Bil. Kami : KTPK 18/4/2.01. Jld. 5 (21)
Tarikh : 9 Oktober 1999

Semua Pengarah Ukur dan Pemetaan Negeri

Tuan,

PEKELILING KETUA PENGARAH UKUR DAN PEMETAAN BIL. 6/1999

GARIS PANDUAN PENGUKURAN MENGGUNAKAN ALAT SISTEM PENENTUDUDUKAN SEJAGAT (GPS) BAGI UKURAN KAWALAN KADASTER DAN UKURAN KADASTER.

1.0 TUJUAN

Pekeliling ini bertujuan untuk membenarkan penggunaan serta menetapkan kaedah dan cara menggunakan alat sistem penentudukan sejagat (GPS) bagi ukuran kawalan kadaster dan ukuran hakmilik tanah bagi kawasan luas dan terpencil.

2.0 LATAR BELAKANG

2.1 Perkembangan pesat dalam bidang ukur satelit telah memungkinkan penggunaan teknologi GPS dalam kerja-kerja ukur kadaster. Berdasarkan kepada beberapa hasil kajian yang dijalankan dalam penggunaan sistem penentudukan sejagat (GPS) bagi menentukan kedudukan titik-titik di permukaan bumi, membuktikan bahawa sistem tersebut mampu memberikan kejituan yang tinggi yang diperlukan dalam ukuran kadaster.

2.2 Justeru itu keupayaan sistem ini sewajarnya dimanfaatkan sepenuhnya termasuk dalam melaksanakan keria-kerja ukuran kadaster yang memerlukan kepada ketepatan dan kejituan yang tinggi.

2.3 Oleh yang demikian penggunaannya di JUPEM terutamanya dalam menentukan kedudukan stesen-stesen ukuran kawalan dan juga ukuran hakmilik tanah memerlukan satu garis panduan yang standard bagi mempastikan kejituan yang dikehendaki dalam ukuran diperolehi.

3.0 GARIS PANDUAN PENGUKURAN KADASTER MENGUNAKAN TEKNIK GPS

Amalan dan kaedah menjalankan ukuran kadaster sepertimana yang dinyatakan dalam buku garis panduan di **Lampiran 'A'** melibatkan perkara-perkara penting yang perlu dipatuhi antaranya adalah seperti berikut**;**

Perenggan ***Perkara***

2.0 GPS Instrumentation

- ***2.1 Receiver Requirements***
- ***2.2 Antenna and Cabling Requirement***
- ***2.3 Data Recording Recommendations***
- ***2.4 Software Recommendations***

3.0 GPS Equiptment Calibration Procedures

- ***3.2 Zero Baseline Test***
- ***3.3 EDM Baseline Test***
- ***3.4 GPS Network Test***

4.0 GPS Cadastral Control Survey

- ***4.2 Field Procedures***
- ***4.3 Office Procedures***
  - ***4.3.1 Data Handling Procedures***
  - ***4.3.2 Baseline Computation Procedures***
  - ***4.3.3 Network Computation Procedures***
  - ***4.3.4 Coordinates Transformation Procedures***
- ***4.4 Final Survey Report Preparation***

5.0 GPS Cadastral Survey

- ***5.2 Field Procedures***

4.0 KAEDAH DAN PROSEDUR UKURAN

4.1 Ukuran Kawalan Kadaster Menggunakan GPS

4.1.1 Ukuran menggunakan teknik GPS merupakan metodologi dimana nilai-nilai koordinat diperolehi sama ada daripada stesen-stesen geodetik atau tanda-tanda sempadan kadaster sedia ada. Ianya memerlukan penggunaan teknik ***Static GPS surveying*** yang menghadkan panjang jarak bagi garisan asas dan sessi cerapan dibuat dalam jangka masa yang bersesuaian. Bearing dan jarak garisan terabas piawai didapatkan daripada nilai-nilai koordinat yang diperolehi daripada cerapan menggunakan teknik tersebut.

4.1.2 Prosedur kerja ukuran hendaklah mematuhi perkara-perkara yang digariskan dalam **buku garis panduan** seperti berikut;

i) Prosedur kerjaluar - perenggan 4.2

ii) Prosedur pejabat - perenggan 4.3
iii) Penyediaan laporan akhir ukuran - perenggan 4.4 (Appendix A.13)

4.2 Ukuran Kadaster Menggunakan GPS

4.2.1 Ukuran bagi tujuan memperolehi nilai-nilai koordinat tanda-tanda sempadan lot yang berhubungkait dengan stesen GPS yang berhampiran (diujudkan melalui ukuran kawalan). Bering dan Jarak sempadan lot yang dikehendaki diukur kemudiannya didapatkan daripada nilai-nilai koordinat yang boleh diperolehi dengan membuat cerapan menggunakan teknik ***Rapid Static GPS Surveying***.

4.2.2 Prosedur kerja ukuran hendaklah mematuhi perkara-perkara yang digariskan dalam **buku garispanduan** saperti berikut;

i) Prosedur kerjaluar - perenggan 5.2
ii) Prosedur Pejabat - perenggan 5.3
iii) Penyediaan Laporan ukuran akhir - perenggan 5.4 (Appendix A.13)

4.3 Penyediaan Pelan akui

Penyediaan Pelan Terabas Piawai bagi ukuran kawalan kadaster dan Pelan Akui bagi ukuran kadaster hendaklah mematuhi Pekeliling KPUP yang sedang berkuatkuasa.

5.0 TARIKH BERKUATKUASA

Pekeliling ini berkuatkuasa mulai dari tarikh pengeluarannya.

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA"

(DATO' ABDUL MAJID BIN MOHAMED)
Ketua Pengarah Ukur dan Pemetaan
Malaysia

Salinan kepada;

Timbalan Ketua Pengarah Ukur dan Pemetaan
Pengarah Ukur Bahagian (Pengurusan dan Pembangunan)
Pengarah Ukur Bahagian (Penyelarasan Kadaster)
Pengarah Ukur Bahagian (Pengeluaran Pemetaan)
Pengarah Ukur Bahagian (Ukur Geodetik)

Setiausaha ,
Lembaga Juruukur Tanah Semenanjung Malaysia

LAMPIRAN 'A'

JABATAN UKUR DAN PEMETAAN MALAYSIA

GPS CADASTRAL SURVEY GUIDELINES

SEMENANJUNG MALAYSIA

1999

CONTENTS

APPENDICES

1.0 INTRODUCTION

With increasing interest being shown in using the GPS technology for all forms of positioning, including in relation to cadastral surveys, it was deemed necessary that surveyors should be provided with guidelines on the recommended practices for the use of GPS. GPS Cadastral Survey Guidelines was specifically developed to provide recommended practices for the use of GPS in cadastral surveying in Peninsular Malaysia, similar to those that already exist for EDM-theodolite procedures. These “recommended practices” provide a means of ensuring the highest quality practices are adhered to with regard to surveys pertaining to land boundaries and title. Guidelines are provided in this document with regards to the following:

- The selection of GPS instrumentations (hardware and software requirements).
- The testing/calibration of GPS equipment.
- Recommended GPS cadastral control survey procedures.
- Recommended GPS cadastral survey procedures.

However, several issues unique to the GPS technology need also be addressed. For example, reference must also be made to the coordinate system that prevails with respect to cadastral practice in Malaysia, and relating that to the coordinate system implicit to the GPS technology. In addition, the "type" of GPS surveying technique, and how it is used for various cadastral surveying tasks, must also be carefully elucidated. Finally, the manner in which the GPS results are "processed" within a least squares procedure, to derive the optimal coordinate results and to transform these to conventional survey quantities such as bearings and distances, must be defined without ambiguity.

Sources of information and advice on the use of GPS technology can be found from many sources, and the surveyor is encouraged to take advantage of them. However, where such advice conflicts with that explicitly given in these guidelines, the surveyor should follow these guidelines in preference to other advice to the contrary. The reader is referred to **Appendix A.1** for discussion on “GPS Surveying Techniques” and **Appendix A.14** for “Recommended Reading and GPS Websites”.

2.0 GPS INSTRUMENTATION

GPS satellite surveying instrumentation issues relate to the following four major functional components: the receiver/processor, the antenna, the recording unit and the data processing software. The following requirements shall be fulfilled regarding the GPS instrumentation to be used for all aspects of the cadastral survey.

2.1 Receiver Requirements

1. The GPS receivers to be used for cadastral surveys must have the capability of measuring the phase on <u>both</u> GPS carrier frequencies (the so-called L1 frequency of 1575.42MHz, and the L2 frequency on 1227.60MHz). *That is, only "dual-frequency GPS receivers" should be used*.

2. The receiver must record the phase of the satellite signals, time-tagged with respect to the receiver clock time. *No "real-time" GPS surveying systems are to be used unless the raw measurement data can be recorded for post-processing*.

3. The receiver should have the capability to track a minimum of six GPS satellites simultaneously. However, it is srongly recommended that the GPS receivers be selected such that measurements to all satellites that are simultaneously in view can be made.

4. No mixing of receiver type shall be allowed. *That is, all receivers must be of the same brand*.

5. The receivers should be capable of displaying an indication of proper operation and data quality.

2.2 Antenna and Cabling Requirements

1. The antenna should be chosen such that inconsistencies such as electrical phase centre variations and mitigate multipath disturbances are minimised. *It is recommended that the manufacturer's "survey-grade" antenna be used*.

2. Antennas should be tested as part of the "zero baseline test", so as to satisfy the surveyor that the error budget for the survey is not exceeded.

3. Different antenna types (even if they are of the same GPS brand) should not be used together in a baseline observation session.

4. The maximum length and type of antenna cable should be that defined by the manufacturer's specifications. In order to maximise the chances of good quality raw measurements are made, the antenna cable (and especially the connectors) should be kept clean and in good condition.

5. It is strongly recommended that a particular antenna, receiver and associated cabling be always be operated together as a "kit". *This is especially important during testing procedures*.

2.3 Data Recording Recommendations

1. The maximum data recording rate for GPS receivers shall be 30 seconds. 15 seconds may be used for *Rapid Static* positioning.

2. The receiver must have suitably sized of memory capacity for the recording of data collected in the field over a whole working day.

3. The recorded measurement data should be download immediately following the field survey on to storage media such as PC harddisks, floppy disks, etc. Backups of the data files should be made and stored in separate media.

2.4 Software Recommendations

1. The manufacturer's data processing software should be used for all baseline computations. Although it is not necessary that the latest data processing software be used, it is the responsibility of the surveyor to ensure that any upgrade to the GPS receiver hardware or firmware does not diminish the quality of the baseline results obtained using his operational software.

2. The installation, operation and validation of the software should be according to the manufacturer's instructions. All problems concerning the software should be referred to the GPS agent for advice and/or resolution.

3. All data processing should follow the standard options offered within the processing software.

4. The surveyor should only use ancillary options in the GPS software (such as datum transformation, least squares network adjustment, determination of projection distances and bearings, etc.) only after extensive testing to validate the models used. *(These guidelines do not prescribe the nature and extent of the testing to be undertaken, but*

it is recommended that documentary test/validation evidence be maintained in the event of an audit.)

3.0 GPS EQUIPMENT CALIBRATION PROCEDURES

3.1 Preamble

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 :

- Has carried out the various test/calibration procedures as required by this Guidelines.

- The survey has followed the "recommended practices for field and office procedures" as described in this 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 are described in the sub-sections below, and are summarised as follows:

- The application of a zero baseline test should be a routine undertaking (see §3.2).

- Regular calibration of the GPS equipment on an EDM baseline (see §3.3).

- A network of stations should be surveyed on a less regular basis (the network may include the existing First Order Geodetic GPS control stations) (see §3.4).

3.2 Zero Baseline Test

1. A **zero baseline test** should be performed to ensure the correct operation of the receivers, antennas, cabling and software.

2. The test shall be carried out by connecting two (2) GPS receivers to the same antenna, using an antenna cable-splitter appropriate for the brand of receiver/antenna (as recommended by the GPS manufacturer).

3. The test shall be used to verify the precision of the receiver measurements (and hence its correct operation), as well as validate the data processing software.

4. Zero baseline test should be performed before any GPS cadastral survey activity is carried out.

5. The experimental setup of the zero baseline test as described in **Appendix A.3** should be followed.

6. The test may be carried out any place where it is convenient, but should be carried out at a site with at least 90% sky visibility.

7. The test should be performed for a minimum of ten (10) minutes observation session, with at least 15 seconds recording interval.

8. The receivers should track at least five (5) satellites during the test session with a GDOP of less than six (6).

9. Cut-off angle of fifteen degrees (15°) should be applied during the baseline processing.

10. The resulting (computed) slope distance between the two (2) receivers being tested must be less than **three (3) millimetres**. *If this tolerance is not met the test should be repeated or the equipment sent to the GPS agent for further testing*.

11. The test should be applied twice, for both antennas.

A sample is given in **Appendix A.4**.

3.3 EDM Baseline Test

1. An **EDM baseline test** should be performed to ensure the correct operation of a pair of GPS receivers (and data processing software) that will be used for baseline measurement.

2. The GPS instrumentation shall be tested on an EDM baseline that itself has been calibrated to a local standard of distance using a special a high quality EDM instrument.

3. The test shall be used to study the precision of the receiver measurements (and hence its correct operation), as well as validate the data processing software.

4. EDM baseline test should be performed on a *six monthly basis* or prior to any large survey campaign being carried out.

5. The test should be carried out at an established EDM baseline test site, by occupying pillars with at least 90% sky visibility.

6. The experimental setup of the EDM baseline test as described in **Appendix A.5** should be followed.

7. The GPS receivers should be tested against the established EDM baseline lengths (between pillars), varying from twenty (20) metres to about one (1) kilometre.

8. Each GPS receiver is to be connected to its designated antenna (mounted on the pillar) using the same antenna cable used during surveys.

9. The test should be performed for a minimum of ten (10) minutes observation sessions.

10. The receivers shall track at least five (5) satellites during the test session with a GDOP of less than six (6).

11. Cut-off angle of fifteen degrees (15°) should be applied during the baseline processing.

12. The resulting difference in slope distance between the GPS measurement and the standard must be less than **ten (10) millimetres**. *If this tolerance is not met the test should be repeated, and if the equipment fails again the instrument should be returned to the GPS agent for repair*.

A sample is given in **Appendix A.6**.

3.4 GPS Network Test

1. A **network test** should be performed to assure the operation of the GPS instrumentation for the purpose of determining high accuracy relative coordinates.

2. The GPS instrumentation must be tested on part of the established high order geodetic network (DSMM Report, 1994, “GPS Derived Coordinates”). The network should include a minimum of three (3) existing First Order GPS Control stations as described in the above DSMM report (1994).

3. The network test should be carried out on an *annual basis*, or when the receiver's firmware or post-processing software is upgraded to a new version. In the later case, the test should include the Zero Baseline Test and EDM Baseline Test.

4. The experimental setup of the network test as described in **Appendix A.7** should be followed.

5. The network test could be carried out over several GPS observation sessions. More than one pair of GPS equipment could be used at the same time.

6. The test should be carried out on a station network with at least 90% sky visibility.

7. The network test should be carried out using the *Static* positioning method, with at least two (2) hours observation sessions. All other recommended procedures should be followed (as defined in these guidelines).

8. The receivers shall track at least five (5) satellites during the observation session with a GDOP of less than six (6).

9. Cut-off angle of fifteen degrees (15°) should be applied during the baseline processing.

10. The minimally constrained network adjustment should be carried out using the computed baselines expressed in the WGS84 datum.

11. The final coordinates should be given in the established local system. The recommended coordinate transformation procedure should be followed (see §4.3.4).

12. The maximum allowable discrepancy between the surveyed coordinates (observed GPS values) and the true coordinates (established values) for the network test must be less than **ten (10) millimetres** in the horizontal component *or* relative accuracy of better than **a + bL millimetres** (a=5mm, b=2ppm, L= baseline length in kilometres), and less than **twenty (20) millimetres** in the vertical component. If this tolerance is not met, the surveyor will be required to validate the results by repeating the test again. If the test fails *again* the datasets and results should be validated by the Geodetic Authority. If the results are still outside tolerance it is advised that the surveyor proceed to carry out zero baseline and EDM baseline tests, or the equipment sent to the GPS agent for further testing.

13. It is suggested that before such network testing is carried out the optical plummet within the instrument tribrachs be tested (**Appendix A.2**), and that zero baseline testing (§3.2) be performed.

A sample is given in **Appendix A.8**.

4.0 GPS CADASTRAL CONTROL SURVEY

4.1 Preamble

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.

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. (Recommendations relating to GPS Cadastral Survey are given in section 5).

4.2 Field Procedures

The recommended field practices for the GPS Cadastral Control Survey are a combination of guidelines for designing which stations/marks are to be occupied by the GPS receivers, the field procedures and documentation to be insisted upon during the data collection process itself. The former are best illustrated by reference to the Case Study (**Appendix A.9**). The latter are essentially those procedures which *must* be followed for Static GPS surveying, and which are intended to supplement the general "good practice" guidelines normally found in the GPS user manual. In this document attention will also be focussed on the fieldbook and other forms of documentation which are insisted upon.

The recommended field practices for GPS Cadastral Control Surveying are summarised below:

1. GPS cadastral control survey baselines must be less than 30 kilometres in length, but longer than 50 metres.

2. Only carrier phase observations using two (or more) receivers are considered.

3. The control survey should be carried out in *Static* mode with minimum observation session lengths of 60 minutes.

4. Satellite geometry implies that a minimum of five (5) satellites must be in view of both receivers for the entire session.

5. Sky coverage should be at least 60%, with telescopic antenna poles of up to 10m being allowed.

6. The elevation mask angle should not be less than 15°.

7. The measurement data recording rate is recommended to be 30 seconds or faster.

8. All points must be surveyed using two independent baselines, from two or more First Order GPS geodetic control stations and a minimum of one "proven" cadastral control mark. *If a GPS Cadastral Survey is to be undertaken, then a minimum of two points must be established, which will function as the nearby GPS control. Such nearby control may be used as the GPS base station(s) from which the boundary points are radiated* (see **Appendix A.10** for the Case Study).

9. Users should follow the recommendations set out in the manufacturer's manuals, unless they contradict this guidelines, this guidelines will take precedence.

10. All ancillary equipment must be in good adjustment and repair, and operated competently by trained personnel. The required equipment should be in good order before observation, following the sample of an **Instrument Checklist** as given in **Appendix A.12**.

11. A clear and comprehensive fieldbook format should be used. Sample of a **Log Sheet** given in **Appendix A.12** should be followed, which provides for a **GPS Station Occupation Report**.

12. A **Field Observation Checklist** must also be included in the **Log Sheet**. The checklist (see **Appendix A.12**) is important to ensure that the proper procedure is followed during the collection of GPS observations.

13. Station description must also be given in the form of a **Site Sketch** which should be included in the sample **Log Sheet** (as shown in **Appendix A.12**).

4.3 Office Procedures

The survey is far from over when the coordinated field data collection by two or more GPS receivers is completed. The steps that are followed, and guidelines related to these, are listed below.

4.3.1 Data Handling Procedures

1. Download GPS observation data as soon as possible. *Most GPS receivers have many hours of internal memory, so daily download is a routine that should be followed*.

2. Follow data download procedures as set out in the GPS user manual.

3. Download to PC harddisk, then to floppy disks, then make backup copies. Store backup disks separately. Label and write-protect floppy disks.

4. Delete files from receiver memory only when data download procedure has been verified. Verify data download, for example by checking number and size of files.

5. Cross-reference fieldbook and log sheets to data files, and maintain with project documentation.

It is strongly recommended that data processing commence as quickly as possible.

4.3.2 Baseline Computation Procedures

The baseline computation procedure is generally described in the GPS user manual. These prescribed steps must be followed. The only issues that need to be explicitly addressed are how the GPS coordinates for one of the stations in the survey are obtained, and what level of data quality validation should be performed at the single baseline computation level. The former is considered in sub-section §4.3.4. As far as the latter is concerned, there are a number of "quality indicators" that may be considered:

- "Root mean square" (RMS) of the observation residuals.
- Number of rejected observations.
- Statistical tests on observation residuals or solution parameters.
- Aposteriori variance factor.
- Variance-Covariance (VCV) matrix of solution.
- The type of baseline solution obtained, and its "trustworthiness".

With respect to the "RMS of residuals" and "rejected observations", the following are recommended:

1. A "low" RMS value and a "low" number of rejected observations often indicate that both the data and solution quality are OK.

2. The GPS user manual often gives recommended maximum values of RMS for a satisfactory baseline solution. *In general, an RMS value below 0.1 cycles (or about 2cm) is considered acceptable*.

3. Data editing is often carried out during solution iterations. This is generally based on some factor, for example 3 x RMS value. Possible reasons for high RMS and data rejection rates are the presence of multipath and uncorrected cycle slips. *Data rejection rates of greater than 10% should be viewed with suspicion, and in such cases the baseline flagged as possibly being of poor quality (though this can only be confirmed at the network computation step)*.

4. Some phase data processing software permits the residuals to be plotted. *In this case it is good practice to plot the residuals and examine whether the pattern is uniformly random*.

With respect to the "statistical tests" and "VCV information", the following are recommended:

1. In general, little statistical testing is carried out on parameters or observation residuals.

2. If the aposteriori variance factor is unity then it is likely that the VCV matrix has been *adaptively* scaled to ensure this happens.

3. In general, however, the output VCV matrix is too *optimistic* , suggesting higher precisions for the parameters than is warranted. This is because the solution does not take into account unmodelled systematic biases (atmospheric refraction, satellite orbit and fixed station errors, etc.) and the correlations between observations. *At the network computation step the VCV matrix will have to be scaled by a factor approximately equal to the network adjustment aposteriori variance factor so as to better reflect the true baseline accuracy*.

4. The standard deviations of baseline components may vary as a function of whether the baseline is a result of a double-difference ambiguity-free (or as it is sometimes referred: "bias float") solution, or a double-difference ambiguity-fixed (or "bias fixed") solution.

There are other several quality indicators related to the "solution characteristics":

1. What is the "optimal" solution? Was a "bias fixed" solution obtained? The "bias fixed" solution is preferred, because it is of higher precision and, if the ambiguity resolution process has been correctly carried out, it is also of higher accuracy.

2. If more than four satellites were tracked for 60 minutes, and there are no breaks in the data record, then for baselines up to 30km it is likely that the solution was a "bias fixed" one. However, were the ambiguities resolved correctly? *Check carefully the output of the baseline processing to see if there is a message indicating doubt about the resolved ambiguities*.

3. If a "bias fixed" solution was obtained, check baseline components. For example, did the baseline solution change by more than 10cm compared to the ambiguity-free solution? *If it did the baseline should be flagged as possibly being of poor quality (though this can only be confirmed at the network computation step).*

4. The formal accuracy estimates for the vertical component is usually twice the magnitude of the horizontal components.

5. Verify (and note) solution characteristics as output in the solution summary file, such as:

   i. Satellites that were used --> *were there less than expected?*
   ii. Data recording rate --> *were there less than expected?*
   iii. Common tracking period --> *as planned, 60 minutes?*
   iv. Apriori station coordinates --> *were the correct WGS84 values used?*
   v. Antenna heights --> *were they correct, according to the field sheets?*
   vi. Elevation mask angle --> *was this correctly set to 15°?*
   vii. What was the satellite geometry indicator --> *PDOP, RDOP, etc.*

4.3.3 Network Computation Procedures

In general, a GPS survey campaign involves the use of a small number of receivers (generally just two) to coordinate a number of stations such that the survey has to be carried out over a number of sessions, each contributing one baseline (per pair of receivers). Hence, to obtain two independent baselines per cadastral station being coordinated two sessions would be required if using two GPS receivers. If three GPS receivers could be deployed simultaneously, two could be sited on known control points (geodetic control stations or cadastral marks) and the third on the cadastral station being coordinated. In general, however, the following are recommended:

1. A GPS control survey involves two types of solutions: a primary adjustment at the single baseline level of the GPS observables, and a secondary adjustment that treats the baseline solution output by the primary adjustment as an observation.

2. The mathematical models used for the adjustment of the independent baseline "observations" within a network shall be based on the theory of least squares adjustment. (Commercial GPS processing software is generally capable of both single baseline determination and network processing of measured baselines, hence obviating the need for specialist network adjustment software.)

3. The methodology is very similar to conventional network adjustments of geodetic observations such as distances, except for the fact that 3-D quantities (the baseline components) are involved. *Hence skill in conventional least squares network adjustment can be applied to assuring the quality of the adjustment*.

4. There must be enough independent baselines so that the redundancy is sufficient to carry out a network adjustment. *As a rule-of-thumb,there should be twice the number of observations than there are parameters to adjust.*

5. The form of network adjustment is known as a "minimally constrained" adjustment, in which the coordinate of only one of the known geodetic control stations or cadastral control marks is held fixed. *The fixed coordinate must be in the geocentric datum such as WGS84*.

6. There are a number of "quality indicators" that may be monitored during the network adjustment, including:

    i. RMS of the baseline observation residuals --> *these should not be more than a factor of 10 greater than the standard deviations of the baseline components from the primary adjustment.*
    ii. Number of rejected baselines --> *these should be checked to verify that they are "outlier" observations, e.g. were they flagged as suspect at the single baseline determination step?*
    iii. Statistical tests on residuals or parameters --> *these are generally applied and should be studied to see if they are satisfactory.*

iv. Aposteriori variance factor --> *this value should pass the Chi squared test at the appropriate level, and if it doesn't the baseline VCV matrices must all be scaled by the aposteriori variance factor.*

v. VCV matrix of solution --> *this reflects the baseline observation VCVs and will reflect more realistic values <u>after</u> scaling of the VCVs by the aposteriori variance factor.*

4.3.4 Coordinates Transformation Procedures

1. The resulting GPS coordinates are in a geocentric datum such as WGS84, and need to be transformed into the established local cadastral coordinate system. The existing coordinate system used for cadastral survey in Semenanjung Malaysia is the local *Cassini Soldner* System.

2. The transformation process comprises the following steps:

   i. Coordinate transformation from WGS84 to local Malayan Revised Triangulation System (MRT).

   ii. Coordinate transformation from local MRT system to the existing local Rectified Skew Orthomorphic Projection System (RSO).

   iii. Coordinate transformation from RSO system to the local Cassini Soldner System (Cassini).

3. Transformation from WGS84 to MRT should be carried out as follows:

   i. The Bursa-Wolf mathematical model should be used. (The detailed of the related formula are given in **Appendix A.11**.)

   ii. The local MRT system should be referenced to the Modified Everest ellipsoid. (Parameters defining the reference ellipsoid are given in **Appendix A.11**.)

   iii. The official seven (7) transformation parameters should be used. Three (3) are the translations parameters, another three (3) are the rotation parameters, and one (1) is the scale factor. (The values of these parameters are given in **Appendix A.11**.)

   iv. The standard algorithm that has been developed for the purpose should be used for the transformation.

4. Transformation from MRT to RSO should be carried out as follows:

   i. The mathematical model that should be used is based on the formula published in the *Projection Tables for Malaya*. (The details of the related formula are given in **Appendix A.11**.)

   ii. The RSO is also based on the Modified Everest reference ellipsoid. (Parameters defining the reference ellipsoid are given in **Appendix A.11**.)

   iii. The origin for the RSO projection system is based on the geographical coordinates of *Kertau* (see **Appendix A.11**).

   iv. The related parameters found in the *Projection Tables for Malaya* should be used. (The list of the parameters used in this transformation are given in **Appendix A.11**.)

   v. The standard algorithm that has been developed for the purpose should be used for the transformation.

5. Transformation from RSO to Cassini should be carried out as follows:

   i. The mathematical model that should be used is based on the formula given in **Appendix A.11**.

   ii. Cassini is a plane coordinate system for cadastral purposes. A number of origins have been adopted when establishing local Cassini projection systems, resulting in each Peninsular Malaysia State using a different origin. (The list of States' origins are given in **Appendix A.11**.)

   iii. The related parameters used in the transformation are given in **Appendix A.11**.

   iv. The standard algorithm that has been developed for the purpose should be used for the transformation.

4.4 Final Survey Report Preparation

1. It shall be the responsibility of the surveyor to supply sufficient information in the report to facilitate evaluation of the quality of the survey.

2. A description of the GPS cadastral control survey that was carried out should be supplied, and include such information as:

   i. A description of the survey location
   ii. The aim of the survey
   iii. Number of occupied points
   iv. A sketch of the survey area including all occupied stations

3. A clear description of the GPS field survey procedure should be supplied, and include such information as:

   i. The time and time span of observations
   ii. Details of the instrumentation used, such as the serial numbers and type of the receivers and antennas used
   iii. Site occupation plan/sketch
   iv. Auxiliary information such as logistics and personnel involved
   v. A diary detailing work accomplished and difficulties encountered

4. There shall also be a clear description of the office procedures used, including:

   i. The software used to process the observations
   ii. The options used in baseline processing, data editing performed, and source of orbital data
   iii. Information on the parameters adjusted and held fixed, and quality control checks performed during the adjustment
   iv. All parameters for any datum transformations used, with worked examples

5. The survey results shall be presented, together with the following items:

   i. The adjusted three-dimensional coordinates of the control stations to the nearest millimetre
   ii. Specification of the coordinate system used
   iii. A full variance-covariance matrix of the adjusted parameters
   iv. A statistical evaluation of the survey results, including analysis of the variance factors, residuals, and outliers
   v. The results of all relevant stages in the data processing shall be included along with all data reliability information compiled throughout the survey

A sample is given in **Appendix A.13**.

5.0 GPS CADASTRAL SURVEY

5.1 Preamble

GPS Cadastral Survey requires the coordinates to be determined of the land parcel, in relation to a nearby GPS mark (established by the Control Survey). *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.

5.2 Field Procedures

The recommended field practices for the GPS Cadastral Survey are, as in section §4.2, a combination of guidelines for designing which stations/marks are to be occupied by the GPS receivers, and the field procedures and documentation to be insisted upon during the data collection process itself. The former are best illustrated by reference to the Case Study (**Appendix A.10**). The latter are essentially those procedures which *must* be followed for Rapid Static or Static methods of GPS survey, and which are intended to supplement the more general "good practice" guidelines normally found in the GPS user manual. In this document particular attention will also be drawn to the fieldbook and other forms of documentation which are insisted upon.

The recommended field practices for GPS Cadastral Surveying are summarised below:

1. GPS cadastral survey baselines must be less than five (5) kilometres in length, but longer than 50 metres.

2. Only carrier phase observations using two (or more) receivers are considered.

3. The survey may be carried out in either the *Static* mode or *Rapid Static* mode. Minimum survey sessions of 30 minutes in length are required for the *Static* mode (or that specified in the GPS user manual, whichever is longer), and at least ten (10) minutes observation session for the *Rapid Static* mode (or that specified in the GPS user manual, whichever is longer).

4. Satellite geometry implies that a minimum of five (5) satellites must be in view of both receivers for the entire session.

5. Sky coverage should be at least 60%, with telescopic antenna poles of up to 10m being allowed.

6. The elevation mask angle should not be less than 15°.

7. The data recording rate is recommended to be 15 or 30 seconds.

8. All points must be surveyed using two independent baselines (see **Appendix A.10** for the Case Study).

9. Users should follow the recommendations set out in the manufacturer's user manual(s), unless they contradict this guidelines, this guidelines will take precedence.

10. All ancillary equipment must be in good adjustment and repair, and operated competently by trained personnel. (A sample **Instrument Checklist** is given in **Appendix A.12**.)

11. A suitable fieldbook format should be defined. (A sample of a **Log Sheet** is given in **Appendix A.12**.)

12. A **Field Observation Checklist** should be included with the **Log Sheet**. This may be identical to that used for GPS Cadastral Control Surveying when using the *Static* mode. If the *Rapid Static* mode is used, an abbreviated version may be used.

13. Station discription should be given in the form of a **Site Sketch** which may be included in the sample **Log Sheet** (as being shown in **Appendix A.12**.)

5.3 Office Procedures

5.3.1 Data Handling Procedures

These are identical to those in §4.3.1.

5.3.2 Baseline Computation Procedures

The same baseline computation procedures should be followed as in §4.3.2 when the *Static* surveying mode is used. In the case of the *Rapid Static* surveying mode, the following are recommended:

1. Only ambiguity-fixed (or "bias fixed") solutions will be accepted. *If the baseline processing indicates that the solution is unreliable then it will be assumed that the survey has "failed" and that the baseline must be reobserved*.

2. The preferred method of GPS survey is the "radiation" of the point of interest from two GPS base stations. *If three GPS receivers are used, two of them may be set up on the base stations while the third is used to survey the boundary points.*

3. This survey methodology is best illustrated by reference to the Case Study (**Appendix A.10**).

4. The two sets of coordinates obtained for each point surveyed, one from each base station, should be within **two (2)** cm of each other (in 3-D position).

5. The "adopted" solution for the point's coordinates is the mean of the two sets of coordinates.

5.3.3 Network Computation Procedures

A network computation procedure need not be applied. If the surveyor does chose to perform a least squares network adjustment, the office procedures outlined in §4.3.3 should be followed. However, it is acceptable to simply take the "adopted" solution for each point from the double radiation (a baseline from each GPS base station). After transforming the coordinates to the Cassini system, the bearings and distances may be derived using the standard formulae (**Appendix A.11**).

5.3.4 Coordinates Transformation Procedures

These are identical to those given in §4.3.4.

5.4 Final Survey Report Preparation

See **Appendix A.13** for a sample.

APPENDIX A.1
GPS Surveying Techniques

In typical surveying applications interest is in determining the position of one or more fixed points, which are usually monumented -- either permanently or temporarily. Often it is the horizontal coordinates of points (a two-dimensional application) that are required, although alternatively there may only be interest in heights (a one-dimensional application), or in all three coordinates. Furthermore, surveyed positions were usually relative, that is, surveyors determine them with respect to the coordinates of one or more other points. The typical surveying technology is capable of distance and/or direction measurements, these days integrated within a single instrument such as a "total station" or "EDM tacheometer". However, the major weakness of such traditional *terrestrial* surveying technology is that all points must be intervisible, that is, there must be a line-of-sight between surveyed points. This has restricted the efficiency of such technology, as the separation of surveyed points must be both short enough to be within the range of distance (typically <10km for standard EDM) or direction (<30km under ideal atmospheric conditions) observations, <u>and</u> to be intervisible. Hence to traverse long distances, a number of intermediate setups would be required. *The GPS technology is able to challenge this short-range-intervisibility constraint.*

The Global Positioning System (GPS) is an all-weather, global, round-the-clock positioning system developed by the U.S. Department of Defense which became available to the civilian community in the early 1980's. The GPS space component consists of a minimum of 24 orbiting satellites, transmitting coherent coded signals on two carrier frequencies (the so-called L1 frequency of 1575.42MHz, and the L2 frequency on 1227.60MHz). All satellites transmit these two frequencies (though the coded messages are different for each satellite), and the satellites orbit at an altitude of approximately 20,000km. Despite the U.S. DoD's control of several "levers" that constrain the GPS navigation performance available to the general public, *use of the appropriate GPS hardware and software can deliver centimetre level relative positioning accuracy between simultaneously observing GPS receivers*. The standard mode of precise differential (or relative) positioning is therefore for one receiver to be located at a reference station whose coordinates are known, while the second receiver's coordinates are determined relative to the reference receiver. No intervisibility of the two GPS antennas is required.

To achieved relative accuracies depends on the distance between the antennas and could range from millimetres (in the case of very short distances) to tens of centimetres (over distances as far apart as hundreds of kilometres or more). Carrier phase measurement data must be used to assure such high positioning accuracy. This measurement is the phase of the received carrier (L1 or L2) with respect to the phase of a carrier generated by a frequency oscillator in the GPS receiver. A lower accuracy "distance" is also measured by all GPS receivers: the pseudo-range. The difference in measurement error of pseudo-range versus carrier phase may be of the order of ten to a hundred times, hence pseudo-range data is of limited benefit to GPS Surveying, except to provide approximate receiver position information (at the metre-level accuracy). The received carrier's phase is related to the phase of the carrier at the satellite through the time interval required for the signal to propagate from the satellite to the receiver's antenna. However, the use of carrier phase data comes at a cost in terms of overall system complexity as is described below.

Ideally, the carrier phase observation would be the total number of full carrier cycles and fractional cycles between the antennas of a satellite and a receiver at any instant (an L1 carrier cycle has a wavelength of approximately 19cm, with the L2 carrier wavelength being approximately 24cm). Unfortunately , a GPS receiver has no way of distinguishing one cycle of the L1 or L2 carrier from any other. The best that it can do is to measure the fractional phase and then keep track of changes to the phase. Hence the measurements are ambiguous satellite-receiver distances, requiring that "ambiguity resolution" (AR) algorithms be an integral part of the data processing procedure. AR is the mathematical process of determining the correct initial (from the point of first signal lock-on) integer number of wavelengths of the L1 or L2 carrier, that when added to the recorded carrier phase observations will convert these ambiguous observations to unambiguous distance values. These observations have similar form to the pseudo-range data, but the major difference is the very low (sub-centimetre-level) carrier measurement noise.

Although all GPS receivers must lock onto and track the signal's carrier in order to measure the pseudo-ranges, they may not record the *integrated* carrier phase observations for external use (fractional phase plus a count of the changes in whole wavelengths since signal lock-on). Hence GPS receivers intended for high accuracy positioning are distinguished by the fact that the hardware is capable of making and recording this special measurement made on the L1 only carrier (the so-called single-frequency receivers), or simultaneously on the L1 and L2 carriers (the so-called dual-frequency receivers). Dual-frequency instrumentation is invariably more expensive than single-frequency hardware because measurements on the L2 carrier require special (typically patented) tracking techniques in order to overcome the obstacles posed by the U.S. DoD's "anti-spoofing" policy.

Following the introduction of this user receiver hardware innovation in the early 1980s, the methodology for GPS Surveying was developed. Integrated carrier phase measurements made by one receiver (located on a point to be surveyed) are combined with those made simultaneously by another receiver (at a reference point of known coordinates in the GPS satellite datum system). Simultaneous observation spans (or sessions) lasting several hours was the norm during the pioneering days of static GPS Surveying. Data so collected would then be transferred from each of the receivers into baseline determination software. Such a post-processing mode of GPS Surveying is still the most common method of determining high accuracy relative coordinates.

Simultaneous data from a pair of receivers are used to form "double differences" in which the effects of satellite and receiver clock errors are eliminated, and the residual biases due to atmospheric refraction and orbit ephemeris errors are very effectively mitigated (the degree to which this is done is a function of the baseline length, hence as the antenna separation increases the effect of residual biases degrades the solution). The estimated baseline components will vary as a function of the type of double-differenced solution. The first type of solution obtained is a double-difference *ambiguity-free* (or as it is sometimes referred: "bias float") solution. This may not be accurate at the subdecimetre-level unless observation data spans are several hours in length. Long data spans also enable the resolution of the unknown integer ambiguities, along with estimation of the relative coordinates of one receiver with respect to the reference receiver, in a double-difference *ambiguity-fixed* (or "bias fixed") solution. Such a solution is more accurate, and is strived for. That is, sufficient data is collected to ensure that AR is successful. It is impossible to predict with an certainty the length of observation sessions for "bias fixed" solutions as it is a function of the number of tracked satellites, the satellites-receiver geometry, the observation noise, the length of the baseline, and whether there is multipath present, dual-frequency observations are available, and pseudo-range data is used. Guidelines are, however, provided by the manufacturers.

In summary, conventional static GPS Surveying has the following characteristics:

(1) The points being coordinated are not moving, i.e. they are "static".
(2) GPS data are collected over some "observation session", typically ranging in length from an hour to several hours (or perhaps days for very precise applications).
(3) The results are not required immediately, for in-the-field use.
(4) The relative positioning mode of operation is the only mode employed, requiring the use of a minimum of two GPS receivers for all survey work.
(5) The measurements used for data reduction are those made on the transmitted L-band carrier wave, requiring specialised hardware and software.
(6) A variety of data processing algorithms can be employed.
(7) Mostly associated with the traditional surveying and mapping functions.

Since the late 1980s considerable attention has been paid to the first three points as they were considered to be unnecessarily restrictive for typical GPS Surveying applications. In particular, if the length of time required to collect phase data for a reliable solution could be shortened, then *GPS survey productivity would improve and the technology would be attractive for many more surveying applications*. This would be especially useful for cadastral surveying and engineering surveying applications. In addition, recent developments make possible high accuracy performance in "real-time" -- that is, in the field, immediately following the measurement, and after the data from the reference receiver has been transmitted to the other field receiver for processing. Real-time precise positioning is even possible when the GPS receiver is in motion. These systems are commonly referred to as **RTK systems** ("real-time kinematic"), and make feasible the use of GPS-RTK for many new *time-critical* applications including machine control for "precision farming", GPS-guided earthworks/excavations, automated haul truck operations, and other autonomous robotic navigation applications.

Hence, as a result of vigorous R&D, new GPS Surveying methodologies have been developed, which complement the "conventional static" technique. These modern GPS Surveying techniques are given a variety of names by different instrument manufacturers, but the following are likely to be relevant for cadastral and engineering surveyors:

- **Rapid static** positioning techniques.
- **Stop & go** techniques.
- **"On-the-fly"** positioning techniques.

Each of the techniques represents a technological solution to the problem of obtaining *high productivity* (measure as many baselines in as short a period of time as possible) and/or *versatility* (for example, the ability to obtain results even while the receiver is in motion) without sacrificing very much in terms of *accuracy* and *reliability*. None of these techniques is as accurate or reliable as conventional static GPS Surveying, and each of these techniques has its special strengths and weaknesses**.** They represent the state-of-the-art in precision GPS positioning, and are a direct outcome of considerable innovation by instrument manufacturers seeking to address survey applications. In many cases the most significant advances are in the software, but nevertheless the receiver hardware is of the top-of-the-line, dual-frequency variety. The "stop & go" and "on-the-fly" GPS techniques will not be discussed further.

Rapid static positioning is the technique which will be considered in the context of cadastral surveying as a counterpoint to the conventional **static positioning** technique. Obviously the former is a more economical technique than the latter as less data collection time is required, and can be the preferred technique if there were no explicit requirements of the surveyor to use the static positioning technique. The difficulty with the rapid static positioning technique is that the length of observation session cannot be predicted with any degree of confidence, though some guidelines may be provided in terms of: (a) baseline length, (b) number of tracked satellites, and (c) satellites-receiver geometry. It is crucial that enough data is collected to ensure correct AR, that is, only a "bias fixed" solution is acceptable. If, for whatever reason, such a solution cannot be obtained (as evidenced from the baseline determination software) *then this baseline solution is considered to be invalid and cannot be used for point fixation, or inclusion within network adjustments of GPS baselines*. The guidelines presented in this document seek to be conservative, so that the surveyor is encouraged to collect sufficient data to ensure AR for the vast majority of baselines that will be observed.

For further information the surveyor is directed to the publications and web sites listed in **Appendix A.14**. Additional useful information may also be found in the "Innovation Column", within the trade magazine *GPS World* (see http://www.gpsworld.com).

APPENDIX A.2
Optical Plummet Testing Procedures

Many tribrachs used for GPS surveys have inbuilt optical plummets, which are used to locate the geometrical centre (or what may be referred to as the physical centre, in contrast to the electrical centre) of the antenna, attached to the top of a tripod, over a groundmark. Check the optical plummet at every six (6) months as any deviation of its line-of-sight from the vertical will lead to centring errors. There are two steps: (a) adjust the circular level (or "spot bubble") of the tribrach, and (b) adjust the verticality of the optical plummet.

(a) The following is a circular level adjustment method:

1. Setup a theodolite in the tribrach, on a tripod, and level up using the plate level.

2. Use the adjustment screws of the circular level to centre the circular bubble, making sure that all the adjustment screws are "firm" (noting that the bubble has four adjusting screws surrounding it, hence as one screw is loosened, the opposite screw must be tightened).

(b) The following is an optical adjustment method which is accurate to about 0.5mm:

1. Setup a theodolite in the tribrach, on a tripod, on a level and sheltered area, and level up using the plate level.

2. Use a sharp pencil to trace the outline of the tribrach base plate on the tripod head (this can be erased later with solvent or water).

3. Secure a piece of graph paper on the floor, and mark the position of the plummet's cross-hairs on the graph paper.

4. Untighten fixing screw and carefully turn the tribrach 120° and fit into the outline previously traced. Tighten the central fixing screw, level up the instrument, and mark the new position of the plummet's cross-hairs on the graph paper.

5. Repeat the process for the third position of the tribrach.

If all three marks coincide, the optical plummet is properly adjusted; if not, adjust the cross-hairs to the point which is the centroid of the three points obtained. In the case of Leica-type tribrach systems the adjustment requires the use of a screwdriver to turn the two adjustment screws (figure 1) as indicated in figure 2 to move the cross-hairs a little at a time (checking this frequently by looking through the plummet).

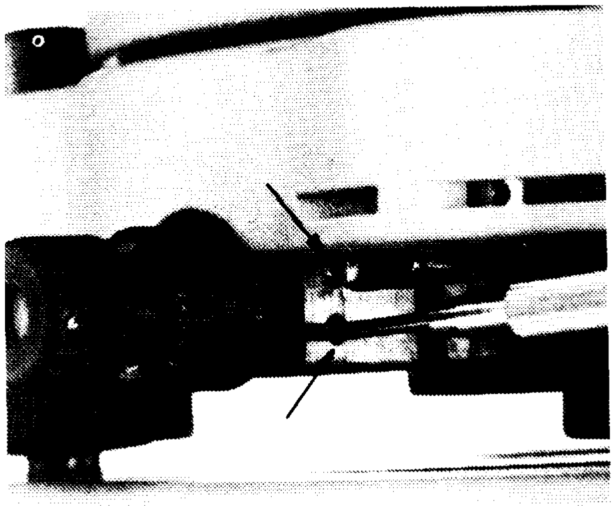

Figure 1. Arrows mark adjustment screws for Leica-type tribrach

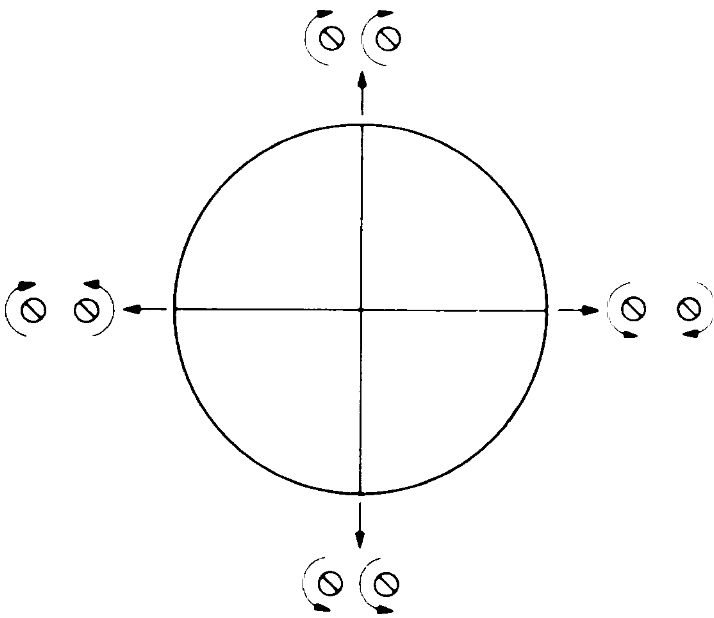

Figure 1. To adjust, turn the adjustment screws as shown to move the cross-hairs in the direction indicated by the straight arrows.

APPENDIX A.3
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, because:

- it can be performed anywhere where sky visibility is sufficient to ensure adequate satellite tracking,
- the coordinates of the antenna do not need to be known, and
- the result that must be obtained is self-evident, that is a "zero length" baseline.

The experimental setup is as follows:

1. The test shall be carried out by connecting two GPS receivers to the same antenna, using an antenna splitter appropriate for the brand of receiver/antenna. Details of the antenna splitter required may be obtained from the GPS manufacturer or his agent. *(The web site for a company which specialises in antenna splitters is: www.fleetpc.com)*

2. The test may be carried out any place where it is convenient, but should be carried out at a site with at least 90% sky visibility. Typically this would be in a parklike area, or on the site of the survey.

3. Once the instruments have been turned on, a minimum of ten minutes of observation shall be collected, with at least 15 seconds recording interval. Care must be taken to ensure that the site conditions and time of day are suitable so as to ensure that at least five satellites are tracked continuously during the test session, with a Geodetic Dilution of Precision (GDOP) value of less than six. *This may be verified by monitoring the status of tracking, or by using "survey planning" utilities provided with the data processing software which produce skyplots, satellite visibility and GDOP plots and tables*.

Once the data files have been downloaded from the receivers, the data may be processed using the standard baseline processing procedures and processing options (for example, maintaining a cut-off angle of 15°). An ambiguity-fixed (or "bias-fixed") solution should be obtained. If this is not the case, the test should be redone, with a longer observation session.

Evidence of the results of a zero baseline test, such as the field log sheet and the output print file from the data processing software, should be kept for possible audit purposes.

APPENDIX A.4

Case Study for Zero Baseline Test

A series of Zero baseline test have been carried out at an open site in UTM. The instrumental setup given in **Appendix A.3** has been followed through out the tests. The list of GPS equipment set being tested are as follow:

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

Table A4.1: 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 following criteria has been observed during each field test:

Observation length	10 minutes
Recording Interval	15 seconds
Number of satellites	≥ 5
GDOP	≤ 6
Sky Clearance	≥ 90 %
Cut Off Angle	15^{0}

Table A4.2: Field test criteria

The baseline processing involving each pair of receiver has been carried out with the following requirements:

Session length used	10 minutes
Ambiguity Resolution	Fixed
Cut Off Angle	15^{0}
Frequency used	L1 dan L2

Table A4.3: Processing requirements

The resulting computed slope distance for each pair of receivers is given below according to the test date in milimeters:

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 A4.4: Test series results

Table A4.4 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.

APPENDIX A.5

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:

- relative latitude, longitude and height, or
- relative Cartesian coordinates with respect to a global geocentric reference frame, or
- 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.

The test is carried out according to the procedure normally used for EDM equipment. That is, the two antennas are moved between the different pillars of the baseline. Care is taken that there is a minimum of 90% sky visibility at each pillar setup.

The experimental setup is as follows:

1. The inter-antenna distances should vary from about twenty metres to the maximum length of the baseline (typically about one kilometre).

2. Each GPS receiver is to be connected to its designated antenna (mounted on the pillar) using the same antenna cable used during surveys.

3. Once the antennas have been deployed on the pillars, a minimum of ten minutes of observation shall be collected, with at least 15 seconds recording interval. Care must be taken to ensure that the site conditions and time of day are suitable so as to ensure that at least five satellites are tracked continuously during the test session, with a GDOP of less than six. *This may be verified by monitoring the status of tracking, or by using "survey planning" utilities provided with the data processing software which produce skyplots, satellite visibility and GDOP plots and tables*.

Once the data files have been downloaded from the receivers, the data may be processed using the standard baseline processing procedures and processing options (for example, maintaining a cut-off angle of 15°). An ambiguity-fixed (or "bias-fixed") solution should be obtained. If this is not the case, the test should be redone, with a longer observation session.

Evidence of the results of an EDM baseline test, such as the field log sheets and the output print files from the data processing software, should be kept for possible audit purposes.

APPENDIX A.6

Case Study for EDM Baseline Test

The purpose of the EDM baseline test is to compare GPS obverved distances with their corresponding established values measured by the EDM. 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 A6.1.

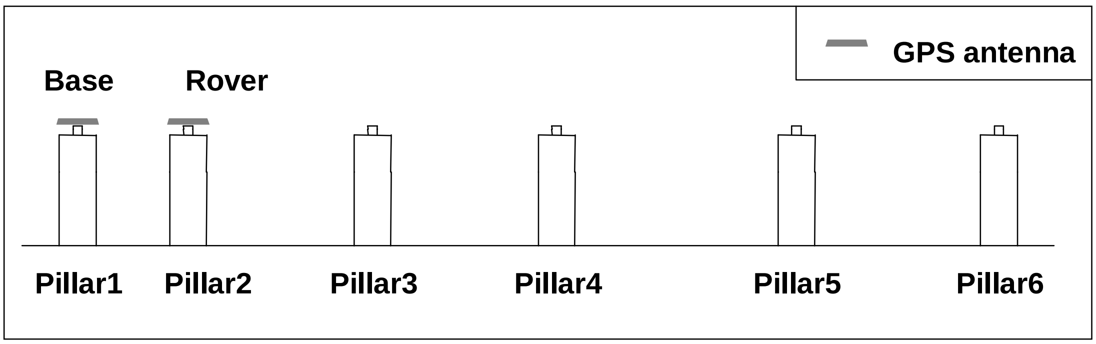

Figure A6.1: UTM EDM baseline test site

The EDM test site comprises of six (6) pillars saperated 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. The instrumental setup given in **Appendix A.5** has been followed through out the tests. 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	*Leica* System 300 (L1& L2)
Number of receivers tested	3 (R1, R2, R3)
Antenna	1 (for each receiver)
Processing software	*SKI* version 2.11

Table A6.1: GPS equipments used in the tests

Three (3) *Leica* dual frequency GPS receivers being used in the test. The following criteria has been observed during the field measurements:

Observation length	10 minutes
Recording Interval	15 seconds
Number of satellites	≥ 5
GDOP	≤ 6
Sky Clearance	≥ 90 %
Cut Off Angle	15^{0}

Table A6.2: Field test criteria

The baseline processing involving each pair of receiver has been carried out with the following requirements:

Session length used	10 minutes
Ambiguity Resolution	Fixed
Cut Off Angle	15^{0}
Frequency used	L1 dan L2

Table A6.3: Processing requirements

The differences between GPS computed distances and their corresponding EDM values for each pair of pillars (receivers) are given in the following two tables (Table A6.4 and Table A6.5):

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 A6.4: 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 A6.4: 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.

APPENDIX A.7

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 Report, 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 using the procedure described in **Appendix A.2**.

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 experimental setup is as follows:

1. All other recommended procedures for Static mode positioning should be followed.

2. Each GPS receiver is to be connected to its designated antenna (mounted on the pillar) using the same antenna cable used during surveys.

3. Once the antennas have been deployed on the stations, a minimum of one hour of observation shall be collected for each baseline. Care must be taken to ensure that the site conditions and time of day are suitable so as to

ensure that at least four satellites are tracked continuously during the test session. *This may be verified by monitoring the status of tracking, or by using "survey planning" utilities provided with the data processing software which produce skyplots, and satellite visibility plots and tables*.

Once the data files have been downloaded from the receivers, the data may be processed using the standard baseline processing procedures and processing options (for example, maintaining a cut-off angle of 15°). Every effort should be made to ensure that the ambiguities have been resolved. If this is not the case for any baseline, that baseline may be excluded from the subsequent network adjustment.

The network adjustment procedure is as follows:

1. The minimally constrained network adjustment should be carried out using the computed baselines expressed in the "satellite datum" (such as WGS84, or one of the ITRF datums). This means that one of the coordinates of the test network, must be held fixed. If necessary, the coordinate is transformed to the "satellite datum" using the procedure specified in **Appendix A.11**.

2. The adjustment procedure should be according to the principles given in §5.3.3.

3. The final coordinates may need to be transformed to the established local datum system (if the known coordinates of all the test network stations are provided in this datum). The recommended coordinate transformation procedure should be followed (**Appendix A.11**).

Evidence of the results of a GPS network test, such as the field log sheets, the output print files from the baseline processing software, and the results of the network adjustment, should be kept for possible audit purposes.

APPENDIX A.8

Case Study for GPS Network Test

The purpose of the GPS network test is to compare GPS obverved 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 A8.1

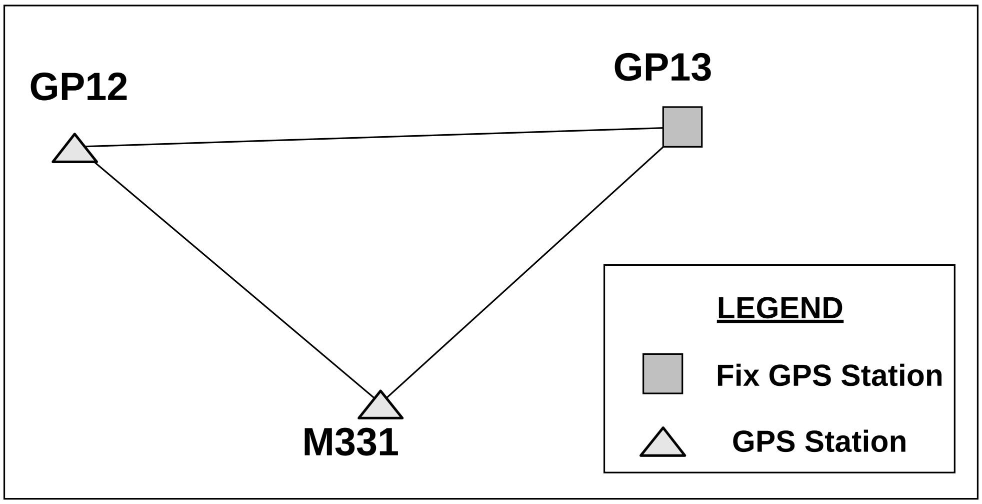

Figure A8.1: GPS network test site

The GPS network test site comprises of three (3) GPS stations (known stations) namely GP13, GP12 and M331 which is saperated about 30km. The test has been carried out using GPS *static* technique. The test setup given in **Appendix A.7** is being followed. The observation has been carried out in one session (approximately 5 hours) using a total of three (3) GPS receivers.

The list of GPS equipment set being used in the test are as follow:

Type of receivers	*Leica* System 300 (L1& L2)
Number of receivers used	3 (R1, R2, R3)
Antenna	1 (for each receiver)
Processing software	*SKI* version 2.11

Table A8.1: GPS equipments used in the tests

Three (3) *Leica* dual frequency GPS receivers being used in the test. The following criteria has been observed during the observation session:

Observation length	> 1 hour
Recording Interval	15 seconds
Number of satellites	≥ 5
GDOP	≤ 6
Sky Clearance	≥ 90 %
Cut Off Angle	15^{0}

Table A8.2: Field test criteria

In the processing step, the observation data has been devided into five (5) saperate sessions of one (1) hour each. The baseline processing involving each pair of receiver has been carried out with the following requirements:

Session length used	1 hour
Ambiguity Resolution	Fixed
Cut Off Angle	15^{0}
Frequency used	L1 dan L2

Table A8.3: Baselines processing requirements

A minimally constrained adjustment is also being carried out using the *SKI* Adjustment Package with the following parameters:

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

Table A8.4: 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 Semenanjung Malaysia is the local *Cassini Soldner* System. The coordinates transformation has been done following procedures outlined in §4.3.4.

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 A8.5: Comparison of coordinates in Cassini system (GP13 fixed)

Table A8.5 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=5mm, b= 2ppm 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 below.

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 A8.6: The computed and allowable accuracies for the corresponding baselines

Table A8.6 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.

APPENDIX A.9

Case Study for GPS Cadastral Control Survey

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 A9.1

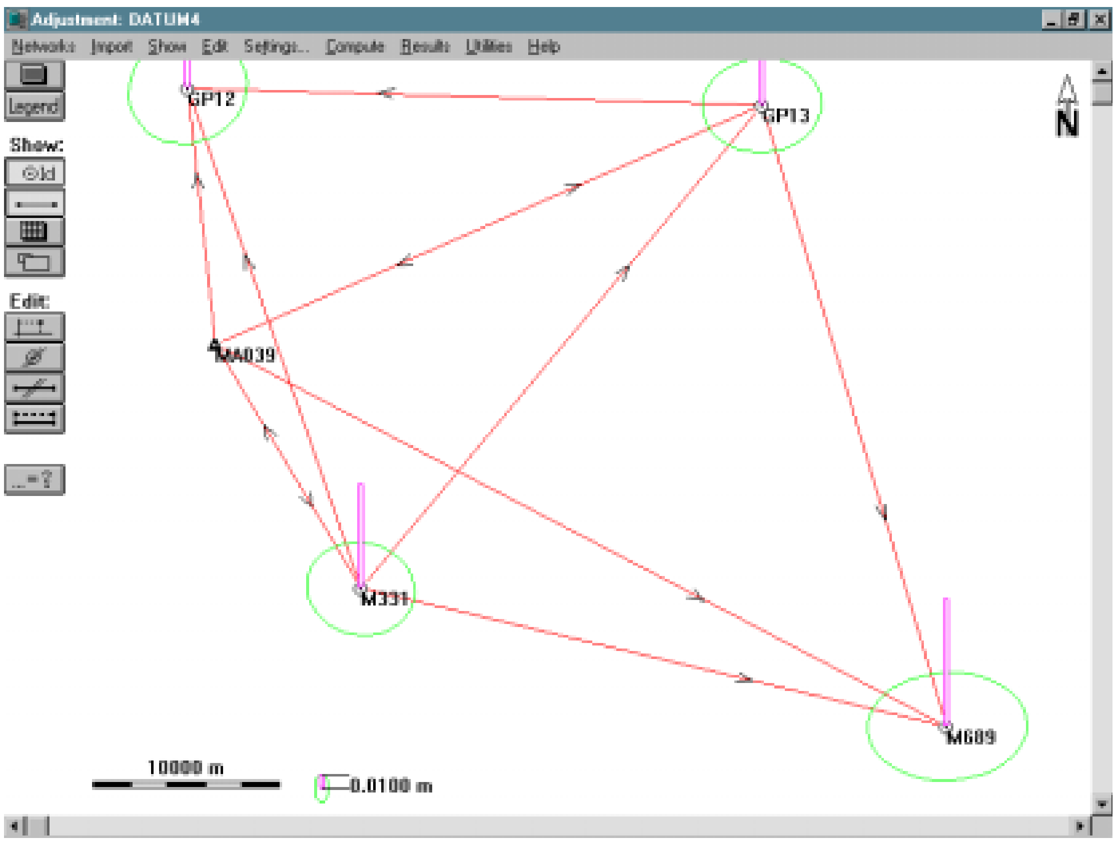

Figure A9.1: GPS cadastral control survey test site

The test site comprises of three (3) GPS stations (known stations) namely GP13, GP12 and M331 which is saperated about 30km apart, and two (2) cadastral standard traverse stations (MA039 and M689). The test has been carried out using GPS *static* technique. The test setup given in **Appendix A.7** is being observed and the field and office procedures given in §5.2 and §5.3 were followed. The observation has been carried out using a total of three (3) GPS receivers.

The list of GPS equipment set being used in the case study are as follow:

Type of receivers	*Leica* System 300 (L1& L2)
Number of receivers used	3 (R1, R2, R3)
Antenna	1 (for each receiver)
Processing software	*SKI* version 2.11

Table A9.1: GPS equipments used in the campaign

Three (3) *Leica* dual frequency GPS receivers being used in the measurements. The following criteria has been observed during the observation session:

Observation length	> 1 hour
Recording Interval	15 seconds
Number of satellites	≥ 5
GDOP	≤ 6
Sky Clearance	≥ 90 %
Cut Off Angle	15^{0}

Table A9.2: Field test criteria

In the processing step, data from one (1) hour observation session has been used. The baseline processing involving each pair of receiver has been carried out with the following requirements:

Session length used	1 hour
Ambiguity Resolution	Fixed
Cut Off Angle	15^{0}
Frequency used	L1 dan L2

Table A9.3: Baselines processing requirements

A minimally constrained adjustment is also being carried out using the *SKI* Adjustment Package with the following parameters:

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

Table A9.4: 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 (see **Appendix A8**)

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 adjusment 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. The coordinates transformation has been done following procedures outlined in §5.3.4.

Adjusted coordinates for M689 is given below 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 A9.5: Comparison of coordinates in Cassini system (MA039 fixed)

Table A9.5 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 below 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 A9.6: The computed and allowable accuracy for Baseline MA039 - M689

Table A9.6 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.

APPENDIX A.10

Case Study for GPS Cadastral Survey

1.0 Test Area

The survey has been carried out on several cadastral 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 A10.1.

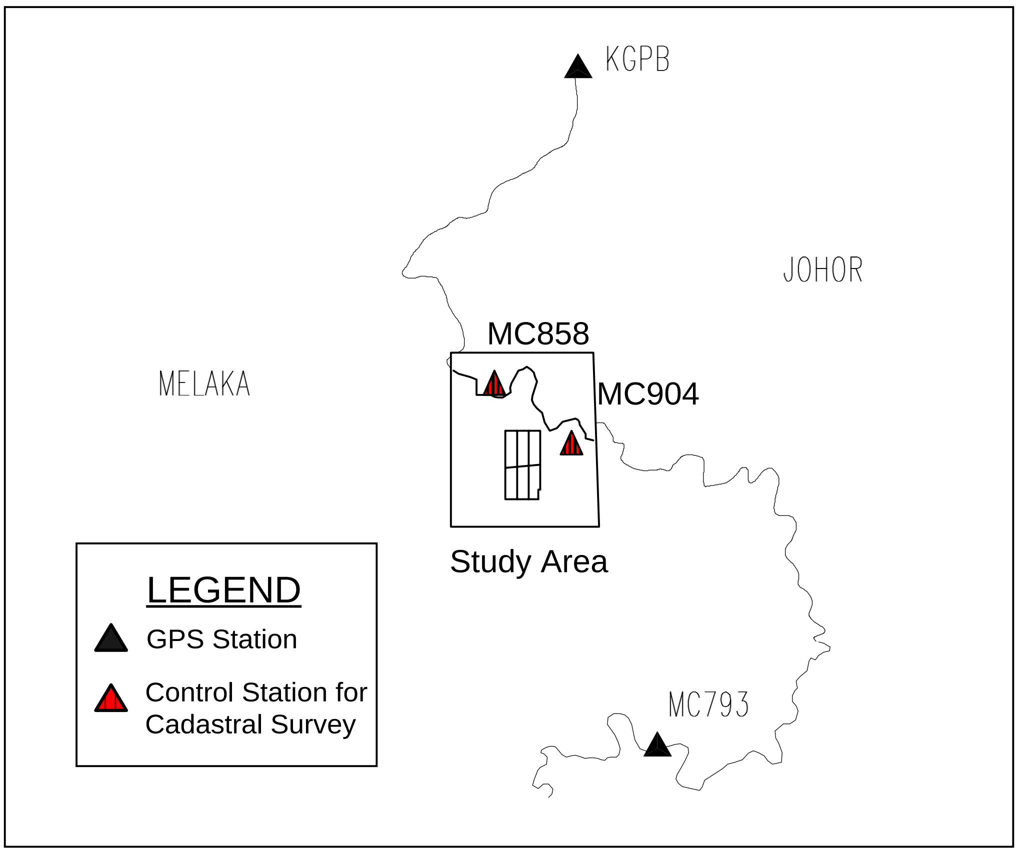

Figure A10.1: Test area for GPS cadastral survey

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 A10.1 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 A10.1: 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.

2.0 GPS Cadastral 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. The detail of the GPS equipments used and the observation Table A10.2.

Type of receivers	*Leica* System 300 (L1& L2)
Number of receivers used	3 (R1, R2, R3)
Processing software used	*SKI* version 2.11

Table A10.2: GPS hardware and software used

Since only three (3) GPS receivers available, observations have been done in two sessions (1 new station for each session) with the following criteria (see Table A10.3).

GPS observation technique	Static
Observation period	> 1 hour
Recording interval	15 seconds
Number of satellites	≥ 5
GDOP	≤ 6
Sky coverage	≥ 90 %
Cut Off Angle	15^{0}

Table A10.3: GPS *static* field observation criteria

GPS baselines processing is being carried out with the following parameters (see Table A10.4).

Observation data used	1/2 hour
Ambiguity Resolution	*Fixed*
Cut Off Angle	15^{0}
Frequencies used	L1 and L2

Table A10.4: Baselines processing parameters 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 A10.5.

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

Table A10.5: Adjusted coordinates for two (2) new control stations

3.0 GPS Cadastral Survey

GPS cadastral survey on the selected lots (see Figure A10.2) 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 A10.6.

Reference Station	MC858 (Base I) MC904 (Base II)
Observation period	10 minutes
Recording interval	15 seconds
Number of satellites	≥ 5
GDOP	≤ 6
Sky coverage	≥ 90 %
Cut Off Angle	15 ^{0}

Table A10.6: GPS *rapid static* field observation criteria

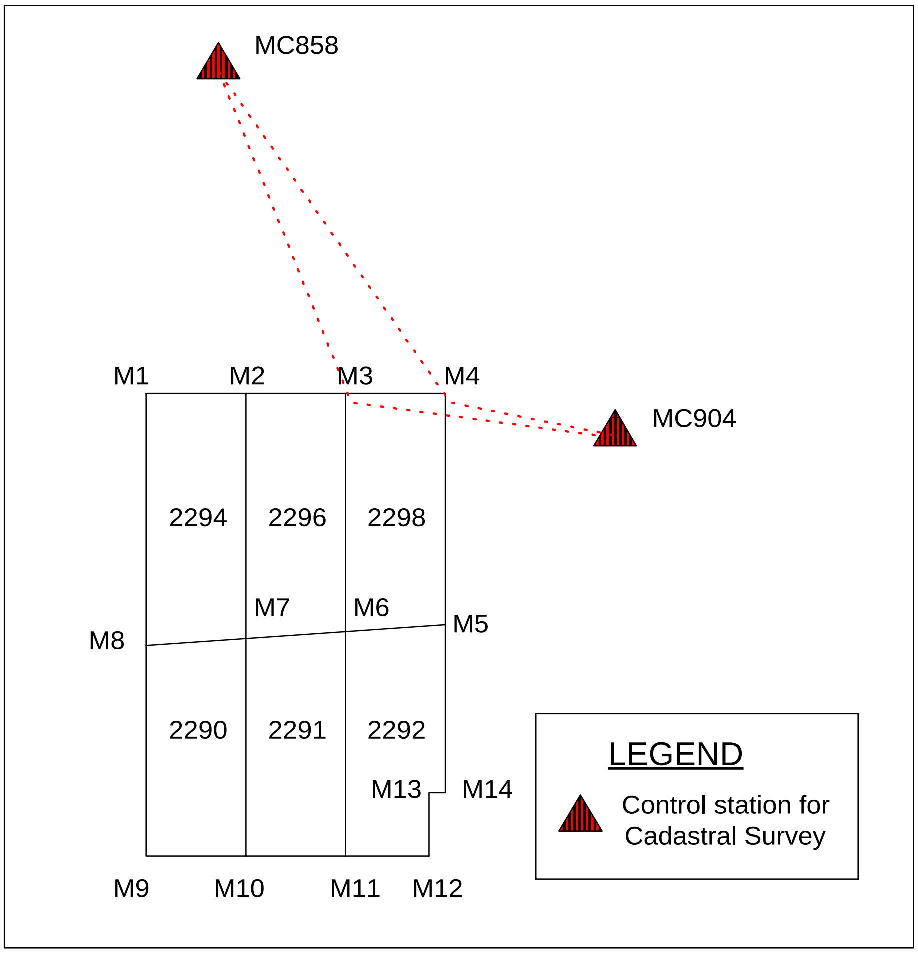

Figure A10.2: Test site for GPS cadastral survey using *rapid static* technique (Mukim Sungei Rambai, Melaka)

GPS baselines processing is being carried out with the following parameters (see Table A10.7).

Obsevation period	10 minutes
Ambiguity Resolution	*Fixed*
Cut Off Angle	15^{0}
Frequencies used	L1 and L2

Table A10.7: 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) following procedure given in **Appendix A.11**. List of two sets of Cassini coordinates for each boundry mark are given in Table A10.8 .

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 A10.8: Differences between two sets of coordinates in Cassini (Base I values refer to MC858 and Base II refer to MC904)

Table A10.8 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 Plan (see Table A10.9).

Lot Number	**Computed (GPS) Area (m^2)**	**Existing (CP) Area (m^2)**	**Diff. (m^2)**
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 A10.9: Area comparison between computed (GPS) and CP values

Table A10.9 indicates that in general differences of less than $1m^2$ 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.

APPENDIX A.12

Sample Log Sheet

GPS STATION OCCUPATION REPORT

Project Title: ____

Mission: ________________ Project:_________________ Job:___________________

Site Name:__________________________ Station ID: _________________________

Location:___________________________ City:______________________________

ReceiverNo.:________________________ AntennaNo.:________________________

Operator:___________________________ Date:______________________________

Scheduled Start Time:_________________ Scheduled End Time: ________________

No. Obs. Epochs:_____________________

Observation Time : _____hour_____minute Observation Interval : ______second

Antenna Height :

	Before	After	Offset	
1.)	____________m	_____________m	_____________m	☐ Slant Height
2.)	____________m	_____________m	_____________m	☐ Vertical Height

Comments On Discrepancies :____

____

Meteorological Data:

Time	Dry (°C)	Wet (°C)	Pressure

Approximate Geodetic Coordinates :

Latitude : __________________________ Datum : ____________________________

Longitude : ________________________ Source of position : ___________________

Height : ______________________meters

Instrument Checklist :

- ☐ Memory Card
- ☐ Antenna Cable
- ☐ Battery Cable
- ☐ Controller Cable
- ☐ Tripod
- ☐ Tribrach
- ☐ Compass
- ☐ Barometer
- ☐ Thermometer
- ☐ Tapemeasure
- ☐ Umbrella
- ☐ Flashlight

Field Observation Checklist :

- ☐ Standpoint number physically confirmed
- ☐ Centring Checked
- ☐ Antenna Oriented to North
- ☐ Antenna Connection confirmed
- ☐ Data File Name Checked
- ☐ On Site Tracking confirmed
- ☐ Auto Timer : Time Zone Confirmed
- ☐ Auto Timer : Start Time Confirmed
- ☐ Auto Timer : Session Length Checked
- ☐ Obstruction diagram (On Reverse)

Battery Indicator

Start : Finish:

Site Sketch

N
Remarks :

APPENDIX A.13

Sample Survey Report

Project Details:

Project Name :

Survey File Name :

Company Name :

Surveyor Name :

Location of Project Area :

Starting Date :

Completion Date :

Type of GPS Survey:

- ☐ GPS Cadastral Control Survey
- ☐ GPS Cadastral Survey

Project Description:

GPS Receivers and Accessories:

Types of Receivers :

Baseline Processing software :

Network Adjustment software :

No.	Receiver Serial Number	Antenna Serial Number

Observation Criteria:

Observation Length:

Recording Interval:

Number of Satellites:

GDOP:

Cut Off Angle:

Baselines Processing Parameters:

Session Length Used:

Cut- Off Angle:

Tropospheric Model Used:

Ionospheric Model Used:

Processing Strategy Used:

Network Adjustment Parameters:

Fixed Station:

Number of Observations:

Number of Unknowns:

Degree of Freedom:

Chi Square Test Result:

Results:
Adjusted Geodetic Coordinates: refer to Table 1
Transformed Plane Coordinates: refer to Table 2

Table 1: Adjusted Coordinates in WGS84 and Local MRT Systems						
Station ID	**WGS 84**			MRT		
	LATITUDE ° ′ ″	**LONGITUDE** ° ′ ″	**ELL. HEIGHT meter**	**LATITUDE** ° ′ ″	**LONGITUDE** ° ′ ″	**ELL. HEIGHT meter**

Table 2: Transformed Coordinates in Local RSO and Cassini Systems					
Station ID	RSO		CASSINI		REMARKS
	N (+) / S(-) meter	E(+) / W(-) meter	N (+) / S(-) meter	E(+) / W(-) meter	

Attachment:

☐ Zero Baseline Test Result (Guideline, Table A4.4)

☐ EDM Baseline Test Result (Guideline, Table A6.4)

☐ Location Map of Project Area

☐ GPS Station Log Sheet (Guideline, Appendix A12)

☐ GPS Data Processing Output

- ☐ Hardcopy
- ☐ Diskette - File Name :

☐ GPS Network Adjustment Output

- ☐ Hardcopy
- ☐ Diskette - File Name :

☐ Certified Plan Number :

Checked by:
Approved by:

APPENDIX A.14

Recommended Reading and GPS Web Sites

Books:

- *Getting Started with GPS Surveying*, S. McElroy, et al., GPSCO (Australia), 1992.
- *GPS Satellite Surveying*, A. Leick, 2nd ed., John Wiley & Sons, 1995.
- *Global Positioning System: Theory and Practice,* Hofmann-Wellenhof, et al., 4th ed., Springer-Verlag, 1998.
- *Principles and Practice of GPS Surveying,* C. Rizos, Monograph 17, School of Geomatic Eng., UNSW, 1997.
- *Guide to GPS Positioning*, D. Wells, et al., Canadian GPS Associates, 1986.
- *World Geodetic System 1984 (WGS84) - Its Definition and Relationships with Local Geodetic Systems,* Defense Mapping Agency (DoD), 2nd ed., 1991.
- *Adjustment Computations,* P.Wolf & C. Ghilani, John Wiley & Sons, New York, 1997

GPS-Related Web Sites:

There are many web sites dedicated to some aspect of GPS. Some sites contain a comprehensive set of WWW links to other sites. These should be consulted for up-to-date links.

- *Introduction to GPS:*

http://www.fksg.utm.my/Dept/Geomatik/ge.html
http://galaxy.einet.net/editors/john-beadles/introgps.htm
http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html
http://homepage.interaccess.com/~maynard/
http://www.iinet.net.au/~yeoh/gps/
http://www.geod.emr.ca/~craymer/tcg/
http://sirius.chinalake.navy.mil/

- *Books, Magazines & News:*

http://www.geoinfosystems.com/
http://www.gpsw orld.com
http://www.itsa.org/
http://www.itsworld.com/
http://www.navtechgps.com

- ***Navtech Seminars and GPS Supply***:

http://www.navtechgps.com/.

- *GPS Manufacturers:*

http://truegnss.com - 3S Navigation
http://www.ashtech.com/ - Ashtech
http://www.marconi.ca/ - Canadian Marconi Company
http://www.garmin.com - Garmin
http://www.geotronics.se - Geotronics

http://www.leica.com - Leica
http://www.novatel.com - Novatel
http://www.nb.rockwell.com - Rockwell
http://www.sokkia.com/ - Sokkia Corporation
http://www.Topcon.com - Topcon
http://www.trimble.com - Trimble Navigation Limited

- *Geodetic Authorities & Information Sources:*

http://www.navcen.uscg.mil/gps/gps.htm - U.S. Coast Guard Navigation Information Center
http://tycho.usno.navy.mil/gps.html - U.S. Naval Observatory Navstar GPS Operations
http://www.ngs.noaa.gov/index.html - National Geodetic Survey
http://www.auslig.gov.au/geodesy/geodesy.htm - AUSLIG
http://www.geod.emr.ca/ - Geodetic Survey of Canada
http://igscb.jpl.nasa.gov/ - IGS Central Bureau
http://www.unb.ca/geodesy/CANSPACE.html - UNB Canspace