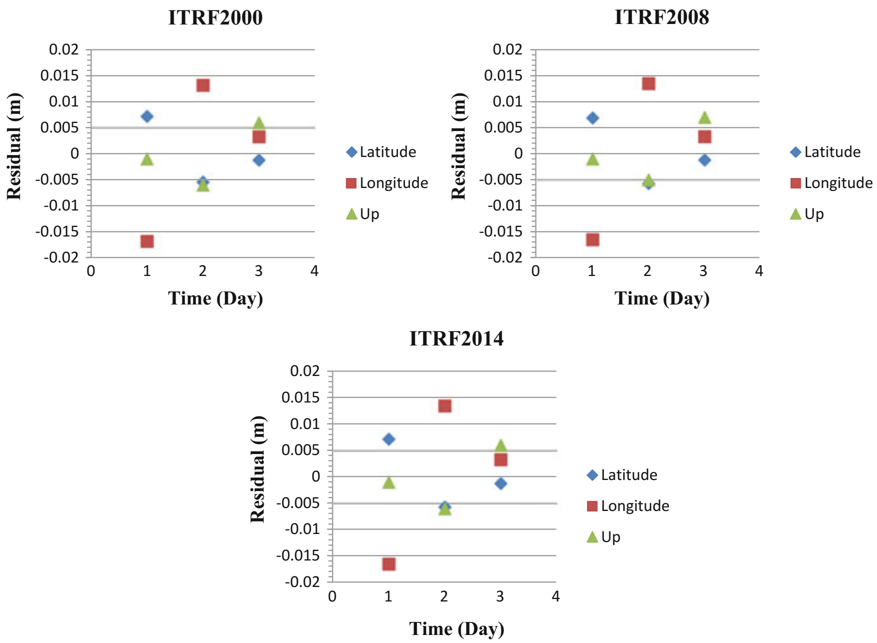

Fig. 3 Residual coordinates of 3 days data in ITRF2000, ITRF2008 and ITRF2014

triggered the movement on tectonic plate, hence causing a shifting in geodetic datum of Malaysia. Even though the differences in height between frames are up to cm level, it is still allowable as the altitude error is always considerably worse than the horizontal.

3.2 Coordinates of Point at Helipad by AUSPOS

AUSPOS used the maximum number of 15 nearby reference stations for processing, which consist of IGS stations as well as APREF stations. However, the chosen stations used for processing on day 1 differed to days 2 and 3. For day 1, only 11 stations (10 IGS + 1 APREF) were used while days 2 and 3 used 14 reference stations (11 IGS + 3 APREF) for processing. This could probably be due to data availability for that particular day on certain stations. Figure 4 shows the distribution of fiducial stations used to process the 3 days data in AUSPOS.

Table 5 shows the coordinate of the point at helipad with respect to ITRF2008 derived by using AUSPOS followed by the time series plot of residual coordinates for the 3 days data in Fig. 5. The standard deviations for the 3 days data are up to cm level with the smallest value in longitude, which is 6 mm, and the biggest value in height, which is 25 mm. Based on Fig. 5, the residual of the coordinates ranges

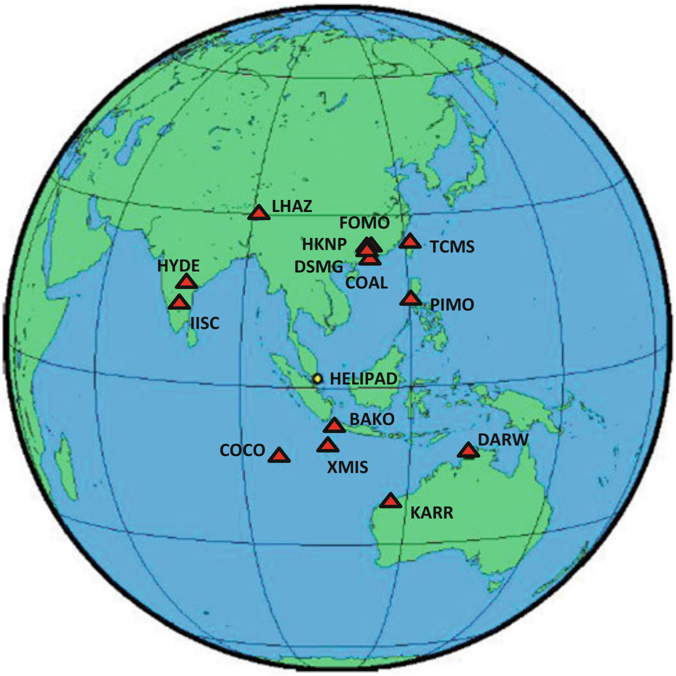

Fig. 4 Distribution of reference stations used in AUSPOS

from −0.0006 to 0.0057 mm for horizontal component (latitude and longitude) and −0.0075 to 0.0153 mm for vertical component (up). In the meantime, by referring to the data presented in Table 6, there is a small difference in horizontal component between the mean coordinates derived by AUSPOS and PPP which are −1.5 mm in latitude and −6.3 mm in longitude. Meanwhile, for the height coordinates, the difference is 24 cm, and it is considered tolerable as the standard deviation for this component is still within the range. To summarize the coordinate difference between AUSPOS and PPP, Fig. 6 portrays the residual differences for 3 days data along with the Root Mean Square Deviation (RMSD) of each component. The RMSD of horizontal components is 0.0047 m for latitude and 0.0115 m for longitude whereas the RMSD of the up component is 0.0061 m. These RMSDs indicate the differences or better known as residuals for evaluation of data.

AUSPOS processing strategy to resolve ambiguity is divided into four. They are code-based (180–6000 km baselines), phase-based L5/L3 (18–200 km baselines), Quasi-Ionosphere-Free (QIF) (18–2000 km baselines) and direct L1/L2 (0–20 km baselines) strategies. The strategy to resolve ambiguity for each baseline was chosen according to baseline length where the shortest baseline between stations COAL-DSMG (4.306 km) was resolved by using direct L1/L2, and the longest baseline between stations HKNP-HYDE (3679.651 km) was resolved by using Code-Based strategy. According to Tables 7, 8 and 9, the average ambiguity

Table 5 Coordinate of the point at helipad derived by AUSPOS based on ITRF2008

	Latitude	STD (m)	Longitude	STD (m)	Height (m)	STD (m)
ITRF2008						
Day 1	1 33 29.59682	0.009	103 38 13.36600	0.006	42.007	0.020
Day 2	1 33 29.59668	0.010	103 38 13.36608	0.006	41.988	0.023
Day 3	1 33 29.59703	0.010	103 38 13.36603	0.006	42.007	0.025
Mean	1 33 29.59684		103 38 13.36604		42.000	

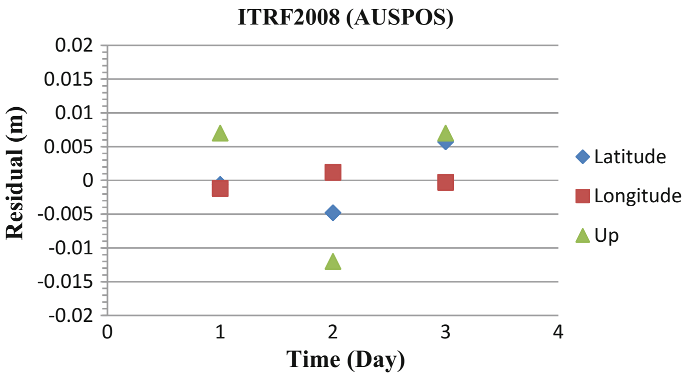

Fig. 5 Residual coordinates of 3 days data in ITRF2008 derived by AUSPOS

Table 6 Coordinate difference between AUSPOS and PPP

	Latitude (m)	Longitude (m)	Height (m)
Day 1	−0.0090	0.0090	−0.232
Day 2	−0.0006	−0.0186	−0.247
Day 3	0.0054	−0.0099	−0.240
Mean	−0.0015	−0.0063	−0.240

resolution for day 1, day 2 and day 3 shows the success rate of 72.3, 72.3 and 72.5%, respectively. The percentage of ambiguities resolved with the rate of 50% or better for a baseline formed by a user site indicates a reliable solution. However, the baseline between stations BAKO-HKNP shows a low percentage of ambiguities resolved for the 3 days, which are 25.9, 19.2 and 8%, respectively, compared to the other longer baseline. This might probably happened due to the data problem during those 3 consecutive days.

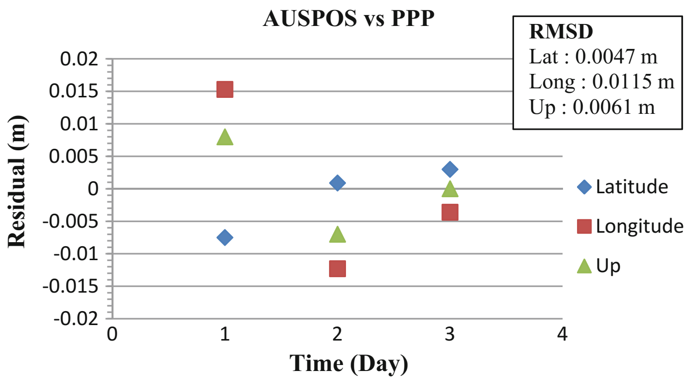

Fig. 6 Residual coordinates difference between AUSPOS and PPP

Table 7 Ambiguity resolution per baseline for day 1

Baseline	Ambiguities resolved (%)	Baseline length (km)
BAKO—HKNP	25.9	3234.634
HKNP—TCMS	82.6	776.860
HKNP—LHAZ	40.0	2406.585
BAKO—HELA	74.1	985.072
KARR—XMIS	83.4	1682.678
DARW—KARR	81.8	1738.492
HKNP—PIMO	76.0	1132.048
FOMO—HKNP	95.5	36.679
HYDE—LHAZ	87.0	1856.740
BAKO—XMIS	66.6	456.023
COCO—XMIS	82.6	984.535
Average	72.3	1387.577

3.3 Coordinates of Boundary Stones at Lot 4199

Coordinates of Cassini-Soldner Geocentric from PA 40225. Cadastral system in Johor, Malaysia used Cassini-Soldner geocentric with respect to ITRF2000 as its reference to carry out cadastral works. With the existing of NDCDB, integration of data can now be done globally as the origin of GDM2000 is at the mass centre of the Earth. According to PA 40225, the coordinates of boundary stones at Lot 4199 are tabulated as shown in Table 10. In order to assess the coordinates of point with different frames, the coordinates of boundary stones from the certified plan (PA 40225) are considered as true values.

Network-based RTK versus PA 40225. Similarly to coordinates from PA 40225, coordinates derived by the technique of network-based RTK are also in

Table 8 Ambiguity resolution per baseline for day 2

Baseline	Ambiguities resolved (%)	Baseline length (km)
BAKO—HKNP	19.2	3234.634
HKNP—TCMS	86.4	776.860
HKNP—LHAZ	30.0	2406.585
COCO—XMIS	86.4	984.535
BAKO—HELB	65.4	958.072
COAL—HKNP	90.9	37.121
COAL—DSMC	93.8	4.306
KARR—XMIS	76.0	1682.678
DARW—KARR	72.0	1738.492
HKNP—PIMO	82.6	1132.048
DSMG—FOMO	93.8	5.048
HYDE—LHAZ	77.3	1856.740
BAKO—XMIS	64.0	456.023
HYDE—IISC	75.0	497.626
Average	72.3	1126.483

Table 9 Ambiguity resolution per baseline for day 3

Baseline	Ambiguities resolved (%)	Baseline length (km)
HKNP—HYDE	35.3	3679.651
BAKO—HKNP	8.0	3234.634
HKNP—TCMS	85.0	776.860
COCO—XMIS	85.7	984.535
BAKO—HELC	62.9	958.072
COAL—HKNP	86.4	37.121
COAL—DSMC	95.8	4.306
KARR—XMIS	85.0	1682.678
DARW—KARR	85.7	1738.492
HKNP—PIMO	80.0	1132.048
DSMG—FOMO	97.7	5.048
HYDE—LHAZ	74.1	1856.740
BAKO—XMIS	57.1	456.023
HYDE—IISC	76.2	497.626
Average	72.5	1217.417

Cassini-Soldner geocentric connected to ITRF2000. This is because of the base stations used; they are the MyRTKnet stations and in Malaysia, MyRTKnet stations use GDM2000 as their datum with ITRF2000 as their reference frame. Table 11 shows the mean coordinates of points at cadastral lot by network-based RTK. The observations were done three times for every 10 epochs, and the mean coordinates

Table 10 Coordinates in Cassini-Soldner geocentric according to PA 40225

Boundary stone	Northing (m)	Easting (m)
3	−60757.255	15434.181
4	−60778.149	15418.435
5	−60765.888	15453.547
12	−60727.827	15253.414
14	−60743.953	15222.431

Table 11 Mean coordinates of points at Lot 4199 by network-based RTK

Boundary stone	Observation status	Northing (m)	Easting (m)
3	Fixed	−60757.317	15434.258
4	Fixed	−60778.217	15418.508
5	Fixed	−60765.945	15453.648
12	Float	−60726.348	15254.409
14	Fixed	−60743.942	15222.455

Table 12 Coordinates difference between network-based RTK and PA 40225

Boundary stones	Northing (m)	Easting (m)
3	−0.062	0.077
4	−0.068	0.073
5	−0.057	0.101
12	−1.479	0.995
14	−0.011	0.024
RMSD	0.0544	0.0742

of each point were calculated. For boundary stones 3, 4, 5 and 14, the ambiguities were managed to be fixed; meanwhile, for boundary stone 12, the observation status was float. This could probably be due to the position of the stone itself as it is located under the roof.

From the coordinate's difference between network-based RTK and PA 40225 as tabulated in Table 12, the differences vary between different points where the biggest difference is for boundary stone 12 and the smallest difference is for boundary stone 14, which are −1.479 m N, 0.995 m E and −0.011 m N, 0.024 m E, respectively.

ITRF2000 versus PA 40225. From the GPS fast static observation, coordinates of boundary stones were derived according to three different frames. TTC software provides coordinates in 3D geographical coordinates (latitude, longitude and height) along with their standard deviations as shown in Tables 13, 16 and 19. In order to do the assessment of coordinates between different frames and coordinates from PA 40225, map projection from 3D to two-dimensional (2D) (northing and easting) needs to be transformed as tabulated in Tables 14, 17 and 20. GDTS (Geodetic Datum Transformation System) software was used to transform

Table 13 Coordinates of points in ITRF2000

	Latitude	STD (m)	Longitude	STD (m)	Height (m)	STD (m)
ITRF2000						
3	1 29 35.10426	0.0181	103 41 59.15239	0.0157	11.9309	0.0267
4	1 29 34.42370	0.0134	103 41 58.64322	0.0160	11.0045	0.0231
5	1 29 34.82358	0.0128	103 41 59.78015	0.0138	11.8215	0.0202
12	1 29 36.05986	0.0667	103 41 53.30243	0.0666	09.5515	0.1131
14	1 29 35.53963	0.0141	103 41 52.30066	0.0137	09.6729	0.0222

Table 14 Coordinates in Cassini-Soldner geocentric based on ITRF2000

Boundary stones	Northing (m)	Easting (m)
ITRF2000		
3	−60757.521	15434.626
4	−60778.426	15418.916
5	−60766.141	15454.057
12	−60728.181	15253.821
14	−60744.162	15222.855

Table 15 Coordinates difference between ITRF2000 and PA 40225

Boundary stones	Northing (m)	Easting (m)
3	−0.266	0.445
4	−0.277	0.481
5	−0.253	0.510
12	−0.354	0.407
14	−0.209	0.424
RMSD	0.2526	0.4662

coordinates in ITRF2000, ITRF2008 and ITRF2014 to Cassini-Soldner geocentric and the state selection was Johor as the boundary stones are all located in Johor.

According to Tables 13, 16 and 19, the overall standard deviations for the horizontal components (latitude and longitude) of the boundary stones 3, 4, 5 and 14 are less than 2 cm whereas the standard deviation for the vertical component (height) is up to 2.7 cm with the biggest values on point 3, which are 1.81, 1.57 and 2.67 cm, respectively. However, for the boundary stone 12, the values of standard deviations for all components are slightly bigger than other points which are up to 11 cm. This could probably be due to the location of boundary stone. Due to multipath, the elevation cut-off to process the fast static data for point 12 is set up to 20° in order to obtain a fixed baseline compared to other points the elevation cut-off is set as default which is 10°. Therefore, boundary stone 12 is excluded from the assessment of coordinates between different frames. Based on Table 15, the coordinate differences between ITRF2000 and PA 40225 are generally range from −0.277 to −0.209 m for northing and from 0.424 to 0.510 m for easting along with

Table 16 Coordinates of points in ITRF2008

	Latitude	STD (m)	Longitude	STD (m)	Height (m)	STD (m)
ITRF2008						
3	1 29 35.10561	0.0181	103 41 59.15238	0.0157	11.9139	0.0267
4	1 29 34.42505	0.0134	103 41 58.64321	0.0160	10.9874	0.0231
5	1 29 34.82493	0.0128	103 41 59.78014	0.0138	11.8044	0.0202
12	1 29 36.06122	0.0666	103 41 53.30242	0.0665	09.5335	0.1129
14	1 29 35.54097	0.0141	103 41 52.30065	0.0137	09.6558	0.0222

Table 17 Coordinates in Cassini-Soldner geocentric based on ITRF2008

Boundary stones	Northing (m)	Easting (m)
ITRF2008		
3	−60757.479	15434.654
4	−60778.384	15418.916
5	−60766.099	15454.060
12	−60728.139	15253.820
14	−60744.120	15222.855

Table 18 Coordinates difference between ITRF2008 and PA 40225

Boundary stones	Northing (m)	Easting (m)
3	−0.224	0.473
4	−0.235	0.481
5	−0.211	0.513
12	−0.311	0.406
14	−0.167	0.424
RMSD	0.2108	0.4738

their RMSD, 0.2526 and 0.4662 m, respectively. Moreover, the differences of each point between coordinates derived from network-based RTK and PA 40225 is smaller for point 3, 4, 5 and 14 compared to differences of coordinates derived by single-based fast static GPS observation (ITRF2000) and certified plan. This could possibly tell that by using network-based RTK, the network correction is applied on each point can reduce the distance-dependent error (Tables 16 and 17).

ITRF2008 versus PA 40225. As Malaysia is using GDM2000 connected to ITRF2000, there would be bigger differences in coordinates between ITRF2008 and PA 40225 compared to ITRF2000 and PA 40225. However, for the northing component, differences of ITRF2008—PA 40225 are smaller where it ranges from −0.235 to −0.167 m except for easting component the differences are slightly bigger as it ranges from 0.424 to 0.513 m, and these differences are shown in Table 18 as well as their RMSD, which are 0.2108 m (northing) and 0.4738 m (easting) (Tables 19 and 20).

Table 19 Coordinates of points in ITRF2014

	Latitude	STD (m)	Longitude	STD (m)	Height (m)	STD (m)
ITRF2014						
3	1 29 35.10555	0.0181	103 41 59.15244	0.0157	11.9119	0.0267
4	1 29 34.42499	0.0134	103 41 58.64327	0.0160	10.9855	0.0231
5	1 29 34.82487	0.0128	103 41 59.78020	0.0138	11.8024	0.0202
12	1 29 36.06116	0.0666	103 41 53.30248	0.0665	09.5315	0.1129
14	1 29 35.54091	0.0141	103 41 52.30071	0.0137	09.6538	0.0222

Table 20 Coordinates in Cassini-Soldner geocentric based on ITRF2014

Boundary stones	Northing (m)	Easting (m)
ITRF2014		
3	−60757.481	15434.656
4	−60778.386	15418.918
5	−60766.101	15454.062
12	−60728.141	15253.822
14	−60744.122	15222.857

ITRF2014 versus PA 40225. As already mentioned in previous section, there should also be bigger differences in coordinates between ITRF2014 and PA 40225 compared to ITRF2000 and PA 40225. But then again, differences in coordinates of ITRF2014—PA 40225 for northing component are smaller within the range of −0.237 to −0.169 m. Aside from easting component, the differences in coordinates are also slightly bigger as it ranges from 0.426 to 0.515 m. The coordinate's differences between ITRF2014 and PA 40225 are tabulated in Table 21. These differences can also be evaluated from the RMSD of each component, which are 0.2128 and 0.4758 m for northing and easting.

The precision of coordinates for each boundary stone can be evaluated from the standard deviations on each component. Figure 7 summarizes the standard deviation of points 3, 4, 5, 12 and 14 based on ITRF2000 from the processing by using TTC software. In general, point 12 has the least precise coordinates, which are 0.0666, 0.0665 and 0.1129 m for latitude, longitude and height due to the location of the boundary stone whereas point 5 has the most precise coordinates with the value of standard deviation of 0.0128, 0.0138 and 0.0202 m, respectively.

Table 21 Coordinates differences between ITRF2014 and PA 40225

Boundary stones	Northing (m)	Easting (m)
3	−0.226	0.475
4	−0.237	0.483
5	−0.213	0.515
12	−0.314	0.408
14	−0.169	0.426
RMSD	0.2128	0.4758

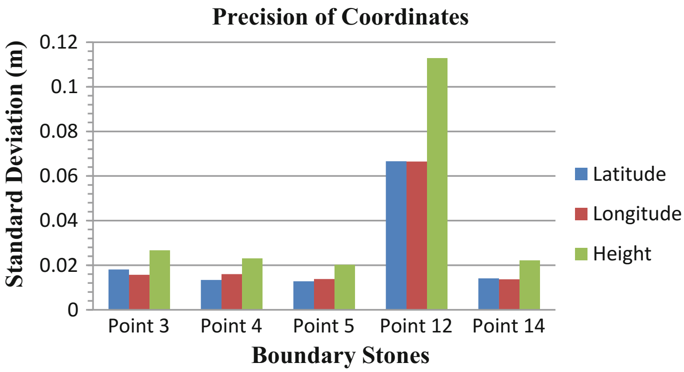

Fig. 7 Standard deviation of coordinates derived by using TTC based on ITRF2000

4 Conclusions

As comprehensively discussed in this paper, the 3 days data is successfully being processed by using Waypoint software in PPP mode with respect to different International Reference Frames (ITRF2000, ITRF2008 and ITRF2014). Undoubtedly, the coordinates derived with respect to the latest frame which is ITRF2014 are the most reliable to be adopted for positioning as they have small value of standard deviation. Moreover, according to Altamimi et al. [11], ITRF2014 is generated with an enhanced modelling of nonlinear station motions, including seasonal signals of station positions and post-seismic deformation for sites that were subject to major earthquake, so it is expected that ITRF2014 will provide a better positional accuracy compared to the previous version of ITRF. Due to dynamic Earth and Post-seismic Deformation (PSD), the origin of reference frames will gradually change across time affecting the position of points on Earth. However, with the existence of ITRF2014 that take into account the PSD by modelling it, the stations that are more prone to earthquake have the potential to accurately describe their actual trajectories. Contrarily, in cadastral survey, a homogenous coordinate system with reference to the global datum is required in mapping integrated purpose. Differences in ITRF give different coordinates for boundary stones on cadastral lot.

In conclusion, GDM2000 has to be revised frequently with respect to the latest version of ITRF in order to give a better positional accuracy and a fix geocentric mapping datum needs to be opted for cadastral integrated purposes in Malaysia.

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