Comparative Analysis of GDM2000, WGS84, and MRT68 Coordinate Reference Systems based on Different Converter Modules

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ABSTRACT

The employment of multiple data and coordinate systems in Malaysia has not only resulted in challenges in surveying and mapping purposes but has also caused data compatibility issues with the local positioning system. This study examines the disparities in coordinates converted from the localized Geocentric Datum of Malaysia 2000 (GDM2000) to the global coordinate system, the World Geodetic System 1984 (WGS84), and from GDM2000 to the Malayan Revised Triangulation 1968 (MRT68). Several coordinate converter tools, available in the mCOORD mobile app, Geodetic Datum Transformation System (GDTS), Global Mapper, and Quantum GIS (QGIS), were employed to analyze the variation between converted coordinates. The locally developed coordinate converter tools, mCOORD and GDTS, exhibit similar levels of accuracy and conform to the standards set by the local survey department. In contrast, the reliability of the coordinate conversion tools in Global Mapper and QGIS seems uncertain. It is recommended that each data revision should establish transparency to the latest geodetic reference frame, with publicly accessible transformation parameters.

Keywords-coordinate reference system; coordinate conversion; GDM2000; WGS84; MRT

I. INTRODUCTION

The Department of Survey and Mapping Malaysia (DSMM) is the leading mapping and surveying organization in the country. Geodetics controls were first established in Peninsular Malaysia in 1886 [1]. The establishment of country-wide trigonometrical stations via conventional triangulation surveys and eventually GNSS observations have laid a strong foundation for its predominant geodetic control framework today, beginning with the Malayan Revised Triangulation 1948

(MRT48), followed by its revision MRT68 in 1968, the Peninsular Malaysia Geodetic Network (PMGN94), the Malaysia Active GPS System (MASS) from 1998 to 2001, and finally, the establishment of the Malaysia Real-Time Kinematic GNSS Network (MyRTKnet) in preparation for the localized Geocentric Datum of Malaysia 2000 (GDM2000) in 2003 [1]. As a consequence of the major earthquakes that occurred in Indonesia between 2004-2007 and 2012, DSMM reviewed its GDM2000 based on the same International Terrestrial Reference Frame (ITRF) 2000 in 2009 and 2016 [2]. Again, DSMM has realigned its coordinates based on ITRF 2014 and established a new geodetic datum known as GDM2020 in October 2021. Table I lists all the common Coordinate Reference Systems (CRSs) that are widely used in Malaysia.

TABLE I. COMMON COORDINATE REFERENCE SYSTEMS IN MALAYSIA

Coordinate Reference System		
No.	**Reference Frame**	**Geodetic Datum**
1	Malaysian Revised Traingulation 1968 (MRT68)	**Kertau** Modified Everest Ellipsoid
2	Malaysian Geodetic Scientific Network 1994 (PMGSN94)	**WGS84** WGS84 Ellipsoid; Reference Frame: WGS84; Epoch: 1987
3	Malaysia Real-Time Kinematic GNSS Network (MyRTKnet)	**GDM2000** GRS80 Ellipsoid; Reference Frame: ITRF2000; Epoch: 2000.0
		GDM2000 (Rev2006) GRS80 Ellipsoid; Reference Frame: ITRF2000; Epoch: 2000.0
		GDM2000 (Rev2009) GRS80 Ellipsoid; Reference Frame: ITRF2000; Epoch: 2000.0
		GDM2000 (Rev2016) GRS80 Ellipsoid; Reference Frame: ITRF2000; Epoch: 2000.0
		GDM2020 GRS80 Ellipsoid; Reference Frame: ITRF2014; Epoch: 2020.0

However, the exercise of numerous datums with different ellipsoid models, which have been used since early times, has not only caused inconveniences in survey and mapping tasks [3] but also raised data incompatibility issues with GNSS positioning [4]. For instance, in these Malaysian CRSs, numerous elegant calculations and time-consuming calculations must be performed behind the basics of datum translation and coordinate conversion. Some of these involve simple coordinate conversions, while others include classy map projections and datum transformations [5].

TABLE II. DIVERSE TYPES OF ELLIPSOID MODELS IN MALAYSIA

No	**Ellipsoid Model**	**Semi-major, a (m)**	**Flattening, f (m)**
1	Modified Everest (Peninsular Malaysia)	6377304.063	300.8017
2	World Geodetic Systen 1984 (WGS84)	6378137.000	298.2572236
3	Geodetic Reference System 1980 (GRS80)	6378137.000	298.2572221

Given the absence of adequately documented datum transformation parameters associated with the GDM2020, GDM2000 (rev2016), GDM2000 (rev2009), and GDM2000 (rev2006) coordinate conversions, this study attempts to analyze the discrepancies between the coordinates converted from GDM2000 to WGS84 [6] and from GDM2000 to MRT68. This study aims to raise awareness among practitioners about how to address this issue in this region.

II. DATA AND METHODS

Although there are several commercially available GIS software (e.g. MapInfo, QGIS, ArcGIS, Global Mapper, etc.) equipped with coordinate conversion tools [7, 8], their reliability in converting coordinates, especially within the context of Malaysia, is often questionable and does not meet the requirements of the DSMM [9, 10]. GIS and geomatics practitioners in Malaysia have experienced substantial issues as a result of the non-alignment of geospatial data. The non-uniformity of CRSs has led to interoperability issues when exchanging geospatial data among various organizations. This problem hinders the seamless alignment and perfect integration of the data. The DSMM technical guide serves as the basis for adopting the fundamental idea and complex mathematical calculations involved in datum translation, map projection, coordinate conversion, and the devoted transformation parameters and details of the respective states' origins [1]. The variation analysis between the coordinates converted from GDM2000 to WGS84 and from GDM2000 to MRT68 was based on the coordinate converter modules provided in mCOORD v1.0 mobile application [11], Geodetic Datum Transformation System (GDTS) v4.01 of Info-Geomatik Sdn Bhd, Global Mapper v24.0, and QGIS v3.28 software. mCOORD and GDTS were developed based on the formula and datum transformation parameters defined by DSMM, while the Global Mapper and QGIS software parameters remain undisclosed. Therefore, to test their accuracy, nine well-defined state origin points were used to compare their discrepancy, as shown in Table III. The origins of each state are based on (0,0) coordinates of the Cassini-Soldner(Geocentric) map projection.

I. ORIGINS OF THE RESPECTIVE STATES IN MALAYSIA IN THE GDM2000 COORDINATES

State	**Geocentric Datum of Malaysia 2000 (GDM2000)**	
	ϕ	**λ**
Johor	2°02'33.20196"	103°33'39.83730"
N.S/ Melaka	2°42'43.63383"	101°56'22.92969"
Pahang	3°42'38.69263"	102°26'04.60772"
Selangor	3°40'48.37778"	101°30'24.48581"
Terengganu	4°56'44.97184"	102°53'37.00496"
P. Pinang	5°25'15.20433"	100°20'40.76024"
Kedah/Perlis	5°57'52.82155"	100°38'10.93860"
Perak	4°51'32.64488"	100°48'55.47038"
Kelantan	5°53'37.07975"	102°10'32.24529"

The datum transformation between GDM2000 and MRT68 was accomplished using the Bursa-Wolf formulae (7), which is a seven-parameter model for transforming three-dimensional cartesian coordinates between two datums. The model, in its matrix-vector form [9], can be written as:

$$\begin{pmatrix} X_{GDM2000} \\ Y_{GDM2000} \\ Z_{GDM2000} \end{pmatrix} = \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{pmatrix} + \begin{pmatrix} 1+\Delta L & R_Z & -R_Y \\ -R_Z & 1+\Delta L & R_X \\ R_Y & -R_X & 1+\Delta L \end{pmatrix} \begin{pmatrix} X_{MRT} \\ Y_{MRT} \\ Z_{MRT} \end{pmatrix} \quad (1)$$

where $X_{GDM2000}$, $Y_{GDM2000}$, and $Z_{GDM2000}$ are the geocentric datum (GRS80) cartesian coordinates and X_{MRT}, Y_{MRT}, and Z_{MRT} are the local datum (MRT) cartesian coordinates.

Thus, to convert the cartesian coordinates XYZ to the geographical coordinates of latitude (ϕ), longitude (λ), and height (h), ellipsoid properties for the respective datum are listed in Table II. Meanwhile, a map projection is required to display the coordinate system of the data on a flat surface. The RSO is typically used to project longitude and latitude coordinates in a defined coordinate reference system onto dedicated flat projected map (N, E) coordinates. This projection is orthomorphic (conformal) and cylindrical. It provides an optimum solution in the sense of minimizing distortion while remaining conformal for Malaysia. The following are the formulas used to compute N, E from given ϕ, λ coordinates:

$$t = \tan(\frac{\pi}{4} - \frac{\phi_c}{2})/[(1 - esin\phi_c)/(1 - esin\phi_c)]^{\frac{e}{2}}$$

$$Q = H/t^B$$

$$S = (Q - \frac{1}{Q})/2$$

$$T = (Q + \frac{1}{Q})/2$$

$$V = \sin(B(\lambda - \lambda_0))$$

$$U = -Vcos(\gamma_0) + Ssin(\gamma_0))/T$$

$$v = Aln\left[\frac{1-U}{1+U}\right]/2B$$

$$\mathrm{u} = \frac{A}{B}\arctan\left[\frac{Scos(\gamma_0)+Vsin(\gamma_0)}{\cos(B(\lambda-\lambda_0))}\right]$$

RSO coordinates are then derived by (2) and (3).

$$E = vcos(\gamma_c) + usin(\gamma_c) + FE \quad (2)$$

$$N = vcos(\gamma_c) + usin(\gamma_c) + FN \quad (3)$$

III. RESULTS AND ANALYSIS

This section provides an assessment of the accuracy of the GDTS, Global Mapper, and QGIS coordinate conversion tools compared to mCOORD, aiming to evaluate the proficiency of the developed mCOORD v1.0 mobile application. This assessment used coordinates from the nine distinctly specified state cadastral origins.

A. Results on the Accuracy of Coordinate Conversion

The disparities in terms of latitude (Δϕ) and longitude (Δλ), total errors (ΣΔ), and RMSE were calculated based on coordinate conversions from GDM2000 to WGS84 (Table IV) and GDM2000 to MRT68 (Table V) using mCOORD, GDTS, Global Mapper and QGIS. These control points were also transformed into $\text{RSO}_{(\text{Geocentric})}$ (Table VI) and $\text{RSO}_{(\text{MRT68})}$ (Table VII), projected into plane coordinates represented as (N, E). F and T-tests were performed to further investigate the disparities between coordinates. These hypothesis tests provide a statistical framework to assess the significance of observed differences.

B. Analysis of the Accuracy of the Coordinate Conversion

The latitude and longitude coordinates transformed using the mCOORD and GDTS tools align precisely with the GDM2000 to WGS84 transformation. Considering the results in Table IV, the coordinate discrepancy patterns between mCOORD versus Global Mapper and mCOORD versus QGIS are relatively consistent. When converting coordinates using mCOORD to Global Mapper, the latitude-specific RMSE is 0.04400" and the longitude-specific RMSE is 0.03747". In contrast, the RMSE obtained from mCOORD to QGIS is 0.04399" in latitude and 0.03746" in longitude. These values are roughly approximately 1.319 m and 1.124 m in positional discrepancy. This assertion is further proven by the T-tests performed on the mCOORD coordinates converted to Global Mapper and QGIS coordinates, yielding p-values indicative of statistically significant differences between the coordinate systems.

The geographic coordinates were also converted from GDM2000 to MRT68 using mCOORD and GDTS, and the displacement in terms of latitude and longitude is quite constant, as shown in Table V. The RMSE for latitude and longitude is 0.00001". The displacement of 0.00001" in both latitude and longitude is unquestionably within the permitted positional margin, approximately equivalent to 0.0003 m. Unlike the converted coordinates from GDM2000 to WGS84, all p-values associated with the conversion from GDM2000 to MRT68 exhibit values below 0.05, indicating a statistically significant difference between the converted coordinates. Meanwhile, the coordinate discrepancies between mCOORD and Global Mapper had 0.04492" RMSE in latitude and 0.03906" RMSE in longitude. For the coordinate conversion of GDM2000 to MRT68 between mCOORD versus QGIS, the minimum and maximum displacement ranged from 0.37623" to 1.47306", with an RMSE of 1.09054" for latitude, and from 4.61230" to 6.06824" with an RMSE of 5.30428" in longitude. Undoubtedly, these displacements exceed the allowed positional margin for precise cadastral survey requirements.

However, the results shown in Table VI demonstrate the differences in $\text{RSO}_{(\text{Geocentric})}$ projected coordinates derived from GDM2000. All displacement errors are relatively small and within the allowed limits for surveying and mapping accuracy. The total conversion error from GDM2000 to projected $\text{RSO}_{(\text{Geocentric})}$ is within ±0.001 m for both Northing and Easting. The RMSE achieved for both the Northing and the Easting is 0.00033 m. For the conversion of GDM2000 coordinates into the old $\text{RSO}_{(\text{MRT68})}$ projected coordinate system (Table VII), the results show that the coordinates difference between mCOORD and GDTS are nearly perfectly aligned, whereas the coordinates difference between mCOORD and Global Mapper showed an RMSE of 1.366 m in Northing and 0.971 m in Easting. However, the conversion results reveal significant positional discrepancies between mCOORD and QGIS, as the RMSE of 33.755 m and 164.149 m in Northing and Easting, respectively, are entirely unacceptable for both surveying and mapping purposes.

Although a single T-test can identify the presence of a consistent bias between the original and transformed coordinates, it may not reveal the extent of variability in those discrepancies. To gain a more comprehensive understanding of these differences, an F-test was also employed. The F-test specifically assesses whether the spread (variance) of these discrepancies is statistically significant between the X and Y axes. As shown in Tables IV-VII, the p-values of the T-tests are predominantly less than 0.05. This statistically significant result indicates that the observed mean difference between the original and transformed coordinates is unlikely due to randomness. In simpler terms, there is a systematic difference present. The F-test results, presented in Tables VII and IX, provide further insight. When the p-value of the F-test exceeds 0.05, it suggests that the variability (spread) of the differences between the original and transformed coordinates is statistically similar. This implies that the magnitude of these discrepancies does not show a significant difference between the X and Y axes. In summary, this scenario indicates that while there is a systematic shift in the coordinates (as shown by the significant T-test), the nature of this shift does not vary much (as shown by the non-significant F-test). Therefore, the transformation has introduced a consistent bias but has not altered the variability of the coordinates.

TABLE III. DISPARITY OF LATITUDE ($\Delta\Phi$) AND LONGITUDE ($\Delta\Lambda$) BETWEEN GDM2000 TO WGS84

	Geographical Coordinates Conversion					
	mCOORD vs GDTS		**mCOORD vs Global Mapper**		**mCOORD vs QGIS**	
	$\Delta\phi$ (sec)	**$\Delta\lambda$ (sec)**	**$\Delta\phi$ (sec)**	**$\Delta\lambda$ (sec)**	**$\Delta\phi$ (sec)**	**$\Delta\lambda$ (sec)**
1	0.00000	0.00000	0.04232	-0.03371	0.04236	-0.03372
2	0.00000	0.00000	0.04215	-0.03619	0.04211	-0.03617
3	0.00000	0.00000	0.04367	-0.03620	0.04365	-0.03624
4	0.00000	0.00000	0.04297	-0.03733	0.04299	-0.03733
5	0.00000	0.00000	0.04545	-0.03652	0.04541	-0.03648
6	0.00000	0.00000	0.04425	-0.03987	0.04423	-0.03990
7	0.00000	0.00000	0.04508	-0.03993	0.04504	-0.03992
8	0.00000	0.00000	0.04388	-0.03899	0.04391	-0.03897
9	0.00000	0.00000	0.04606	-0.03803	0.04602	-0.03801
$\Sigma\Delta$	**0.00000**	**0.00000**	**0.39583**	**-0.33677**	**0.39572**	**-0.33674**
RMSE	**0.00000**	**0.00000**	**0.04400**	**0.03747**	**0.04399**	**0.03746**
p-value	**NA**	**NA**	**1.23200e-11**	**1.50300e-13**	**1.22700e-11**	**1.35400e-13**

TABLE IV. DISPARITY OF LATITUDE ($\Delta\Phi$) AND LONGITUDE ($\Delta\Lambda$) BETWEEN GDM2000 TO MRT68

	Geographical Coordinates Conversion					
	mCOORD vs GDTS		**mCOORD vs Global Mapper**		**mCOORD vs QGIS**	
	$\Delta\phi$ (sec)	**$\Delta\lambda$ (sec)**	**$\Delta\phi$ (sec)**	**$\Delta\lambda$ (sec)**	**$\Delta\phi$ (sec)**	**$\Delta\lambda$ (sec)**
1	0.00001	-0.00001	0.04279	-0.03535	0.37623	6.06824
2	0.00001	-0.00001	0.04254	-0.03780	0.58960	5.31382
3	0.00001	-0.00001	0.04407	-0.03779	0.84695	5.56647
4	0.00001	-0.00001	0.04342	-0.03895	0.85574	5.12845
5	0.00001	-0.00001	0.04582	-0.03812	1.16978	5.80402
6	0.00001	-0.00001	0.04912	-0.04147	1.33450	4.61230
7	0.00001	-0.00001	0.04540	-0.04151	1.47306	4.75650
8	0.00001	-0.00002	0.04431	-0.04052	1.17954	4.82400
9	0.00001	-0.00002	0.04642	-0.03958	1.43328	5.47874
$\Sigma\Delta$	**0.00009**	**-0.00011**	**0.40389**	**-0.35109**	**9.25868**	**47.55254**
RMSE	**0.00001**	**0.00001**	**0.04492**	**0.03906**	**1.09054**	**5.30428**
p-value	**3.30300e-05**	**4.36700e-05**	**8.13100e-12**	**3.54800e-12**	**1.00300e-09**	**4.21300e-05**

TABLE V. DISPARITY OF RSO$_{(MRT68)}$ PROJECTED COORDINATES IN GDM2000

	Projected Coordinates Conversion					
	mCOORD vs GDTS		**mCOORD vs Global Mapper**		**mCOORD vs QGIS**	
	ΔN (m)	**ΔE (m)**	**ΔN (m)**	**ΔE (m)**	**ΔN (m)**	**ΔE (m)**
1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.00000	-0.00100	0.00000	0.00000	0.00000	0.00000
3	0.00000	0.00000	0.00100	0.00000	0.00000	0.00000
4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5	0.00000	0.00000	0.00000	-0.00100	0.00000	-0.00100
6	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
7	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8	0.00100	0.00000	0.00100	0.00000	0.00100	0.00000
9	0.00000	0.00000	0.00100	0.00000	0.00100	0.00000
$\Sigma\Delta$	**0.00100**	**-0.00100**	**0.00300**	**-0.00100**	**0.00100**	**-0.00100**
RMSE	**0.00033**	**0.00033**	**0.00058**	**0.00033**	**0.00036**	**0.00027**
p-value	**0.42840**	**0.34660**	**0.34660**	**0.08052**	**0.346600**	**0.16900**

TABLE VI. DISPARITY OF RSO$_{(MRT68)}$ PROJECTED COORDINATES IN MRT68.

	Projected Coordinates Conversion					
	mCOORD vs GDTS		**mCOORD vs Global Mapper**		**mCOORD vs QGIS**	
	ΔN (m)	**ΔE (m)**	**ΔN (m)**	**ΔE (m)**	**ΔN (m)**	**ΔE (m)**
1	0.00000	0.00000	1.31400	-0.86200	11.74337	188.29113
2	-0.00100	0.00000	1.30800	-0.93500	18.17395	164.72268
3	0.00000	0.00000	1.35500	-0.93600	26.27444	172.40975
4	0.00000	0.00100	1.33600	-0.96800	26.38835	158.81148
5	-0.00100	0.00000	1.40800	-0.94300	36.49228	179.53683
6	-0.00100	0.00000	1.37600	-1.04100	41.09624	142.49618
7	0.00000	0.00000	1.40100	-1.04200	45.47813	146.82870
8	-0.00100	0.00000	1.36600	-1.01500	36.35349	149.15481
9	0.00000	0.00000	1.42800	-0.98700	44.60109	169.19128
ΣΔ	**-0.00400**	**0.00100**	**12.29200**	**-8.72900**	**286.60133**	**1471.44285**
RMSE	**0.00067**	**0.00033**	**1.36635**	**0.97145**	**33.75495**	**164.14880**
p-value	**0.34660**	**0.03527**	**2.9300e-11**	**1.32700e-13**	**1.10500e-09**	**4.19100e-05**

TABLE VII. P-VALUES FROM F-TEST HYPOTHESIS

	GDM2000 TO WGS84	**GDM2000 TO MRT68**
mCOORD vs GDTS	NA	0.4458
mCOORD vs Global Mapper	0.2907	0.9209
mCOORD vs QGIS	0.2756	0.484

TABLE VIII. P-VALUES FROM F-TEST HYPOTHESIS

	RSO$_{(MRT68)}$ projected coordinates in GDM2000	**RSO$_{(MRT68)}$ projected coordinates in MRT68**
mCOORD vs GDTS	8.636e-06	0.2165
mCOORD vs Global Mapper	0.2725	0.3648
mCOORD vs QGIS	0.4458	0.4633

IV. CONCLUSION AND RECOMMENDATION

This study has successfully addressed the capability to convert coordinates between different CRS using mCOORD, GDTS, Global Mapper, and QGIS, specifically within the Malaysian context. This paper examined and analyzed nine well-defined control coordinates in GDM2000, transforming them from GDM2000 to WGS84 and MRT68, subsequently converting them into a projected plane coordinate system in RSO$_{(Geocentric)}$ and RSO$_{(MRT68)}$ for positional purposes. The findings show that the coordinate conversion tools in Global Mapper and QGIS exhibit unreliability and raise doubts about their coordinate conversion. mCOORD and GDTS demonstrate similar accuracy levels and adhere to the standards set by DSMM. Both coordinate converter tools are developed based on the transformation formula and the parameters documented in [1]. Undoubtedly, when developing their respective coordinate conversion tools, Global Mapper and QGIS may not apply the homogenous datum transformation parameters. This lack of homogeneity in the transformation process has led to issues such as non-alignment of coordinates, particularly affecting interoperability when exchanging geospatial data across multiple organizations. Thus, this study recommends that all relevant government agencies worldwide publish comprehensive guidelines that detail datum transformation, map projection, and coordinate conversion procedures. Every datum revision should be transparently established according to the latest geodetic reference frame, and the transformation parameters should be made publicly available.

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