

POTENTIAL USE OF GPS FOR CADASTRAL SURVEYS IN MALAYSIA

By

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Abstract

The Department of Surveying and Mapping, Malaysia (DSMM) has proposed a feasibility study on the issues related with introducing a Coordinated Cadastral System (CCS) for Malaysia. One of the several project themes that has been carried out is a study related to the *legal traceability* issues concerning GPS for cadastre, testing of GPS equipment, and recommended practices for GPS cadastral surveys in the country.

The practice of cadastral surveying which is regulated by legislation requires distance measurements (by EDM or chain) that are traceable to primary standards of measurement by means of calibration. However, the implications for GPS cadastral surveying are unclear as GPS position is not a defined physical quantity. An alternative solution to the problem of GPS *legal traceability* using the conventional approach of calibration against a *standard* being proposed.

It has been identified that a set of *recommended practices* or *guidelines* regarding the use of GPS for Cadastral surveys in the country need to be developed. The *guidelines* concerning among others the survey planning and design, the testing/calibration of GPS equipment, the selection of the appropriate GPS field technique, and the related field and office operation procedures. Results on the GPS equipment testing and calibrations following the proposed guidelines have been presented together with the GPS survey results over the boundary markers of the selected cadastral lots.

1.0 Introduction

The new Geodetic GPS Network for Peninsular Malaysia was first observed in early 1992 and completed in 1993 providing a consistence set of coordinates in WGS84. The network consisting of 238 GPS stations were observed using Ashtech dual frequency receivers with average spacing of about 30km (Samad Abu and Majid Kadir, 1993). Since then, GPS surveying has been practiced for various applications particularly in providing control for large engineering projects in the country. However an increasing interest has been noticed lately in using GPS for cadastral surveys particularly in relation with the future implementation of CCS in Malaysia.

It has been recognized that in order to use GPS technology for cadastral surveys, GPS measurements must be legally traceable. The issue of "legal traceability" of GPS for cadastral surveys has been investigated in this studies. It has been realized that there is a need to develop a set of procedures for testing GPS equipments for cadastral survey as well as a guideline in carrying out the GPS cadastral surveys. As a result, a set of GPS Cadastral Survey Guidelines (DSMM, 1999) was specifically developed to provide recommended practices for the use of GPS in cadastral surveying in Peninsular Malaysia. These are guidelines related to: planning a GPS cadastral survey and how the coordinates are to be determined through appropriate connection to survey control; testing/calibration of GPS equipment; field procedures for operating the equipment, documentation, quality assurance and verification procedures, and; office procedures for data reduction and result submission. This paper concerned with test results on the GPS equipment calibration procedures as required by the Guidelines. GPS survey results over the boundary markers of the selected cadastral lots which has followed the "recommended practices for field and office procedures" as described in the Guidelines are also presented.

2.0 GPS Equipment Calibration for Cadastral Survey

In general, measurements are only "legal" if they are "traceable" to primary standards of measurement. Accordingly, the definition of "legal traceability" is that a GPS measurement (in actual fact the baseline derived from the processing of the raw carrier phase observations made by two GPS receivers) is "legally traceable" if : (i) has carried out the various test/calibration procedures as required by the Guidelines, and ; (ii) the survey has followed the "recommended practices for field and office procedures" as described in the Guidelines.

A GPS system testing/calibration program is considered as a prerequisite for demonstrating "competence" and for assuring that GPS-derived coordinates are of a uniformly high quality. The results of such testing should be retained by the surveyor and made available for audit on request. These tests require the application of a zero baseline test, and calibration of the GPS equipment on an EDM baseline and a network of existing First Order Geodetic GPS control stations.

2.1 Zero Baseline Test

A **zero baseline test** is performed in order to ensure the correct operation of a pair of GPS receivers, associated antennas and cabling, and data processing software. The test is carried out by connecting two GPS receivers to a single antenna, using an antenna splitter appropriate for the brand of receiver/antenna (as recommended by the GPS manufacturer). This is a comparatively simple test that can verify the precision of the receiver measurements (and hence its correct operation), as well as validate the data processing software.

A series of test have been carried out at an open site in UTM. The list of GPS equipment set being tested are given in Table 1.

Type of receivers	<i>Leica System 300 (L1& L2)</i>
Number of receivers tested	3 (R1, R2, R3)
Antenna with splitter	1 (for each test)
Processing software	<i>SKI version 2.11</i>

Table 1: GPS equipments used in the tests

Three (3) *Leica* dual frequency GPS receivers were subjected in the test series where two (2) of them being used in each test. The criteria in Table 2 has been observed during each field test and the baseline processing involving each pair of receiver has been carried out following requirements in Table 3.

Observation length	10 minutes
Recording Interval	15 seconds
Number of satellites	≥ 5
GDOP	≤ 6
Sky Clearance	$\geq 90\%$
Cut Off Angle	15°

Table 2: Field test criteria

Session length used	10 minutes
Ambiguity Resolution	Fixed
Cut Off Angle	15°
Frequency used	L1 dan L2

Table 3: Processing requirements

The resulting computed slope distance for each pair of receivers is given in Table 4 according to the test date in millimeters.

Test Date	Slope distance between receivers (mm)		
	R1- R2	R1- R3	R2- R3
11.12.97	0.1	0	0
16.1.98	0.1	0.1	0.1
18.2.98	0.4	0.4	0.5
14.3.98	0.6	0.5	0.1
15.4.98	1.2	0.3	1.4
4.5.98	0.1	0.3	0.4
30.6.98	0.1	0.1	0.1

Table 4: Test series results

Table 4 indicate that magnitude of the resulting slope distance between receivers is fairly closed to the theoretical values (zero) with the maximum of being 1.4mm. Therefore the receivers and the processing software used in the test series are in good order.

2.2 EDM Baseline Test

An **EDM baseline test** is performed in order to ensure that the operation of a pair of GPS receivers, associated antennas and cabling, and data processing software, give distance results that can be compared with calibrated baseline data. EDM calibration baselines have been established throughout Malaysia to service the land surveying community. These baselines have themselves been calibrated against a "standard", and hence can fulfill the requirements of "legal traceability" of GPS-derived distances.

GPS can be used to measure the three components of a baseline, that is, expressed as either: (i) relative latitude, longitude and height, or ; (ii) relative Cartesian coordinates with respect to a global geocentric reference frame, or ; (iii) distance, azimuth and height difference between the two antennas. However, EDM baseline testing only considers the distance component.

EDM baselines are rarely longer than one kilometre, well short of the baseline length "range" over which GPS can operate. Hence, only comparatively short distances can be checked. However, it is assumed that if the GPS equipment can verify the known distances between the markers on the pillars of the EDM baseline, the equipment is in good order and capable of delivering baseline solutions that are within specification.

A series of EDM baseline test have been carried out at the existing EDM baseline calibration test site in UTM on the 10th April 1998. The site is being maintained by UTM and their layout is shown in Figure 1.

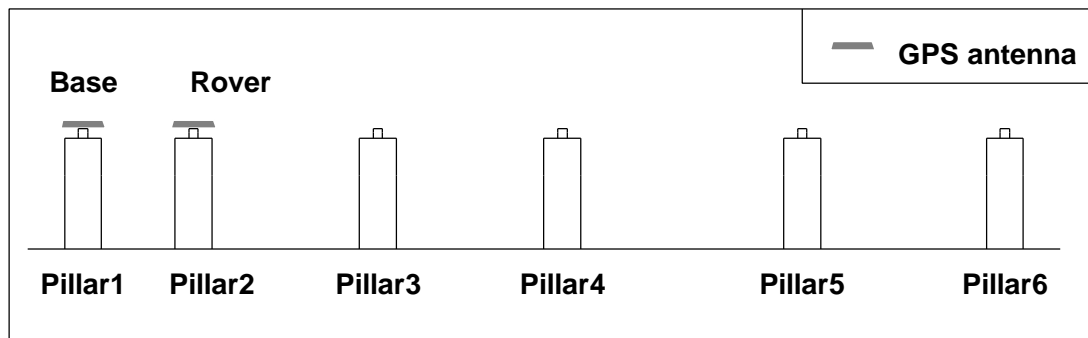


Figure 1: UTM EDM baseline test site

The EDM test site comprises of six (6) pillars separated at specified interval with the longest baseline of about one (1) kilometer. The length between pillars has been routinely measured and documented as the published true values.

The test has been carried out using GPS *rapid static* technique. One receiver (R1) was remained at the Pillar 1 during the entire observations while the other two (R1 and R2) were roving. The list of GPS equipment set being tested are as follow:

Type of receivers	<i>Leica System 300 (L1& L2)</i>
Number of receivers tested	3 (R1, R2, R3)
Antenna	1 (for each receiver)
Processing software	<i>SKI version 2.11</i>

Table 5: GPS equipments used in the tests

Three (3) *Leica* dual frequency GPS receivers being used in the test following field criteria and processing requirements given in Table 2 and Table 3, respectively. The differences between GPS computed distances and their corresponding EDM values for each pair of pillars (receivers) are given in Table 6 and Table 7, respectively.

Baselines (pillars)	Distances		
	R1- R2 (m)	EDM (m)	Differences (mm)
1 - 2	10.035	10.031	-4
1 - 3	190.005	190.004	-1
1 - 4	540.026	540.023	-3
1 - 5	805.207	805.204	-3
1 - 6	900.155	900.161	6

Table 6: Differences between GPS and EDM values for R1/R2 receiver pair

Baselines (pillars)	Distances		
	R1- R3 (m)	EDM (m)	Differences (mm)
1 - 2	10.031	10.031	0
1 - 3	190.005	190.004	-1
1 - 4	540.017	540.023	6
1 - 5	805.196	805.204	8
1 - 6	900.171	900.161	-10

Table 7: Differences between GPS and EDM values for R1/R3 receiver pair

The Tables indicate that, for both pairs of the receivers, differences of less than 10mm has been given. This shows that the GPS equipment set being used are in good condition.

2.3 GPS Network Test

A **GPS network test** is performed in order to ensure that the operation of GPS receivers, associated antennas and cabling, and data processing software, give high accuracy coordinate results. Such a test is the most realistic form of test as it ensures that the results for all inter-antenna distances can be checked. The surveyor must select a series of established control stations that satisfy the following conditions:

- All coordinates of the test network are known in the local geodetic system.
- All stations have sky visibility of at least 90%.
- The test network should include a minimum of three (3) stations of the First Order GPS Network of Peninsular Malaysia (DSMM, 1994: “GPS Derived Coordinates”).

Such a test network may be identified and used by all surveyors, or each surveyor may define which stations belong to "his" test network. To ensure that high quality results are obtained when the antennas are setup on a tripod, centred over a groundmark (where there are no trig station pillars available), the optical plummet(s) within the tribrachs should also be checked.

Each pair of antennas is setup at two stations in the test network, and data collected using the procedures defined for a static mode survey. To derive a reliable set of coordinates (which are then compared to the known coordinates of the control stations), enough baselines must be observed to ensure sufficient redundancy in the network adjustment. Hence a minimum of double the number of independent baselines must be observed. (In the case of six stations in the network, there are five independent baselines, and therefore ten baselines are observed.) More than one pair of GPS receivers may be used but care may have to be exercised in determining which receiver is malfunctioning if the network coordinate results are out of tolerance.

The purpose of the GPS network test is to compare GPS observed coordinates with their corresponding established GPS geodetic values. A sample GPS network test has been carried out at the existing GPS geodetic network in the State of Melaka on the 2nd July 1998. Layout of the GPS network test site is shown in Figure 2.

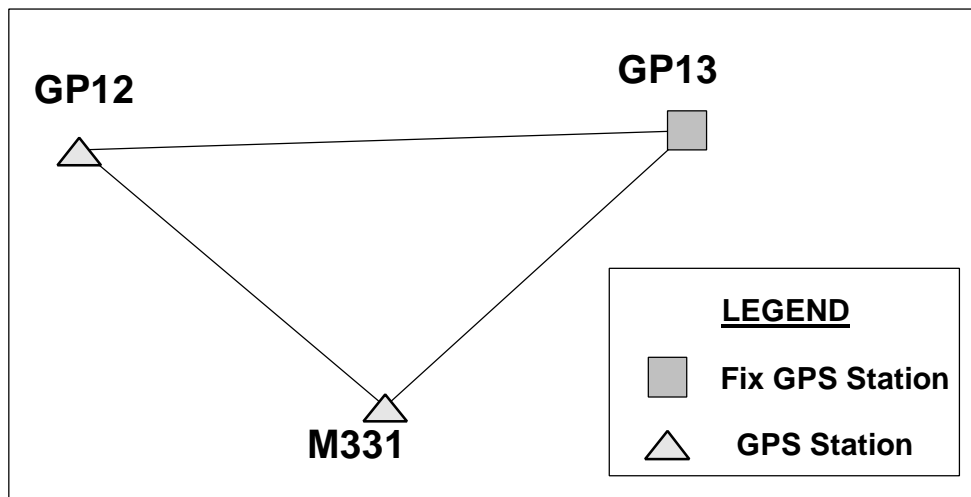


Figure 2: GPS network test site

The GPS network test site comprises of three (3) GPS stations (known stations) namely GP13, GP12 and M331 which is separated about 30km. The test has been carried out using GPS *static* technique. The observation has been carried out in one session (approximately 5 hours) using a total of three (3) GPS receivers. In the processing step, the observation data has been divided into five (5) separate sessions of one (1) hour each.

A minimally constrained adjustment is also being carried out using the *SKI* Adjustment Package with the parameters given in Table 8.

Fixed Station	GP13
Number of observation	12
Number of unknown	6
Degree of freedom	6

Table 8: Network adjustment parameters

In the adjustment, the geodetic coordinates for station GP13 given in WGS84 was held fixed. The adjusted GPS coordinates are in a geocentric datum (WGS84), and need to be transformed into the established local cadastral coordinate system. The existing

coordinate system used for cadastral mapping in Peninsular Malaysia is the local *Cassini Soldner* System (Majid Kadir, 1986).

Finally the adjusted coordinates for GP12 and M331 is given below in Cassini. The coordinates were compared to their corresponding known (established) values.

Stn	Adjusted (m)		Known (m)		Difference (m)	
	N	E	N	E	δN	δE
GP12	-30130.346	14487.109	-30130.339	14487.054	-0.007	0.055
M331	-55921.006	23455.468	-55921.019	23455.478	0.013	-0.010

Table 9: Comparison of coordinates in Cassini system (GP13 fixed)

Table 9 shows that the maximum difference of 5cm is being noticed for easting component of station GP12. The existing GPS network is known to having accuracy of $a + b.L$ ($a=5\text{mm}$, $b= 2\text{ppm}$ and $L=$ baseline length in kilometres) which is should be taken into account in evaluating the quality of the adjusted values. The newly GPS derived distances for two baselines (GP13-GP12 and GP13-M331) and their related accuracies is also given in Table 10.

Lines	Distances, L (km)	Computed Accuracy	Allowable Accuracy ($5+2.L$ mm)
GP13 – GP12	29.8	55mm	64mm
GP13 – M331	32.5	16mm	70mm

Table 10: The computed and allowable accuracies for the corresponding baselines

Table 10 shows that for distances of about 30km, accuracies for the observed GPS distances is within the allowable limits. This also indicates that the GPS equipment set being used are in good condition.

3.0 GPS Cadastral Control Survey

GPS Cadastral Control Surveying is the methodology by which coordinates are obtained from the existing geodetic control stations or other cadastral marks. This will require the use of the Static GPS surveying technique. There is a restriction on the length of the baseline, and recommendations are made on the length of observation session.

A sample GPS cadastral control survey has been carried out at the existing Cadastral Standard Traverse in the State of Melaka on the 2nd July 1998. Layout of the GPS network test site is shown in Figure 3.

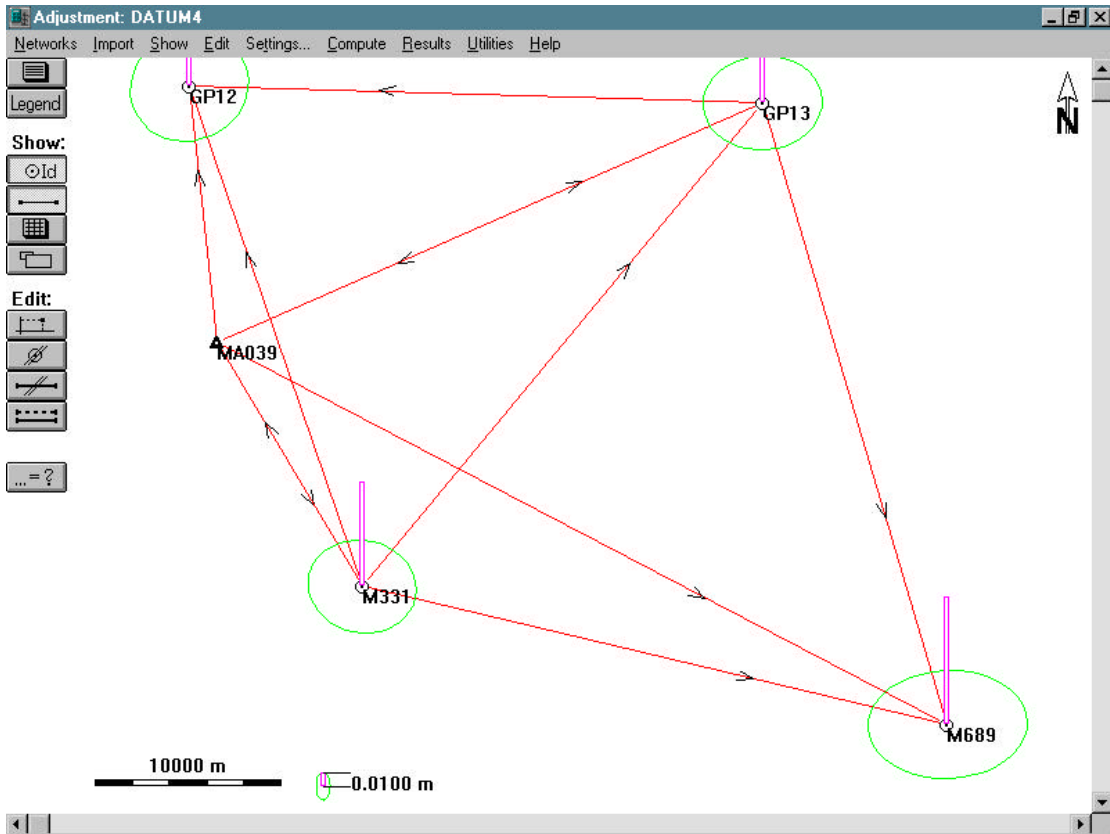


Figure 3: GPS cadastral control survey test site

The test site comprises of three (3) GPS stations (known stations) namely GP13, GP12 and M331 which is separated about 30km apart, and two (2) cadastral standard traverse stations (MA039 and M689). The test has been carried out using GPS *static* technique. Three (3) *Leica* dual frequency GPS receivers being used in the measurements.

In the processing step, data from one (1) hour observation session has been used. A minimally constrained adjustment is also being carried out using the *SKI* Adjustment Package with the parameters given in Table 11.

Fixed Station	MA039
Number of observation	24
Number of unknown	12
Degree of freedom	12

Table 11: Network adjustment parameters

The adjustment of the GPS network have been carried out in two stages:

Stage I: Minimal constraint adjustment by fixing one of the GPS known station in WGS84 System.

Stage II: Minimal constraint adjustment by fixing one of the existing cadastral station in WGS84 System. The 3-dimensional WGS84 coordinates of the fixed cadastral mark is obtained as follows:

- i. The horizontal coordinates is obtained from reverse transformation from local Cassini to WGS84:

$$(N,E)_{CAS} \Rightarrow (N,E)_{RSO} \Rightarrow (\varphi, \lambda)_{MRT} \Rightarrow (\varphi, \lambda)_{WGS84}$$

- ii. The ellipsoidal height (h_{WGS84}) of the fixed cadastral mark is obtained from the first adjustment result (Stage I).

In the first adjustment (Stage I), the WGS84 coordinates for GP13 was held fixed. This was then followed by the second adjustment (Stage II) where the coordinates for standard traverse station MA039 given in WGS84 was held fixed (The 3-D WGS84 coordinates of the station were derived as above). The adjusted coordinates for GP12, GP13, M331 and M689 need to be transformed again into the Cassini system.

Adjusted coordinates for M689 is given in Table 12 in Cassini. The coordinates were compared to their corresponding known values from Standard Traverse in Cassini.

Stn	Adjusted (m)		Std Traverse (m)		Difference (m)	
	N	E	N	E	δN	δE
M689	-63059.549	53866.326	-63058.827	53866.432	0.722	0.106

Table 12: Comparison of coordinates in Cassini system (MA039 fixed)

Table 12 shows that the difference of 72cm is being noticed for northing component of station M689. The existing standard traverse is known to having linear accuracy of 1:25,000 which is should be taken into account in evaluating the quality of the adjusted values. The newly GPS derived distances for baseline MA039 - M689 is also given in Table 13 together with the related linear accuracy.

Lines	Distances (m)	Linear Accuracy	Allowable linear Accuracy
MA039 – M689	42,769	1:58,609	1:25,000

Table 13: The computed and allowable accuracy for Baseline MA039 - M689

Table 13 shows that for distances of about 43km, linear accuracy for the observed GPS distances is within the allowable limits. This indicates that GPS is possible to be used for transferring coordinate purposes and in providing control for Cadastral work.

4.0 GPS Cadastral Survey

GPS Cadastral Survey, on the other hand, requires the coordinates to be determined of the land parcel, in relation to a nearby GPS mark (established, for example, by the Control Survey). These coordinates may then be transformed to bearing and distance, or otherwise used. This may be done using the Rapid Static GPS surveying technique. However, there will be a restriction on the length of the baseline, and recommendations are made concerning the length of the observation session.

A sample GPS cadastral survey has been carried out on several lots in the State of Melaka. The area is chosen closed to the existing Cadastral Standard Traverse along the Melaka-Johor border. The survey area comprised of six (6) cadastral lots (2290, 2291, 2292, 2294, 2296 and 2298) which have been surveyed in Second Class. The area is agricultural land of paddy field where the sky clearance is good enough for GPS survey. The location diagram of the site is shown in Figure 4.

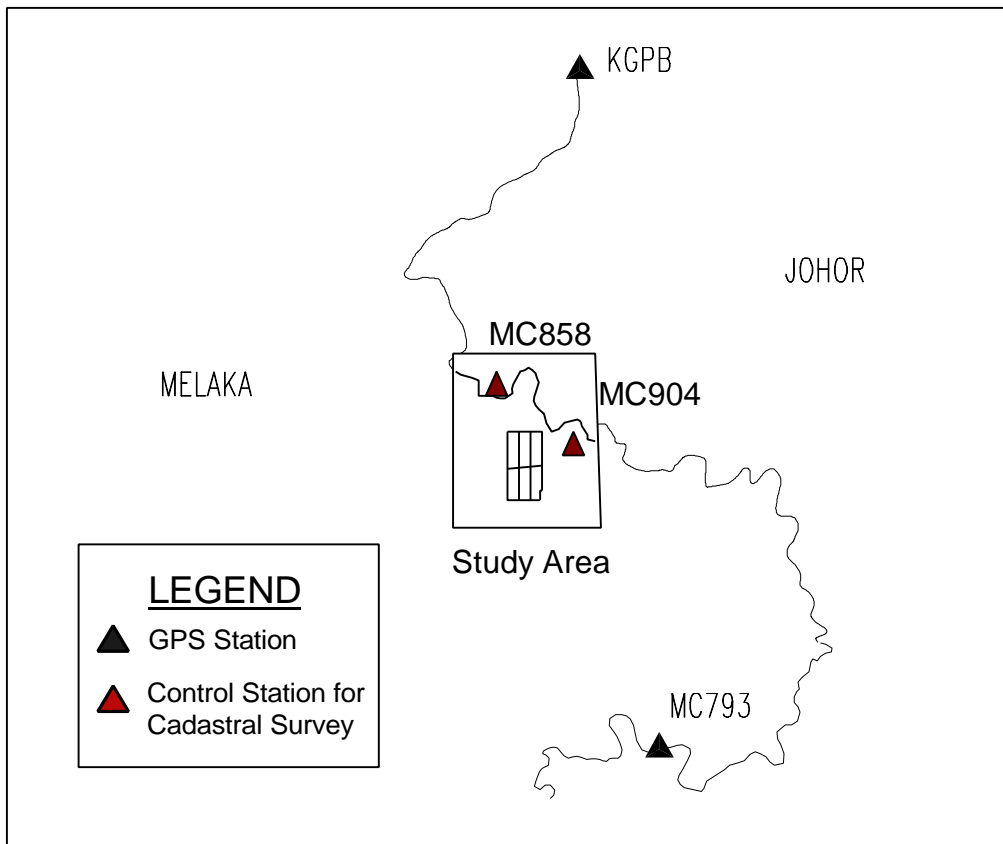


Figure 4 : Test area for GPS cadastral survey

MC793 and KGPB are part of the existing Cadastral Standard Traverse stations which have been occupied by GPS. Those stations were previously connected to the National First Order GPS Network. The adjusted values of coordinate for the stations is given in Table 14 in WGS84.

Station	WGS84		
	Latitude	Longitude	Ellipsoidal Height (m)
KGPB	2° 13' 33".73981	102° 29' 51".72109	5.770
MC793	2° 07' 20".37861	102° 30' 40".55199	3.526

Table 14 : Adjusted coordinates for KGPB and MC793 in WGS84

Since both stations are more than 10km apart (11.6km), they are not suitable to provide control for the proposed GPS cadastral survey on the selected lots which will be carried out using *rapid static* technique. Alternatively, two (2) nearby standard traverse stations namely MC858 and MC904 have been selected to be occupied by GPS for control purposes.

4.1 Control Survey

GPS observation for establishing the control is being carried out by connecting MC858 and MC904 to the existing control stations of MC793 and KGPB. A network of four (4) stations is being observed using GPS *static* technique (1 hour). Since only three (3) GPS receivers available, observations have been done in two sessions (1 new station for each session).

GPS network adjustment has been done in WGS84 using *SKI Software* with stations MC793 and KGPB being held fixed. The resulting coordinates were then being transformed to their corresponding values in local RSO and Cassini. The list of adjusted coordinates for two (2) new GPS stations that will be used to provide control (base station for *rapid static*) for GPS cadastral survey are listed in Table 15.

Station	WGS84	RSO (m)	Cassini (m)
MC904	Lat 2° 10' 8".64950	N 239967.037	N -60989.321
	Long 102° 30' 12".12966	E 500857.333	E 62460.282
	Ell. Height 5.610m		
MC858	Lat 2° 10' 44".04578	N 241057.346	N -59902.881
	Long 102° 28' 58".47236	E 498582.908	E 60183.967
	Ell. Height 5.202m		

Table 15: Adjusted coordinates for two (2) new control stations

4.2 Cadastral Survey with GPS

GPS cadastral survey on the selected lots (see Figure 5) were carried out using *rapid static* technique. Surveys were done using three (3) receivers with two (2) of them remained at the base stations (MC904 and MC858) and another one is roving receiver. The survey was planned so that the fourteen (14) selected boundary marks were occupied successively by the roving receiver. Two base stations have been used to provide independent check on the resulting GPS coordinates for each marker. The GPS observing criteria for the entire surveys is given in Table 16 and the baselines processing has been carried out following the parameters listed in Table 17.

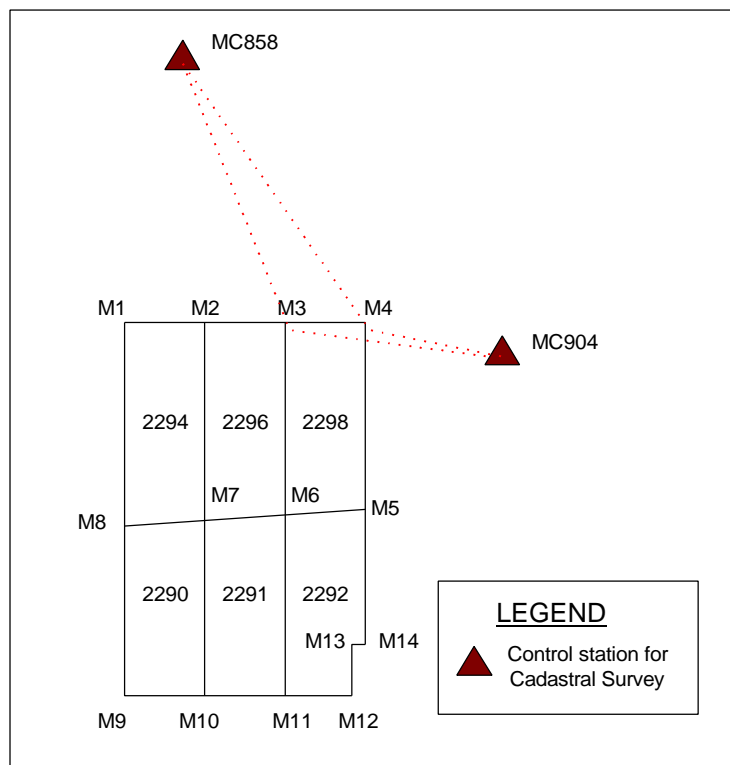


Figure 5 : Test site for GPS cadastral survey using *rapid static* technique (Mukim Sungei Rambai, Melaka)

Reference Station	MC858 (Base I) MC904 (Base II)
Observation period	10 minutes
Recording interval	15 seconds
Number of satellites	≥ 5
GDOP	≤ 6
Sky coverage	$\geq 90 \%$
Cut Off Angle	15°

Table 16 : GPS *rapid static* field observation criteria

Observation period	10 minutes
Ambiguity Resolution	<i>Fixed</i>
Cut Off Angle	15 ⁰
Frequencies used	L1 and L2

Table 17 : Baselines processing parameters for GPS *rapid static*

Two sets of the resulting GPS coordinates for fourteen (14) boundary marks were first computed in WGS84. The first set is referred to base station MC858 (Base I) and another set is referred to base station MC904 (Base II). The coordinates were then transformed into their corresponding values in local Cassini (WGS84-MRT-RSO-Cassini) (Majid Kadir et. al., 1998). List of two sets of Cassini coordinates for each boundary mark are given in Table 18 .

Stn	Base I		Base II		Diff. (mm)	
	N (m)	E (m)	N (m)	E (m)	N(I)-N(II)	E(I)-E(II)
M1	-60819.188	61809.244	-60819.189	61809.247	1	-3
M2	-60819.630	61853.070	-60819.640	61853.073	10	-3
M3	-60823.116	61895.421	-60823.119	61895.424	3	-3
M4	-60825.366	61922.758	-60825.368	61922.762	3	-3
M5	-60946.291	61928.587	-60946.293	61928.590	2	-3
M6	-60950.479	61891.854	-60950.483	61891.855	3	-1
M7	-60954.757	61854.418	-60954.759	61854.419	2	-1
M8	-60959.671	61811.432	-60959.674	61811.433	3	-1
M9	-61158.919	61814.636	-61158.922	61814.635	3	1
M10	-61155.081	61857.135	-61155.085	61857.130	3	5
M11	-61152.312	61900.138	-61152.310	61900.142	-1	-4
M12	-61150.356	61930.428	-61150.361	61930.425	6	3
M13	-61121.911	61928.846	-61121.916	61928.849	6	-3
M14	-61122.017	61936.025	-61122.026	61936.029	9	-4
				Max (mm)	10	5
				Min (mm)	1	1
				RMS(mm)	3	3

Table 18: Differences between two sets of coordinates in Cassini (Base I values refer to MC858 and Base II refer to MC904)

Table 18 shows that RMS differences of 3mm is being achieved in both components (Easting and Northing) which indicates the potential of GPS *rapid static* technique to be used for GPS cadastral survey.

Further analysis has been done by calculating the area for individual lot and comparing with their corresponding values shown on the Certified Plans (see Table 19).

Lot Number	Computed (GPS) Area (m²)	Existing (CP) Area (m²)	Diff. (m²)
2290	8,552	8,551	1
2291	8,107	8,108	-1
2292	7,312	7,312	0
2294	5,985	5,985	0
2296	5,235	5,236	-1
2298	3,978	3,978	0
Total	39,169	39,170	-1

Table 19 : Area comparison between computed (GPS) and CP values

Table 19 indicates that in general differences of less than 1m² could be achieved for lot area of less than 1hectare (less than 1% difference). Again this shows the potential of using *rapid static* technique in GPS cadastral survey.

Conclusion

Results from this studies indicate that the proposed GPS Cadastral Survey Guidelines could be used as a guide in carrying out GPS cadastral surveys in Malaysia. The Guidelines will be adopted by the DSMM as a standard practices to be followed by the surveyors in carrying out cadastral surveys using GPS. A series of workshop or training session is being conducted by the DSMM in giving exposure to the cadastral surveyors to get familiar with this new technique in conducting cadastral surveys. It is necessary at this stage to educate the cadastral surveyors on the beauty and simplicity of using GPS surveying technique without being haunted by the complexity of the system. Similar to those that already exist EDM-theodolite technique, the GPS technology will be soon accepted as an alternative tool for cadastral surveys. It will not replace the existing survey techniques but it will provide another means in carrying out cadastral surveys especially in the area where conventional technique is not economical. Furthermore it has been proven that GPS technique provides an excellent way for cadastral coordinates transfer purposes.

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