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TAJUK PROJEK : Study Towards Real Time Precise Point Positioning System Using GPS Engine.

Saya Prof. Madya. Kamaludin Mohd. Omar
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STUDY TOWARDS REAL TIME PRECISE POINT POSITIONING SYSTEM USING GPS ENGINE

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ABSTRACT

Since the Selective Availability (SA) was set to zero, the point positioning becomes an interesting field of study. The precise single point positioning using single frequency GPS receiver is one of the challenging researches. This study was to initial study towards development of the precise single point position solution with accuracy better than 2 m using a low cost single frequency GPS receiver. The positioning algorithm was written in Matlab™ and it incorporates all the significant errors and bias. The significant errors and bias are satellite clock errors, receiver clock errors, tropospheric and ionospheric bias, relativistic effect, earth rotation effect, and satellite antenna phase center offset. Some simulations were performed to validate the result. The results of the study showed significant improvements in accuracy after the SA was set to zero and this fits to the statement of the White House USA that the accuracy will be ten times better than before. The findings suggest that it could be enhanced for better accuracy and integrated in a single built system of hardware and software for further and higher investigations as a low cost commercial GPS equipment.

ABSTRAK

Semenjak Selective Availability (SA) dimansuhkan, penentududukan mutlak menjadi satu kajian yang menarik. Penentududukan mutlak yang jitu dengan menggunakan penerima GPS frekuensi tunggal merupakan salah satu penyelidikan yang mencabar. Kajian ini adalah kajian awal untuk membangunkan perisian penentududukan mutlak yang jitu dengan ketepatan lebih baik dari 2 m menggunakan suatu penerima GPS frekuensi tunggal yang berkos rendah. Algorithma penentududukan ditulis dalam bahasa Matlab™ dan ianya mengambil kira semua selisih yang bererti. Selisih-selisih tersebut adalah selisih jam satelit, selisih jam penerima, selisih ionosfera dan troposfera, selisih akibat relativistic, selisih akibat putaran bumi, dan selisih offset pusat fasa antenna. Beberapa simulasi telah dilakukan untuk mengesahkan hasil kajian. Hasil kajian menunjukkan peningkatan ketepatan yang bererti setelah SA dimansuhkan dan ini sesuai dengan pernyataan White House USA bahawa ketepatan akan menjadi 10 kali lebih jitu daripada sebelum SA dimansuhkan. Penemuan ini mencadangkan bahawa kajian lain yang lebih terperinci dapat dilakukan untuk mendapatkan ketepatan yang lebih baik dan diintegrasikan menjadi satu sistem yang terdiri daripada perkakasan dan perisian sebagai suatu peralatan GPS komersial yang berkos rendah.

LIST OF CONTENT

CHAPTER I

INTRODUCTION

1.1 General Background

The discontinuation of SA (Selective Availability) gives a great impact to the accuracy; ten times better than before and directly affects many application fields (Clinton, 2000). The accuracy of point positioning using C/A code will be better than 20 m (Witchayangkon,2000).

To take benefits from the discontinuation of SA and further study about the removal and reducing of the other significant errors (after removal of SA) to obtain a low cost real time precise single point positioning is a very interesting and challenging research. The price could be cheaper due to the use of single frequency OEM GPS, own designed algorithm and free software.

Since the Selective Availability was set to zero, the point positioning becomes an interesting field to study. Reliance on only single frequency receiver due to the low cost aspect makes the single point positioning more challenging due to the ionospheric and tropospheric delay estimation. To be real time or near real time, instead of using the precise ephemeris, the broadcast ephemeris is sufficient to use.

Unlike in relative positioning, common mode errors do not cancel in Precise Single Point Positioning (PSPP). Station movements due to geophysical phenomena such as tectonic plate motion; earth tides and ocean loading enter the PSPP solution in full, as do observation errors resulting from the troposphere and ionosphere.

Relevant satellite specific errors are satellite clocks and orbit error, satellite antenna phase center offset and satellite orientation, earth rotation effect and satellite antenna phase wind – up error. Receiver specific errors are receiver clock error, receiver antenna phase center offset, multipath and receiver antenna phase wind-up. Atmospheric delay such as ionospheric and tropospheric delay must be taken into account (Leick,2004).

Ocean loading, earth tides, receiver antenna phase center offset , multipath and receiver antenna phase wind-up and satellite antenna phase wind-up are not incorporated in order to make the model simpler. After removing all the errors and bias, least square adjustment is applied to obtain the point position for single epoch (10 Hz and 1 Hz).

1.2 Problem Statements

As some geodesists in some countries have the attention to investigate the precise single point positioning due to the discontinuation of SA, it also attracts other geodesists in other countries to do breakthrough research to conduct that method. One of the possible methods to be developed could be called as Precise Single Point Positioning Using Low Cost Single Frequency GPS Receiver.

1.3 Research Objectives

a) To study and investigate the precise single point positioning using single frequency OEM GPS due to the discontinuation of SA.
b) To design algorithms in Matlab Language which model the errors and bias in GPS data and apply least square adjustment in order to obtain the point position with accuracy better than 2 m.

1.4 Research Scopes

The research scopes are:

a) GPS Observation using Single Frequency OEM GPS to download the raw data real time to computer.
b) GPS raw binary data converted to RINEX format to obtain code / pseudorange data and broadcast ephemeris.
c) Satellites' Position Computation.
d) Enhancement of the Observation Data. Removal, reducing, and modeling the remaining bias and error especially satellite and receiver clock error, relativistic effect, earth rotation effect, satellite antenna phase center offset, tropospheric and ionospheric delay.
e) Single Point Position Computation.
f) Validation of the result by comparing the obtained point position to the known point position.
g) Analysis of the result in static mode single by single epoch (1 Hz and 10 Hz data).

1.5 Research Contributions

This research is expected to give contribution in knowledge to other researchers and it can contribute to the geodesists in investigating further the low cost real time precise single point positioning using Single Frequency OEM GPS. At the end of this research, it could be commercialized and has a potency to be used in utilities surveying, mapping, mining, GIS application and other fields, which is related with position on earth such as navigation, fishery, and recreation.

In general, the research methodology can be presented through figure 1.1.

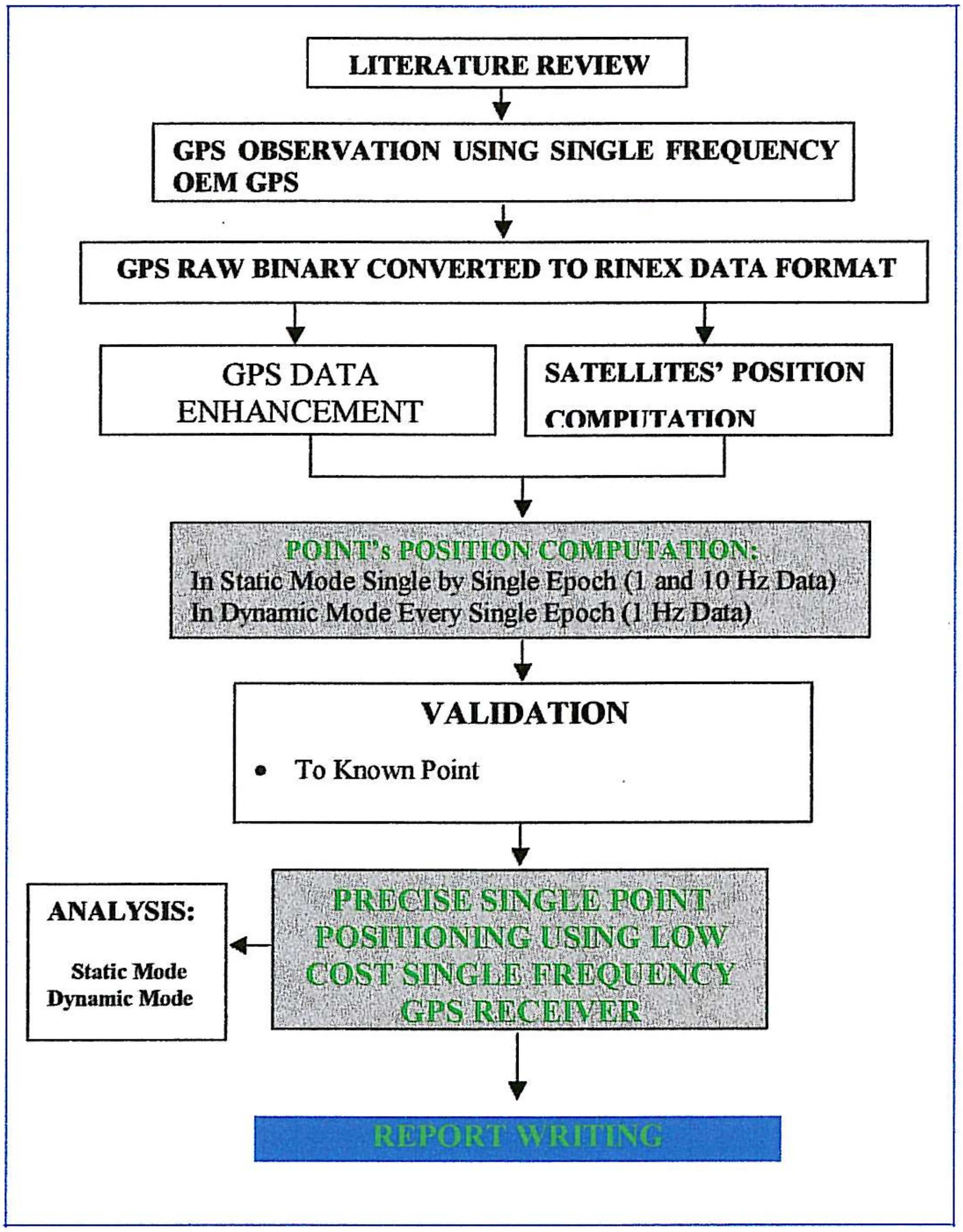

Figure 1.1 : Research Methodology

CHAPTER II

ELEMENTS OF PRECISE SINGLE POINT POSITIONING

2.1 Introduction

Since the Selective Availability was set to zero, the point positioning becomes interesting to study. Unlike in relative positioning, common mode errors do not cancel in Precise Single Point Positioning (PSPP).

Station movements due to geophysical phenomena such as tectonic plate motion; earth tides and ocean loading enter the PSPP solution in full, as do observation errors resulting from the troposphere and ionosphere. Relevant satellite specific errors are satellite clocks and orbit error, satellite antenna phase center offset and satellite orientation, earth rotation effect and satellite antenna phase wind – up error. Receiver specific errors are receiver clock error, receiver antenna phase center offset, multipath and receiver antenna phase wind-up. Atmospheric delay such as ionospheric and tropospheric delay must be taken into account (Leick,2004).

Reliance on only single frequency receiver due to the low cost aspect makes the solution more challenging due to the ionospheric delay estimation. To be real time or near real time, instead of using the precise ephemeris, the broadcast ephemeris is sufficient to be used.

Ocean loading, earth tides, receiver antenna phase center offset , multipath and receiver antenna phase wind-up and satellite antenna phase wind-up are not incorporated in order to make the model simpler.

2.2 GPS System

GPS is a Satellite Navigation System known as The Navigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System (GPS). GPS is funded by and controlled by the U. S. Department of Defense (DOD). GPS provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity and time. Four GPS satellite signals are used to compute positions in three dimensions and the time offset in the receiver clock.

The Navigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System (GPS) achieved its initial operating capability on 8 December 1993 when 24 GPS satellites were successfully operating simultaneously. During the development and experimental phases, GPS gained rapid growth in popularity. The advances in electronic components and computer or processing technology have resulted in smaller receivers that consume less power and nowadays OEM GPS or GPS card is on demand, which is small enough and handy to bring in hands (Leick,2004).

On 31 January 1994, Anti Spoofing (AS) was implemented. The purpose of AS is to make the P-Codes available only to authorized (military) users. Before 2 May 2000, at 4 UT, Selective Availability (SA) was implemented. SA entailed falsification of the satellite clock (SA-dither) and the broadcast satellite ephemeris (SA-epsilon), which is part of the navigation message (Clinton,2000).

There are three major components of GPS namely space segment, control segment, and user segment. The space segment consists of the GPS satellites, which transmit signals on two phase-modulated frequencies. The satellites also transmit a navigation message that contains, among other things, orbital data for computing the positions of all satellites.

The nominal GPS Operational Constellation consists of 24 satellites that orbit the earth in 12 hours. There are often more than 24 operational satellites as new ones are launched to replace older satellites. The orbit altitude is such that the satellites repeat the same track and configuration over any point approximately each 24 hours (4 minutes earlier each day). There are six orbital planes (with nominally four SVs in each), equally spaced (60 degrees apart), and inclined at about fifty-five degrees with respect to the equatorial plane. This constellation provides the user with between five and eight SVs visible from any point on the earth.

The control segment consists of a Master Control Station located near Colorado Springs and some monitoring stations located around the world. This control segment is to monitor the satellite transmissions continuously, to predict the satellite ephemeris, and to update the navigation message periodically.

The user segment simply stands for whoever uses GPS. The user will observe and record the transmissions of several satellites using GPS receiver and apply solution algorithms to obtain position, velocity and time.

2.3 GPS Satellite Signal

GPS Satellites transmit two microwave carrier signals. The L1 frequency (1575.42 MHz) carries the navigation message and the C/A code signals. The L2 frequency (1227.60 MHz) carries the navigation message and the P- Code which is encrypted into Y-Code using Anti Spoofing Policy.

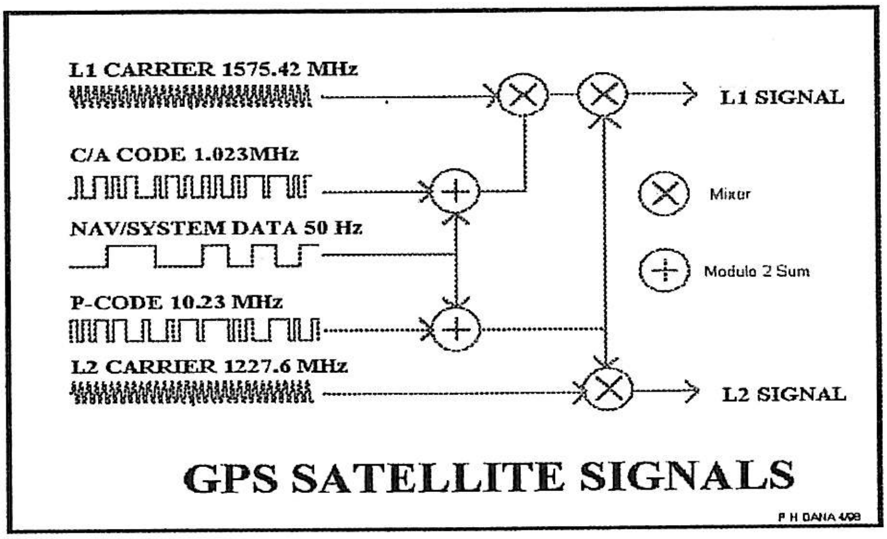

Figure 2.1:GPS Satellite Signals
(Source: Peter H. Dana,1994)

The C/A Code (Coarse Acquisition) modulates the L1 carrier phase. The C/A code is a repeating 1 MHz Pseudo Random Noise (PRN) Code. This noise-like code modulates the L1 carrier signal, "spreading" the spectrum over a 1 MHz bandwidth. The C/A code repeats every 1023 bits (one millisecond). There is a different C/A code PRN for each SV. Their PRN number, the unique identifier for each pseudo-random-noise code, often identifies GPS satellites.

The P-Code (Precise) modulates both the L1 and L2 carrier phases. The P-Code is a very long (seven days) 10 MHz PRN code. In the Anti-Spoofing (AS) mode of operation, the P-Code is encrypted into the Y-Code. The encrypted Y-Code requires a classified AS Module for each receiver channel and is for use only by authorized users with cryptographic keys.

The Navigation Message also modulates the L1 and L2 signal. The Navigation Message is a 50 Hz signal consisting of data bits that describe the GPS satellite orbits, clock corrections, and other system parameters.

2.4 GPS Observation Data

The users observe and record the GPS observation data, which will be processed further using solution algorithm provided by the manufacturer of GPS receiver or own designed algorithm.

The GPS observation data could be described in three major components as: code data, carrier phase data, and navigation message (broadcast ephemeris).

2.4.1 C/A Code Data

The GPS receiver produces replicas of the C/A and/or P (Y)-Code. Each PRN code is a noise-like, but pre-determined, unique series of bits. The receiver produces the C/A code sequence for a specific SV with some form of a C/A code generator. Modern receivers usually store a complete set of pre-computed C/A code chips in memory. The C/A code generator repeats the same 1023-chip PRN-code sequence every millisecond. The receiver slides a replica of the code in time until there is correlation with the SV code. The time taken by the receiver to correlate with the SV code multiplied by the speed of light, v, will become the pseudorange. This pseudorange will be used to compute the position of the receiver.

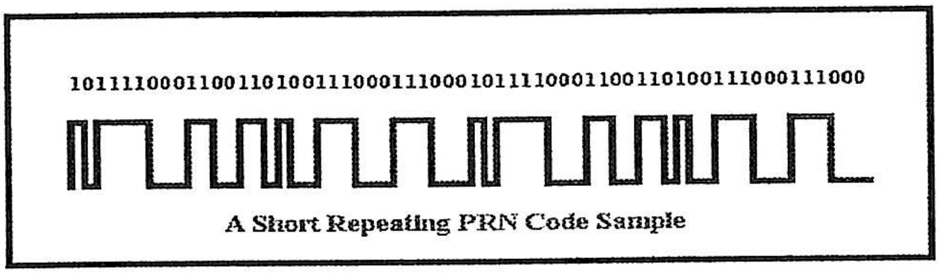

Figure 2.2: PRN Code Sample
(Source: Peter H. Dana,1994)

2.4.2 Carrier Phase Data

The L1 and/or L2 carrier signals are used as carrier phase data. L1 carrier cycles has 10.23 x 154 MHz equals to 1575.42 MHz (wavelength of 19 centimeters) and L2 = 10.23 x 120 = 1227.6 MHz (wavelength of 24.4 cm). If tracked and measured these carrier signals can provide ranging measurements with relative accuracies of millimeters if we insure that carrier phase cycles are properly accounted for. In using this carrier phase data, we face the problem to find out the integer of the cycle ambiguity.

2.4.3 Navigation Message

Each satellite transmits a data stream called the navigation message on L1 and L2 at a rate of 50 Hz. The navigation message contains information on ephemeris, age of data, clock errors, and health of satellite. Ephemeris contains the information necessary to determine the location/position of the satellite in space. Broadcast Ephemeris is ephemeris received by the receiver from the GPS satellites at the time of measurements.

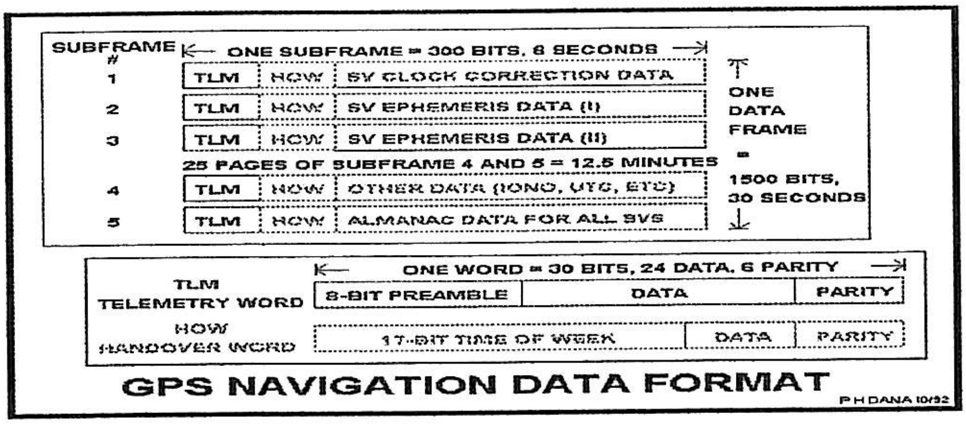

Figure 2.3: GPS Navigation Data Format

(Source : Peter H.Dana,1994)

2.5 Errors And Bias In Precise Single Point Positioning

GPS errors are a combination of noise, bias, and blunders. Noise errors are the combined effect of PRN code noise (around 1 meter) and noise within the receiver noise (around 1 meter) (Peter H.Dana,1994).

Bias errors resulted from Selective Availability (SA) and it has been cancelled or set to zero since 2 May 2000, at 4 UT (Clinton,2000) and other factors. SA was the intentional degradation of the SPS signals by a time varying bias. SA was controlled by the DOD to limit accuracy for non-U. S. military and government users. The potential accuracy of the C/A code of around 30 meters is reduced to 100 meters (two standard deviations) (Peter H.Dana,1994).

Other Bias Error sources: (Peter H.Dana,1994).

- SV clock errors uncorrected by Control Segment can result in one meter errors.
- Ephemeris data errors: 1 meter.
- Tropospheric delays: 1 meter. The troposphere is the lower part (ground level to from 8 to 13 km) of the atmosphere that experiences the changes in temperature, pressure, and humidity associated with weather changes.
- Unmodeled ionosphere delays: 10 meters. The ionosphere is the layer of the atmosphere from 50 to 500 km that consists of ionized air. The transmitted model can only remove about half of the possible 70 ns of delay leaving a ten meter un-modeled residual.
- Multipath: 0.5 meters. Multipath is caused by reflected signals from surfaces near the receiver that can either interfere with or be mistaken for the signal that follows the straight line path from the satellite. Multipath is difficult to detect and sometime hard to avoid.

Blunders can result in errors of hundred of kilometers. Control segment mistakes due to computer or human error can cause errors from one meter to hundreds of kilometers. User mistakes, including incorrect geodetic datum selection, can cause errors from 1 to hundreds of meters. Receiver errors from software or hardware failures can cause blunder errors of any size (Peter H.Dana,1994).

Noise and bias errors combine, resulting in typical ranging errors of around fifteen meters for each satellite used in the position solution. (Peter H.Dana,1994).

Unlike in relative positioning, common mode errors do not cancel in Precise Single Point Positioning (PSPP). Station movements that result from geophysical phenomena such as tectonic plate motion; earth tides and ocean loading enter the PSPP solution in full, as do observation errors resulting from the troposphere and ionosphere. Relevant satellite specific errors are satellite clocks, satellite antenna phase center offset, group delay differential, relativity and satellite antenna phase wind – up error. Receiver specific errors are receiver clock error, receiver antenna phase center offset , multipath and receiver antenna phase wind-up. Since SA (Selective Availability) off, the ionospheric and tropospheric delays are the main source of error.

2.5.1 Satellite Clock and Orbit Errors

Selective Availability (SA) entailed falsification of the satellite clock (SA-dither) and the broadcast satellite ephemeris (SA-epsilon), which was part of the navigation message (Strang,G. and K.Borre, 1997). Since it was set to zero, the satellite clock and orbit errors have been eliminated or reduced to the minimum. Before 2nd May 2000, at 4 UT, satellite clock and orbit errors were the main errors in GPS data (Clinton,2000).

2.5.2 Satellite Antenna Phase Center Offset and Satellite Orientation

Satellite antenna phase center offset do not cancel for PSPP. These offsets are given in the same satellite-fixed coordinate system that is also used to express the solar radiation pressure (Leick,1995). The origin of the coordinate system is at the satellite's center of mass, the *k*-axis points toward the earth center, the *j*-axis points along the solar panel axis, the i-axis completes the right-handed coordinate system and lies in the sun-satellite-earth plane (Witchayangkon,2000).

GPS satellite antenna phase center offset for Block II/IIA satellites is: (i,j,k) = (0.279m, 0.000m, 1.023m) while for Block IIR, the offset is (i,j,k) = (0.000m, 0.000m, 0.000m) (Leick,2004).

2.5.3 Earth Rotation Correction

Earth rotation correction corrects the satellite position for earth rotation during signal travel time (Strang,G. and K.Borre, 1997).

2.5.4 Receiver Clock Error

Receiver clock error is treated as the fourth unknown which is estimated together with the coordinates of the receiver (point position) using least square adjustment method.

2.5.5 Tropospheric and Ionospheric Delay

After SA has been discontinued, the largest errors come from the delay when a signal travels through the atmosphere (Strang,G. and K.Borre, 1997). In a vacuum the speed of an electromagnetic wave is c. In the atmosphere, this speed is reduced to v. The dimensionless ratio $n = \frac{c}{v}$ is the refractive index. The number v is related to the angular frequency ω and wave number k by $v = \frac{\omega}{k}$ (Strang,G. and K.Borre, 1997).

In a dispersive medium, these numbers are functions of ω. A packet of waves with frequencies near ω will travel not with the velocity v but with the group velocity:

$$v_{group} = \frac{d\omega}{dk} = v + k\frac{dv}{dk} \qquad (2.1)$$

The refractive index becomes $n_{group} = c / v_{group}$. The wave travels from satellite to receiver along the quickest path S (by Fermat's principle of least time). At a planar interface in the medium, this principle yields Snell's law (Strang,G. and K.Borre, 1997).

The delay along S of the carrier in comparison to the straight – line path L in a vacuum, is $dt_{\tau\phi}$: (Strang,G. and K.Borre, 1997).

$$dt_{\phi} = \int_S \frac{dS}{v} - \int_L \frac{dL}{c} \qquad (2.2)$$

Most of this delay comes from change of speed, a smaller part comes from change of path. Multiplying by c, the two parts are:

$$cdt_{\phi} = \int_L (n-1)dL + \int_S ndS - \int_L ndL \qquad (2.3)$$

The modified Hopfield model is used to compute the tropospheric delay (Goad, C.C. & Goodman, L.,1974). This tropospheric delay is experienced by the GPS signal as it travels through the troposphere.

The tropospheric delay dT of GPS signals received at a position with the latitude φ, at a zenith distance of z = 90° – elevation angle, and with air pressure Po in millibars at height H in km, at temperature To ° K and partial pressure of water vapor e_o in milibars, is: (Strang,G. and K.Borre, 1997).

Since the receiver used in this study is single frequency, the ionospheric delay is estimated by using Klobuchar Model. The Klobuchar algorithm can compensate for 50-60% of the actual group delay (Leick,2004).

2.6 Reference Frames

2.6.1 Time Reference

Any device capable of generating a sequence of constant intervals in time can serve as a clock. The best timing scales available today make use of quartz crystal oscillations or state transitions of atoms. In GPS surveying and navigation, these time scales must be related to the earth's rotation. After all, the topocentric distance to a satellite is directly relate to the rotational position of the earth, which, in turn is a function of time. In GPS system, GPS satellites carry the atomic clocks which are the highest accurate clock , while the GPS receivers carry the quarts crystal clocks which are less accurate compared to atomic clocks. Atomic clocks and quarts crystal clocks generate independent time scales so there is a need to coordinate these times or in other words a time reference is needed.

2.6.1.1 Astronomic Time

There are three astronomic time scales namely sidereal time (ST), universal (solar) time (UT), and ephemeris time. Sidereal time and universal time are based on the earth's rotation, whereas ephemeris time is based on the orbital motion of the sun and the moon following the law of gravitation. (Leick, 1995). The hour of angles of the true and mean vernal equinox are called the apparent sidereal time (AST) and mean sidereal time (MST), respectively. The small difference between AST and MST is called the equation of equinox. This difference is the result of the nutations of rotation axis.

The apparent sidereal time is corrected for the polar motion. Using the equation of equinox, then the mean sidereal time corrected for the polar motion is obtained. Next, the longitude of the observing station in the Conventional Terrestrial Reference System (CTRS) is subtracted from MST corrected for the polar motion, yielding an expression for the Greenwich mean sidereal time (GMST).

Sidereal time and universal time are mathematically related through the mean time scale as follows:

$$\text{GMST} = \text{UT1} + \alpha_m - 12^h \tag{2.4}$$

With

$$\alpha_m = 18^h 41^m 50^s.54841 + 8640184^s.812866 T_U + 0^s.093104 T_U^2 - 6^s.2\times10^{-6} T_U^3 \tag{2.5}$$

where T_U is the number of Julian centuries of 36,525 days of universal time elapsed since 2000 Greenwich noon, 1 January, 12^h UT1 (JD 2,451,545.0). UT1 is the universal time of Greenwich meridian. (Leick, 1995).

2.6.1.2 Atomic Time

The length of atomic second was defined at the 13th General Conference of Weights and Measures (CGPM) in Paris as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium-133 atom.(Leick, 1995).

2.6.1.3 Time Link to Earth Rotation

The atomic time is not related to the earth rotation but to the laws of nature governing the transition of energy levels in atoms. For navigation and surveying, however, it is necessary to relate time to the rotation of the earth. Atomic time is tied to earth rotation by introducing the universal coordinated time (UTC) scale. This is a hybrid time scale in the sense that the UTC second is the international system (SI) second as established and made available through the highly stable atomic time TAI , and the epoch of UTC is such that

$$|UT1 - UTC| < 0^s.9$$

UTC is also referred to as broadcast time and is the basis for all daily civilian timing requirements. The rotation of the earth means that clock A can be synchronized with B, and B with C, but clock C is not synchronized with A. So a universal time is needed that goes at a different rate from local time. This coordinated Universal Time (UTC) is maintained at the GPS control center in Colorado Springs. (Strang,G. and K.Borre, 1997).

2.6.1.4 GPS Time and Julian Date

The GPS satellites follow GPS time (GPST). This time scale is steered to be within one microsecond of UTC. The initial epoch of GPST is 0^h UTC January 6, 1980. Since that epoch , GPST has not been adjusted to account for the leap seconds. It follows that GPST – TAI = -19^s, i.e., equal to the offset of TAI and UTC at the initial GPST epoch. Each satellite carries several atomic clocks, including the spare clock. These clocks establish the space vehicle time. The control center synchronizes the clocks of the various space vehicles to GPST. (Leick,2004).

All epoch times in the GPS data i.e. RINEX file use time in the format : year, month, day, hour, minutes, and seconds. So, basically a conversion is needed to convert from this date format to GPS time (week number and second of week). Traditionally geodesists and astronomers solve this problem by introducing the (modified) Julian Day number.

The Julian day date (JD) is a convenient continuous counter of mean solar days from the beginning of the year 4713 B.C. By tradition, the Julian day date begins at Greenwich noon, i.e. 12^h UT1. Conversion of any Gregorian calendar date

(Y=year, M=month, D=day) to JD for Greenwich noon is accomplished by (van Flandern and Pulkkinen,1979):

$$JD = 367 \times Y - 7 \times [Y + (M + 9)/12]/4 + 275 \times M/9 + D + 1{,}721{,}014 \qquad (2.6)$$

This expression is valid for dates since March 1900. The Modified Julian Date (MJD), starting at midnight, is defined as: (Strang,G. and K.Borre, 1997)

$$MJD = JD - 2\ 400\ 000.5 \qquad (2.7)$$

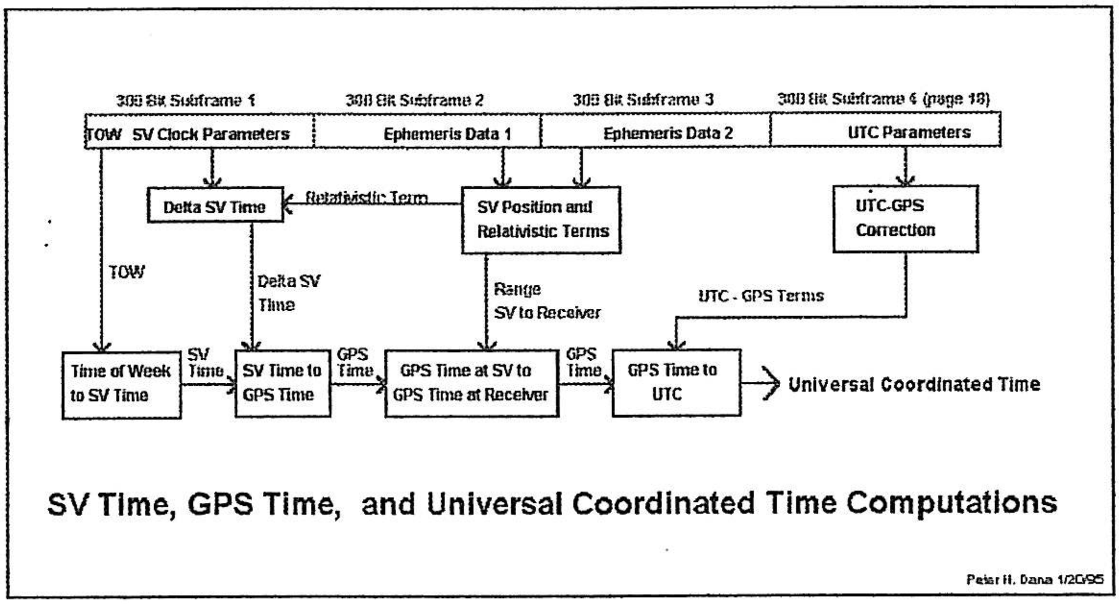

Figure 2.4: SV Time (Atomic Time), GPS Time and UTC

(Source: Peter H.Dana,1994)

2.6.2 Coordinates Reference

The earth, as with all celestial bodies, is not static in nature. The earth moves, rotates and undergoes deformation. Since motion and position are not absolute concepts, they can be mathematically described only with respect to some reference of coordinates (Kovalevsky and Mueller,1989). The purpose of a reference frame is to provide the means to materialize a reference system so that it can be used for the quantitative description of positions and motions on the Earth (terrestrial frames) or of celestial bodies including the earth in space (celestial frames) (Kovalevsky and

Mueller,1989). Many reference frames and systems have been introduced and made available to the public. World Geodetic System (WGS-84) and International Terrestrial Reference Frame (ITRF) are the examples.

2.6.2.1 GPS WGS-84

The military reference frame World Geodetic System 1984(WGS-84) is applied to the GPS system. The WGS-84 coordinate system is a Conventional Terrestrial Reference System (CTRS) utilizing a right-handed Earth-fixed orthogonal coordinate system. Its z-axis is in the direction of the IERS Reference Pole (IRP) that corresponds to the direction of the BIH Conventional Terrestrial Pole (CTP) at epoch 1984 with an uncertainty of 0.005" (IERS Conventions, 1996, page 11; NIMA, 1997,page 2-2). Its X-axis is the intersection of the IERS Reference Meridian (IRM) with the plane passing through the origin and normal to the Z-axis (NIMA, 1997,page 2-2). The IRM is coincident with the BIH Zero Meridian at epoch 1984 with an uncertainty of 0.005" (IERS Conventions, 1996, page 11). Its Y-axis completes a right-handed ECEF orthogonal coordinate system. The latest realization of WGS-84 frame is at epoch 2000 and the name has been given as WGS-84 (G1160). This realization is implemented by the National Imagery and Mapping Agency (NIMA). The letter 'G' indicates that the observation were obatined through GPS technique and that Doppler data were not included in the observations. The number '1160' is the GPS week number when coordinate frame was made available through NIMA GPS ephemerides. This is the fourth edition of WGS-84. The previous versions of WGS reference frames are WGS-84, WGS-84(G730), and WGS-84(G873). WGS-84(G1160) is implemented in the GPS Operational Control Segment (OCS) and incorporated into the Keppler elements of the broadcast message.

2.6.2.2 ITRF 2000

ITRF-2000 is an adoption of the newest ITRS (International Terrestrial Reference System) realization. ITRF-2000 consists of not only a set of positions and velocities of global network tracking stations, but also related useful markers recognized by a wide application community such as geodesy, cartography, etc. ITRF-2000 includes the previous ITRF stations and expands to cover other types of points: (Witchayangkon,2000)

- PRARE stations
- IGEX-98 GLONASS stations
- Points located at tide gauges, following the GLOSS (Global Sea Level Observing System) and related programs such as EOSS (European Sea-Level Observing System) or EUVN (European Vertical Reference Network)
- Points linking high accuracy gravity sensors or time/frequency laboratories
- Calibration sites for satellite altimetry and
- Markers useful for national surveying agencies.

2.6.3 Agreement Between WGS-84 and ITRF

In Malaysia, ITRF-2000 has been adopted and the name is GDM2000 (Geocentric Datum of Malaysia 2000) (JUPEM,2003). A comparison of coordinates between two reference frame systems can be made after the adjustment of a best fitting seven parameters transformation. Malys and Slater (1994) reported an agreement between WGS-84(G730) and ITRF-92 at the 0.1 m level. Daily comparisons of WGS-84(G873) and ITRF-94 through their respective precise orbits reveal systematic differences no larger than 2 cm. The day to day dispersion on these parameters indicates that these differences are statistically insignificant (NIMA, 1997). WGS-84(G1160) therefore can be used to express ITRF2000 or GDM2000.

CHAPTER III

ALGORITHM OF PRECISE SINGLE POINT POSITIONING USING LOW COST SINGLE FREQUENCY GPS RECEIVER

3.1 Introduction

In this chapter, the algorithm of Precise Single Point Positioning will be presented. It is based on some reference books and written in Matlab language. The algorithm can be shown as below:

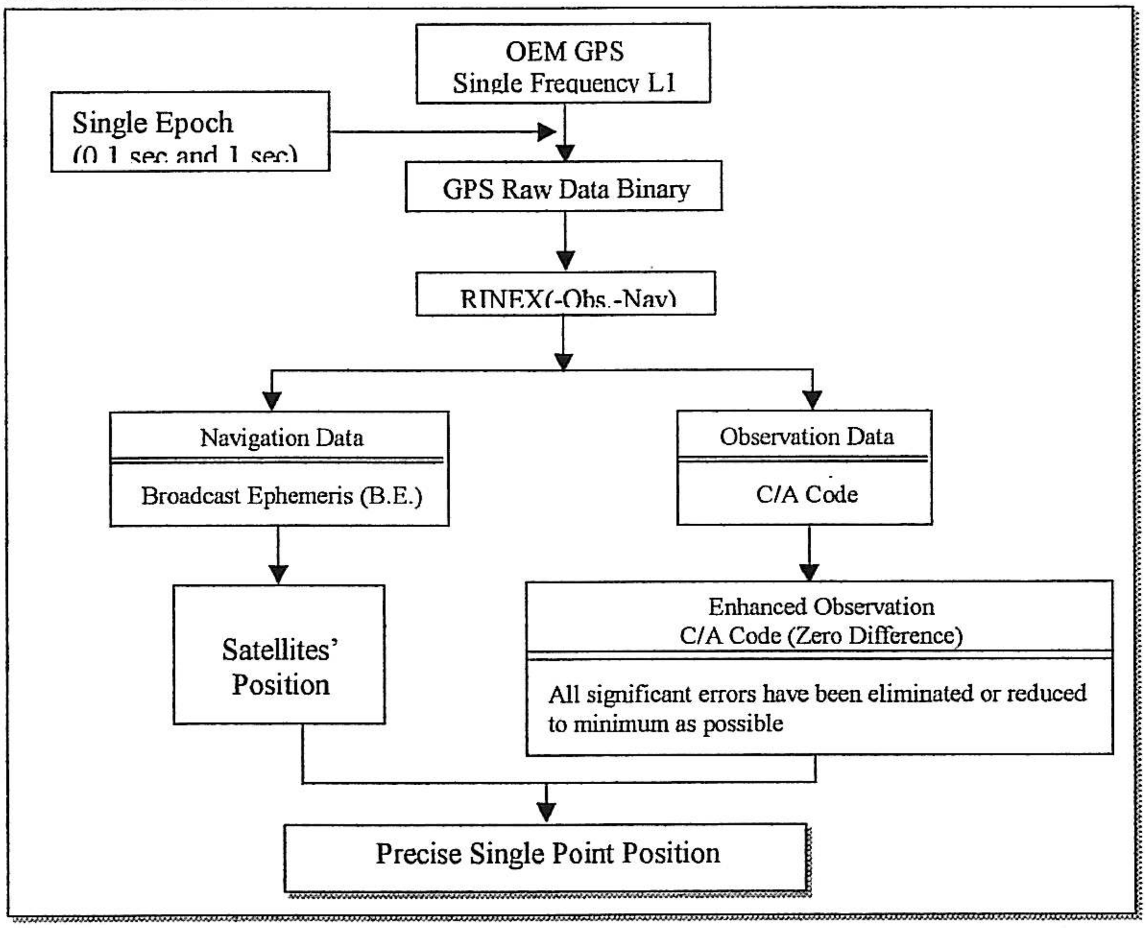

Figure 3.1: Precise Single Point Positioning Algorithm

1. Input or Data reading and formatting.
2. Data Enhancement.
3. Satellites' Position Computation.
4. Precise Single Point Position Computation.
5. Output or Result Storage.

3.2 Input Or Data Reading And Formatting

Input to the routines is the GPS data. Using the CMC Allstar OEM GPS Single Frequency collects this GPS data. The GPS data is in the format binary. This binary format is converted into RINEX format 2.10 using TEQC.exe (Transfer, edit, and quality check) program. Then the RINEX format data is read by the routines. RINEXEku.m (the m-file/matlab routine) is reading the broadcast ephemeris data and arrange it into matrice format. ObsRinex.m is reading the observation data i.e. C/A code (L1 pseudorange) and arrange it into matrice format. Both of these data, broadcast ephemeris and C/A code, will incorporate together. Broadcast ephemeris to compute the satellites positions and together with the C/A code, the point position could be determined.

3.2.1 Broadcast Ephemeris Data RINEX Format

The broadcast ephemeris of each GPS satellite in RINEX format is read by RINEXEku.m and it arrange the data into matrice format (m x n, where m is no of ephemeredes data, n is no of satellites). The ephemeris data of each satellite as the following:

1. svprn : satellite PRN number.
2. af2 : satellite Vehicle clock drift rate.
3. M_0 : mean anomaly at reference time.
4. roota : square root of semi major axis of the orbit.
5. deltan : the correction to the mean motion.
6. ecc : eccentricity of the orbit.

7. ω :argument of perigee.
8. C_{uc} : amplitude of the cosine harmonic correction term to the argument of latitude.
9. C_{us} : amplitude of the sine harmonic correction term to the argument of latitude.
10. C_{rc} : amplitude of the cosine harmonic correction term to the orbit radius.
11. C_{rs} : amplitude of the sine harmonic correction term to the orbit radius.
12. i_0 : inclination angle at reference time.
13. idot : rate of inclination angle.
14. C_{ic} : amplitude of the cosine harmonic correction term to the angle of inclination.
15. C_{is} : amplitude of the sine harmonic correction term to the angle of inclination.
16. Ω_0 : longitude of ascending node of orbit plane at weekly epoch.
17. $\dot{\Omega}$: rate of the right ascension.
18. toe : reference time ephemeris.
19. af0 : satellite vehicle clock bias.
20. af1 : satellite vehicle clock drift.

3.2.2 GPS Observation Data RINEX Format

The observation data of each GPS satellite in RINEX format is read by ObsRinex.m and it arrange the data into matrice format (m x n, where m is no of C/A code, n is no of satellites). The observation data of each satellite as the following:

1. Epoch : year (2 digits), month, day, hour, min, sec
2. PRNs (satellite number) in current epoch
3. Observation data i.e. C/A code of each PRN (satellite)

3.3 Data Enhancement

The data enhancement will play the important part. In the data enhancement, error and bias modeling and least square adjustment will be applied.

3.3.1 Basic Equation Of GPS C/A Code Observation

The basic equation for a code observation (distance but not phase) looks like: (Strang,G. and K.Borre, 1997).

$$P_r^s = \rho_r^s + cdt_r + I_r^s + T_r^s + e_r^s \tag{3.1}$$

The ionospheric delay is I_r^s, the tropospheric delay is T_r^s, and c denotes the speed of light. The receiver clock offset is dt_r and e_s^r denotes other errors.

The distance between satellite *s* and receiver *r*, corrected for earth rotation, is defined by:

$$\rho_r^s = \left\| R_3(\omega_e \tau_r^s) r^k (t - \tau_s^r)_{ECEF} - r_r(t)_{ECEF} \right\| \tag{3.2}$$

The rotation matrix is necessary when using vectors referenced to an Earth centered and Earth fixed system (ECEF). The travel time from the satellite *s* to the receiver *r* is denoted τ_r^s. The rotation rate of the earth is ω_e. Position vectors in the ECEF are denoted $r(t)_{ECEF}$. The argument *t* emphasizes on dependence on time.

The matrice R_3 accounts for rotation by the angle $\omega_e \tau_r^s$ while the signal is traveling:

$$R_3(\omega_e \tau_r^s) = \begin{bmatrix} \cos(\omega_e \tau_r^s) & \sin(\omega_e \tau_r^s) & 0 \\ -\sin(\omega_e \tau_r^s) & \cos(\omega_e \tau_r^s) & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (3.3)$$

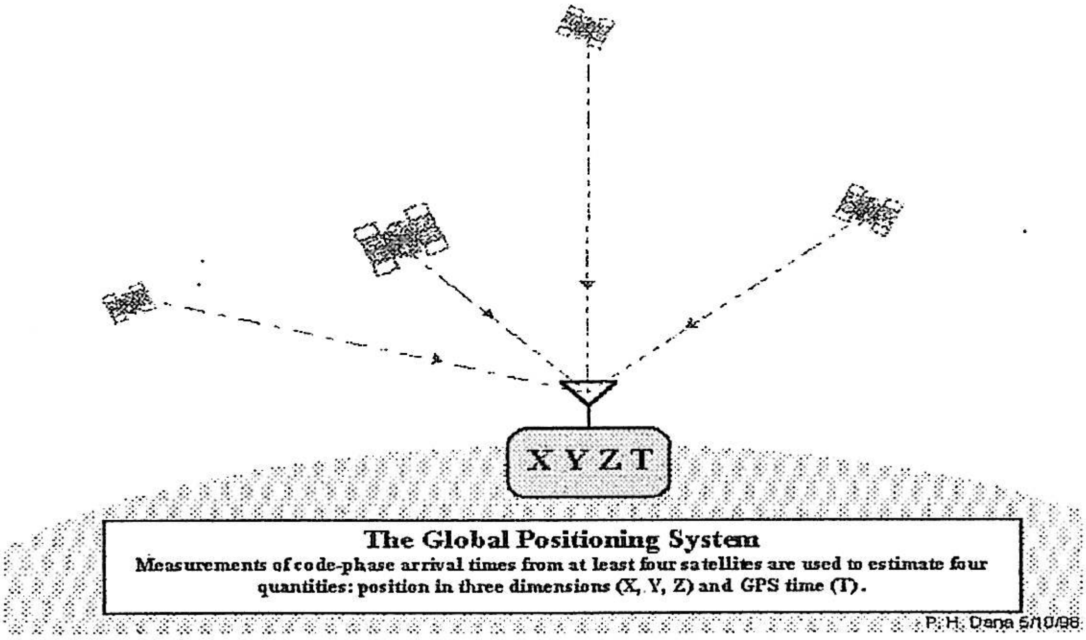

Figure 3.1: Determination of Point Position From Four GPS Satellites

(Source: Peter H.Dana,1994)

3.3.2 Error and Bias Modeling In GPS Data

Since the Selective Availability was set to zero, the point positioning becomes interesting to study. Reliance on only single frequency receiver due to the low cost aspect makes the Single Point Positioning more challenging due to the ionospheric and tropospheric delay estimation. To be real time or near real time, instead of using the precise ephemeris, the broadcast ephemeris is sufficient to be used.

Unlike in relative positioning, common mode errors do not cancel in Precise Single Point Positioning (PSPP). Station movements that result from geophysical phenomena such as tectonic plate motion; earth tides and ocean loading enter the PSPP solution in full, as do observation errors resulting from the troposphere and ionosphere. Relevant satellite specific errors are satellite clocks and orbit error, satellite antenna phase center offset and satellite orientation, earth rotation effect and satellite antenna phase wind – up error. Receiver specific errors are receiver clock error, receiver antenna phase center offset , multipath and receiver antenna phase wind-up. Atmospheric delay such as ionospheric and tropospheric delay must be taken into account. (Leick,2004).

Ocean loading, earth tides, receiver antenna phase center offset , multipath and receiver antenna phase wind-up and satellite antenna phase wind-up are not incorporated in order to make the model simpler. After removing all the errors and bias, least square adjustment is applied to obtain the point position for single epoch (0.1 sec and 1 sec).

3.3.2.1 Satellite Clock and Orbit Errors

Selective Availability (SA) entailed falsification of the satellite clock (SA-dither) and the broadcast satellite ephemeris (SA-epsilon), which was part of the navigation message.(Strang,G. and K.Borre, 1997). Since it was set to zero, the satellite clock and orbit errors have been eliminated or reduced to the minimum. Before 2nd May 2000, at 4 UT, satellite clock and orbit errors were the main errors in GPS data. (Clinton,2000).

3.3.2.2 Satellite Antenna Phase Center Offset and Satellite Orientation

Satellite antenna phase center offset do not cancel for PSPP (precise single point positioning). These offsets are given in the same satellite-fixed coordinate system that is also used to express the solar radiation pressure (Leick,1995). The origin of the coordinate system is at the satellite's center of mass, the *k*-axis points toward the earth center, the *j*-axis points along the solar panel axis, the *i*-axis completes the right-handed coordinate system and lies in the sun-satellite-earth plane (Witchayangkon,2000).

GPS satellite antenna phase center offset for Block II/IIA satellites is:

$$(i,j,k) = (0.279\text{m}, 0.000\text{m}, 1.023\text{m})$$

while for Block IIR, the offset is:

$$(i,j,k) = (0.000\text{m}, 0.000\text{m}, 0.000\text{m}).$$

Let X_{sat} and X_{sun} be the GPS satellite and the Sun coordinates in the ECEF system respectively (Leick,2004). Unit vector e at the satellite and pointing towards the sun is :

$$e = \frac{Xsun - Xsat}{abs(Xsun - Xsat)} \tag{3.4}$$

Unit vector at the satellite center of mass and pointing to the Earth's center is:

$$k = \frac{-Xsat}{abs(Xsat)} \tag{3.5}$$

Unit vector along the solar panel axis is:

$$j = k \times e \tag{3.6}$$

The direction that completes the satellite-fixed right handed coordinates system is:

$$i = j \times k \tag{3.7}$$

If O denotes the antenna offset expressed in the satellite fixed (i,j,k) coordinate system then the offset expressed in the ECEF coordinates system is:

$$\Delta Xsat = R^{-1}O \tag{3.8}$$

where R is the rotation matrix, $R = \begin{bmatrix} i^T \\ j^T \\ k^T \end{bmatrix}$. (3.9)

Sun's coordinates computation can be read for detail in (Reidel,1971). The routine IONOSLSA.m (the matlab file) incorporates satellite antenna phase center offset and satellite orientation.

3.3.2.3 Earth Rotation Correction

Earth rotation correction corrects the satellite position for earth rotation during signal travel time. Let ω_e denotes the earth's rotation rate, Xs the satellite's position before rotation and Xs_rot the satellite's position after rotation. The rotation matrix is R_3, equation 3.3, and the angle is $\omega_t = \omega_e \, {}^{\rho}\!/_{c}$. ρ is the pseudorange and c is the speed of light. (Strang,G. and K.Borre, 1997). This correction is written in e_r_corr.m (the matlab file).

3.3.2.4 Receiver Clock Error

Receiver clock error is treated as the fourth unknown which is estimated together with the coordinates of the receiver (point position) using least square adjustment method.

3.3.2.5 Tropospheric Delay

The modified Hopfield model is used to compute the tropospheric delay (Goad, C.C. & Goodman, L.,1974). This tropospheric delay is experienced by the GPS signal as it travels through the troposphere. The tropospheric delay dT of GPS signals received at a position with the latitude φ, at a zenith distance of z = 90° – elevation angle, and with air pressure *Po* in millibars at height H in km, at temperature *To* ° K and partial pressure of water vapor e_o in milibars, is: (Strang,G. and K.Borre, 1997).

$$dT = 0.002277\frac{1+0.0026\cos 2\varphi + 0.00028H}{\cos z}\left(Po + \left(\frac{1255}{To} + 0.05\right)eo\right) \quad (3.10)$$

Azimuth and elevation angle of each satellite at the given epoch have to be determined first before using the above formula. The azimuth and elevation angle of each satellite can be determined as follows:

Transform the topocentric vector *x* into a local ***e, n, u*** coordinate system with u in the direction of the plumb line, n pointing north, and e pointing east. The topocentric vector *x* is given by the geocentric vector of the point position (*Xr*) and the satellite's position (*Xs*).

$$\begin{bmatrix} E \\ N \\ U \end{bmatrix} = \begin{bmatrix} -\sin\lambda & -\sin\varphi\cos\lambda & \cos\varphi\cos\lambda \\ \cos\lambda & -\sin\varphi\sin\lambda & \cos\varphi\sin\lambda \\ 0 & \cos\varphi & \sin\varphi \end{bmatrix} \begin{bmatrix} \\ Xs - Xr \\ \\ \end{bmatrix} \quad (3.11)$$

Azimuth : $Az = \arctan(E/N)$ (3.12)

Elevation angle : $El = \arctan\left(\frac{U}{\sqrt{N^2 + E^2}}\right)$ (3.13)

Where :

$E = east$
$N = north$
$U = up$
$\varphi = latitude$
$\lambda = longitude$

This tropospheric delay is applied in tropo.m and topocentrion.m.

3.3.2.6 Ionospheric Delay

Since the receiver used in this study is single frequency, the ionospheric delay is estimated by using Klobuchar Model. The Klobuchar algorithm can compensate for 50-60% of the actual group delay.(Leick,2004). The algorithm is as follows: (Leick,2004)

φ, λ = geodetic latitude and longitude of receiver (SC, semicircle)
α_k^p, β_k^p = azimuth and elevation of satellite (SC, semicircle)
T = GPS time (s)
α_n, γ_n = broadcast coefficients

$$F = 1 + 16(0.53 - \beta_k^p)^3 \tag{3.14}$$

$$\psi = \frac{0.0137}{\alpha_k^p + 0.11} - 0.022 \tag{3.15}$$

$$\varphi_{IP} = \begin{cases} \varphi + \psi \cos \alpha_k^p, if |\varphi_{IP}| \leq 0.416 \\ 0.416, if \varphi_{IP} \rangle 0.416 \\ -0.416, if \varphi_{IP} \langle -0.416 \end{cases} \tag{3.16}$$

$$\varphi_{IP} = \lambda + \frac{\psi \sin \alpha_k^p}{\cos \varphi_{IP}} \tag{3.17}$$

$$\phi = \varphi_{IP} + 0.064 \cos(\lambda_{IP} - 1.617) \tag{3.18}$$

$$t = \begin{cases} \lambda_{IP} 4.32x10^4 + T, if \cdots 0 \le t < 86400 \\ \lambda_{IP} 4.32x10^4 + T - 86400, if \cdots t \ge 86400 \\ \lambda_{IP} 4.32x10^4 + T + 86400, if \cdots t \le 0 \end{cases} \quad (3.19)$$

$$P = \begin{cases} \sum_{n=0}^{3} \gamma_n \phi^n, if \cdots P \ge 72000 \\ 72000, if \cdots P < 72000 \end{cases} \quad (3.20)$$

$$x = \frac{2\pi(t - 50400)}{P} \quad (3.21)$$

$$A = \begin{cases} \sum_{n=0}^{3} \alpha_n \phi^n, if \cdots A \ge 0 \\ A = 0, if \cdots A < 0 \end{cases} \quad (3.22)$$

$$I_k^p = \begin{cases} cF\left[5x10^{-9} + A(1 - \frac{x^2}{2} + \frac{x^4}{24})\right], if|x| < 1.57 \\ cF(5x10^{-9}), if|x| > 1.57 \end{cases} \quad (3.23)$$

$c = speed\ of\ light$

I_k^p =*ionospheric delay of each satellite (sec)*

This ionospheric delay is written in IONOSLSA.m.

3.4 Computation Of Satellite Position

To be real time or near real time, instead of using the precise ephemeris, the broadcast ephemeris is sufficient to be used. The algorithm of the satellite position is written in SATPOS.m. To obtain a satellite position in the Earth centered Earth fixed system, all the information from the ephemeris data is used. The Earth centered Earth fixed coordinates of a satellite in space described by Keplerian orbit elements.

The orbit plane intersects the Earth equator plane in the nodal line. The direction in which the satellite moves from south to north is called the ascending node

K. The angle between the equator plane and the orbit plane is the inclination *i*. The angle at the earth's center *C* between the X-axis and the ascending node *K* is called Ω, it is a right ascension. The angle at *C* between *K* and the perigee *P* is called argument of perigee ω. It increases counter-clockwise viewed from the positive Z-axis.

The ξ-axis points to the perigee and the η-axis towards the descending node. The ζ-axis is perpendicular to the orbit plane. There are eccentric anomaly *E* and the true anomaly *f*. Hence:

$$\xi = r\cos f = a\cos E - ae = a(\cos E - e) \tag{3.24}$$

$$\eta = r\sin f = b\sin E = a\sqrt{1-e^2}\sin E \tag{3.25}$$

Hence the position vector ***r*** of the satellite with respect to the center of the earth *C* is :

$$r = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix} = \begin{bmatrix} a(\cos E - e) \\ a\sqrt{1-e^2}\sin E \\ 0 \end{bmatrix} \tag{3.26}$$

Simple trigonometry leads to the following expression for the norm

$$|r| = a(1 - e\cos E) \tag{3.27}$$

In general *E* varies with time *t* while *a* and *e* are nearly constant. $|r|$ is the geometric distance between satellite S and the earth center C. The mean motion *n* which is the mean angular satellite velocity is:

$$n = \frac{T}{2\pi} = \sqrt{\frac{GM}{a^3}} \tag{3.28}$$

where,

T is the period of one revolution of the satellite

GM is the WGS 84 value of the earth's universal gravitational parameter

Let t_o be the time the satellite passes perigee, so that $\mu(t) = n(t - t_o)$. Kepler's famous equation relates the mean anomaly μ and the eccentric anomaly E:

$$\mathbf{E = \mu + e \sin E} \tag{3.29}$$

From equation 3.24 and 3.25, finally:

$$f = \arctan\frac{\eta}{\xi} = \arctan\frac{\sqrt{1-e^2}\sin E}{\cos E - e} \tag{3.30}$$

These relations are basic for every calculation of a satellite position.

Then the geocentric coordinates of satellite s at time t_j are given as:

$$\begin{bmatrix} X^s(t_j) \\ Y^s(t_j) \\ Z^s(t_j) \end{bmatrix} = R_3(-\Omega_j^{\ s})R_1(-i_j^{\ s})R_3(-\omega_j^{\ s})\begin{bmatrix} r_j^{\ s}\cos f_j^{\ s} \\ r_j^{\ s}\sin f_j^{\ s} \\ 0 \end{bmatrix} \tag{3.31}$$

where $r_j^{\ s} = |r(t_j)|$ comes from (3.27) with a,e, and E evaluated for $t = t_j$.

Here is the systematic algorithm to compute the satellite position based on the above theory: (Leick,1994)

Table 3.1: Ephemeris Algorithm

$\mu = 3.986005 \times 10^{14} meters^3 / \sec^2$	WGS 84 value of the earth's universal gravitational parameter
$\dot{\Omega}_e = 7.2921151467 \times 10^{-5} rad / \sec$	WGS 84 value of earth's rotation rate
$a = \left(\sqrt{a}\right)^2$	Semi major axis
$n_0 = \sqrt{\frac{\mu}{a^3}}$	Computed mean motion – rad/sec
$t_k = t - t_{oe}$	Time from ephemeris reference epoch
$n = n_0 + \Delta n$	Corrected mean motion
$M_k = M_0 + nt_k$	Mean anomaly
$E_k = M_k + e \sin E_k$	Keppler's equation for eccentric anomaly
$\cos f_k = (\cos E_k - e)/(1 - e\cos E_k)$ $\sin f_k = \sqrt{1-e^2} \sin E_k /(1 - e\cos E_k)$	True anomaly
$f_k = \tan^{-1} \frac{\sqrt{1-e^2} \sin E_k}{\cos E_k - e}$	
$E_k = \cos^{-1}\left[\frac{e + \cos f_k}{1 + e\cos f_k}\right]$	Eccentricity anomaly
$\phi_k = f_k + \omega$	Argument of latitude
$\delta u_k = C_{us} \sin 2\phi_k + C_{uc} \cos 2\phi_k$	Argument of latitude correction
$\delta r_k = C_{rs} \sin 2\phi_k + C_{rc} \cos 2\phi_k$	Radius correction
$\delta i_k = C_{is} \sin 2\phi_k + C_{ic} \cos 2\phi_k$	Correction to inclination
$u_k = \phi_k + \delta u_k$	Corrected argument of latitude
$r_k = a(1 - e\cos E_k) + \delta r_k$	Corrected radius
$i_k = i_0 + \delta i_k + (IDOT)t_k$	Corrected inclination
$x'_k = r_k \cos u_k$ $y'_k = r_k \sin u_k$	Positions in orbital plane
$\Omega = \Omega_0 + (\dot{\Omega} - \dot{\Omega}_e)t_k - \dot{\Omega}_e t_{oe}$	Corrected longitude of ascending node

$$X_k = x'_k \cos\Omega_k - y'_k \cos i_k \sin\Omega_k$$
$$Y_k = x'_k \sin\Omega_k + y'_k \cos i_k \sin\Omega_k \qquad \text{Earth fixed coordinates}$$
$$Z_k = y'_k \sin i_k$$

t is GPS time at time of transmission, i.e. GPS time corrected for transit time (range/speed of light). Furthermore, t_k shall be the actual total time difference between the time t and the epoch time t_{oe}, and must account for beginning or end of week crossovers. That is, if t_k is greater than 302,400 sec then subtract 604,800 sec from t_k. If t_k is less than −302,400 sec then add 604,800 sec to t_k.

In the broadcast ephemeris and observation data , the time is in the format : year, month, day, hour, minutes, and seconds (UT). So basically a conversion from this date-format to GPS time (week number and seconds of week) is needed. In this case, Julian Date is introduced to solve the problem.

3.5 Precise Single Point Position Computation

After data enhancement completed, the computation of the point position is starting. For every single epoch, there are usually eight to eleven enhanced pseudoranges with the satellite position. There are redundant observations for minimum four pseudoranges are only required. Hence, the least square adjustment will be applied to obtain the position. The least square adjustment routine is written in the Bancroft.m and LSA.m.

3.5.1 Least Square Adjustment Of The GPS Observation

The GPS observation used to compute the point position is the pseudorange. The equation of the basic pseudorange, which travels through atmosphere could be expressed as: (Strang,G. and K.Borre, 1997)

$$P_r^s = \rho_r^s + I_r^s + T_r^s + e_r^s \, . \tag{3.32}$$

$$\rho_r^s = \sqrt{(Xs - Xr)^2 + (Ys - Yr)^2 + (Zs - Zr)^2} + cdt \tag{3.33}$$

where:

P_r^s = pseudorange between satellite and receiver. (m)

I_r^s = ionospheric delay experienced by GPS signal (C/A code). (m)

T_r^s = tropospheric delay experienced by GPS signal (C/A code). (m)

e_r^s = other errors.

ρ_r^s = the distance between satellite and receiver which only contains the receiver clock error (cdt)

Xs, Ys, Zs = the satellites' coordinates in WGS'84.

Xr, Yr, Zr = the receiver's coordinates in WGS'84.

cdt = the receiver's clock error expressed in distance.

3.5.2 Least Square Adjustment Model

Minimum four pseudoranges are required to solve the equations to obtain the receiver's position and receiver's clock error. When more than four pseudoranges are observed, then least square adjustment is applied. Using the OEM GPS ALLSTAR CMC, there are usually eight to eleven satellites observed at every single epoch.

After removing all the errors and bias i.e. satellite clocks and orbit error, satellite antenna phase center offset and satellite orientation, earth rotation effect, ionospheric and tropospheric delay, which result into the following corrected pseudorange equation:

$$\rho_r^s = \sqrt{(Xs - Xr)^2 + (Ys - Yr)^2 + (Zs - Zr)^2} + b \tag{3.34}$$

with $b = cdt$.

Then the least square adjustment is applied. Since the equation is non linear, it must be linearized using Taylor series 1st order.

$$\rho_r^s = \rho^o + \delta\rho \tag{3.35}$$

$$\delta\rho = \frac{-(Xs - X_r^o)\delta Xr - (Ys - Y_r^o)\delta Yr - (Zs - Z_r^o)\delta Zr}{\sqrt{(Xs - X_r^o)^2 + (Ys - Y_r^o)^2 + (Zs - Z_r^o)^2}} + \delta b \tag{3.36}$$

Then the linearized equations are arranged into matrix form :

$$V = Ax + L \tag{3.37}$$

with,

$$A = \begin{pmatrix} \frac{-(Xs_i - X_r^o)}{\rho_i^o - b_i^o} & \frac{-(Ys_i - Y_r^o)}{\rho_i^o - b_i^o} & \frac{-(Zs_i - Z_r^o)}{\rho_i^o - b_i^o} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \end{pmatrix} \tag{3.38}$$

$$L = \begin{pmatrix} \rho^o - \rho_r^s \\ \vdots \\ \vdots \\ \vdots \end{pmatrix} \tag{3.39}$$

$$x = \begin{pmatrix} \delta Xr \\ \delta Yr \\ \delta Zr \\ \delta b \end{pmatrix} = \begin{pmatrix} Xr - X_r^o \\ Yr - Y_r^o \\ Zr - Z_r^o \\ b - b^o \end{pmatrix} = -(A^T W A)^{-1} A^T W L \tag{3.40}$$

where : $\rho^o = approximated\ corrected\ pseudorange.$

$X_r^o, Y_r^o, Z_r^o = approximated\ receiver's\ coordinates.$

$b^o = approximated\ receiver's\ clock\ error.$

$W = weighted\ matrix.$

The computation will be done iteratively until matrice x becomes stable.

3.5.3 Alternative Solution of Non Linear Equation of GPS Point Position Using Bancroft Method

Here is a clever method that does some algebraic manipulations to reduce the equations to a least square problem. The non linear equation can be solved without linearizing it first (Bancroft,1985). Here is the detail:

After data enhancement, the observation equation is :

$$\rho_r^s = \sqrt{(Xs - Xr)^2 + (Ys - Yr)^2 + (Zs - Zr)^2} + b \qquad (3.41)$$

with $b = cdt$.

Move b to the left side, and square both sides:

$$(\sqrt{(Xs-Xr)^2+(Ys-Yr)^2+(Zs-Zr)^2})^2 = (\rho_r^s - b)^2$$

$$Xs^2 - 2XsXr + Xr^2 + Ys^2 - 2YsYr + Yr^2 + Zs^2 - 2ZsZr + Zr^2 = \rho_r^{s^2} - 2\rho_r^s b + b^2$$

$$(Xs^2 + Ys^2 + Zs^2 - \rho_r^{s^2}) - 2(XsXr + YsYr + ZsZr - \rho_r^s b) + (Xr^2 + Yr^2 + Zr^2 - b^2) = 0$$

Motivated by the form of the value within the parentheses, there is a modified dot product, called Lorentz inner product:

$$< u, v >= u_1 v_1 + u_2 v_2 + u_3 v_3 - u_4 v_4$$

Then the equation can be arranged as:

$$\frac{1}{2} < s, s > - < s, u > + \frac{1}{2} < u, u >= 0 \qquad (3.42)$$

with,

$s = Xs, Ys, Zs, \rho^s{}_r$

$u = Xr, Yr, Zr, b$

Then , let:

$$B = \begin{pmatrix} Xs & Ys & Zs & -\rho_r^s \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \end{pmatrix}$$

$$a = \frac{1}{2}\begin{pmatrix} <s,s> \\ \vdots \end{pmatrix}$$

$$e = \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}$$

$$\Delta = \frac{1}{2} <u,u>$$

The equation can be expressed as:

$$Bu = (a + \Delta e) \tag{3.43}$$

then the least square solution solves the normal equation:

$$B^T Bu = B^T (a + \Delta e)$$
$$u = (B^T B)^{-1} B^T (a + \Delta e) = B^* (a + \Delta e)$$
$$\Delta = \frac{1}{2} <u,u>$$
$$= \frac{1}{2} <B^* (a + \Delta e), B^* (a + \Delta e)>$$
$$= \frac{1}{2} <B^* a, B^* a> + \Delta <B^* a, B^* e> + \frac{1}{2}\Delta^2 <B^* e, B^* e>$$
$$\Rightarrow \Delta^2 <B^* e, B^* e> + 2\Delta(<B^* a, B^* e> - 1) + <B^* a, B^* a> = 0 \tag{3.44}$$

This is a quadratic equation in Δ, so it can be solved for two possible values of Δ which finally will give two solutions, u_1 and u_2 . One of the solution will make sense that it will be on the surface of earth and another one won't.

3.6 Coordinates Transformation

The coordinate transformation here involves the transformation from Cartesian coordinates to Geodetic coordinates and vice versa. From the equation (3.40) and (3.44), the output is in Cartesian coordinates X, Y, and Z. Then this Cartesian coordinates is transformed into geodetic or geographical coordinates, latitude (φ) , longitude (λ), and height (h).

3.6.1 Cartesian To Geodetic Coordinates Transformation

To determine a point above the surface of the earth, we use geographical coordinates, latitude (φ) , longitude (λ), and height (h). The height above the ellipsoid is measured along a perpendicular line. This transformation is written in TOGEOD.m. Given Cartesian coordinates (X, Y, Z) and directly the longitude (λ) can be computed as: (Strang,G. and K.Borre, 1997)

$$\lambda = \arctan\,(Y/X) \tag{3.45}$$

To compute the latitude (φ) and height (h) requires iteration as the following:

$$\varphi = \arctan\left(\frac{Z}{\sqrt{X^2+Y^2}}\left(1-\frac{(2-f)fN}{N+h}\right)^{-1}\right) \tag{3.46}$$

$$h = \frac{\sqrt{X^2+Y^2}}{\cos\varphi} - N \tag{3.47}$$

3.6.2 Geodetic To Cartesian Coordinates Transformation

Geodetic coordinates (φ , λ , h) can be transformed into Cartesian coordinates (X,Y,Z) using the following formula: (Strang,G. and K.Borre, 1997)

$$X = (N + h)\cos\varphi\cos\lambda \qquad 3.48$$

$$Y = (N + h)\cos\varphi\sin\lambda \qquad 3.49$$

$$Z = ((1 - f)^2 N + h)\sin\varphi \qquad 3.50$$

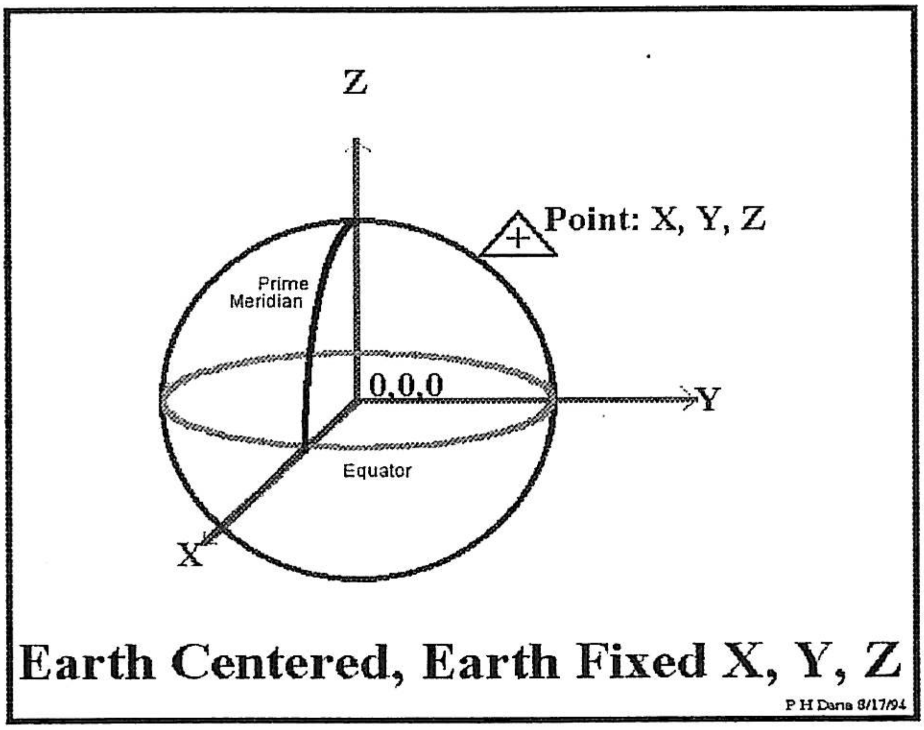

Figure 3.2: Cartesian Coordinates

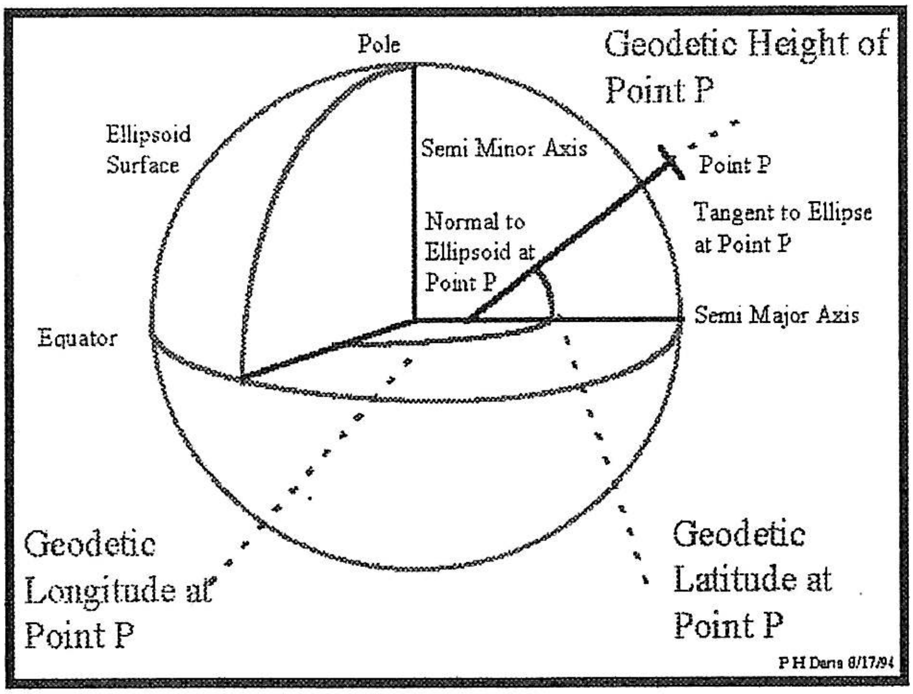

Figure 3.3: Geodetic Coordinates

3.7 Output and Result Storage

Output of the processing is the point's geodetic coordinates (φ, λ, h) which is devided into : horizontal coordinates (φ, λ) and vertical coordinate (h). The accuracy i.e. the difference between the computed point position and known point position also becomes the output. Epoch by epoch output is written into one text file as the result storage.

3.8 Summary

The algorithm of precise single point positioning that incorporates the error and bias modeling and least square adjustment has been finished. The algorithm read the RINEX raw data which is converted from the binary raw data obtained from OEM GPS. It also output the results in a text file. The results will be then further analyzed in the next chapter.

CHAPTER IV

DATA COLLECTION, PROCESSING, RESULT AND ANALYSIS

4.1 Introduction

Using OEM GPS CMC Allstar Single Frequency, data collection has been done successfully. Some systematic data sets have been acquired for further processing, analysis and validation.

4.2 Data Collection

Data collection is using the OEM GPS CMC Allstar Single Frequency. There are some data sets as follows:

- Static Mode, long occupation with epoch 1 Hz, one day for each point, approximate 1 hour per session in the morning, noon, afternoon, and evening.
- Static Mode, short occupation with epoch 10 Hz, one day for each point, approximate 1 minute per session in the morning, noon, afternoon, and evening.

4.2.1 OEM GPS CMC Allstar Single Frequency

The Allstar CMC GPS OEM single frequency is an-all-in-one 12 channel GPS receiver that is powered by an ARM60 microprocessor. It is equipped with a GP2021 12 channel correlator and a GP2015 RF front and set of ASICs (Bae Systems 1998). The price of the board is USD 100 (GPS World Magazine,2000).

The board has the following specifications (Bae Systems 1998):

Table 4.1: OEM GPS CMC Allstar Single Frequency Specification

Parameter	**Value**
CPU	ARM60 running at 40 MHz
Power Power Consumption	5.0 (+0.5/-0.25)VDC input 600 mW
I/O	3 TTL-level RS232 ports – 1 for debugging and 2 general purposes
Sensitivity	-124 to –130 dBm
Warm Start TTFF	17 sec
Cold Start TTFF	45 sec
SV Tracking	12 Channel parallel receiver C/A code
Weight	50 gr
Dimensions	66 x 46.5 x 12 mm

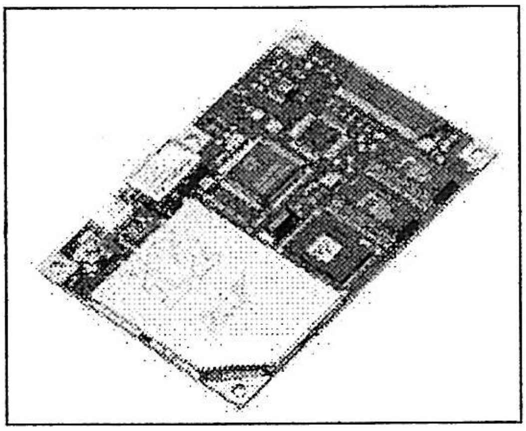

Figure 4.1: OEM GPS CMC ALLSTAR SINGLE FREQUENCY

4.3 Data Processing And Results

The sets of data have been processed using the algorithm made in this study. The followings will show the result.

4.3.1 Data Set I

Data set I is Static Mode, long occupation with epoch 1 Hz, one day for each point, 3000 epochs in the morning (6.00 AM – 12 Mid day), noon (12.00 PM – 3.00 PM), afternoon (3.00 PM – 6.00 PM), and evening (6.00 PM – 12.00 Mid night). It means there will be 12000 point positions for each test point i.e. G01 and G11 while for G05 there will be 11929 point positions.

4.3.1.1 Results Of G01

The results of point accuracy is obtained by comparing to the known point (G01) which is published in (Othman, 2001). Since the single point positioning is applied to obtain the point position in the latest WGS'84 then the known coordinates (G01) are first transformed into ITRF2000.

G01 coordinates:

Latitude : 1°34'10.83655" N

Longitude : 103°38'42.17103" E

Ellipsoid Height : 142.906 m

The following is the result of data processing:

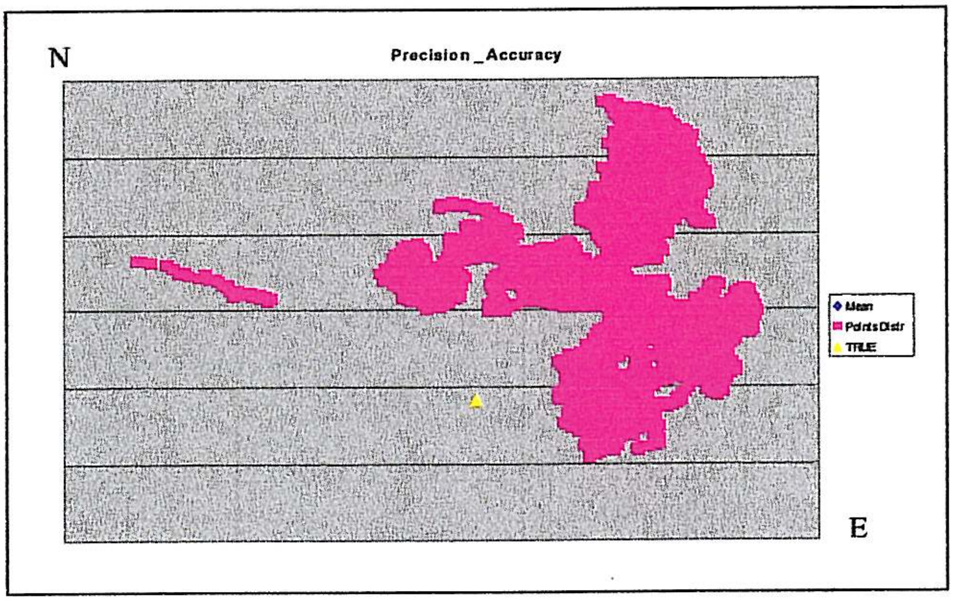

Figure 4.1: Distribution of Point Positions Results on G01

Table 4.1: Information of Data Set 1 G01

No.	Session	Epochs
1.	Morning	3000
2.	Noon	3000
3.	Afternoon	3000
4.	Evening	3000
	Total	12000

Table 4.2: Statistics of The Accuracy At G01

	North (m)	East (m)	Horizontal (m)	Vertical (m)
Maximum	8.621	7.975	9.407	1.262
Minimum	0.002	0.002	1.947	-31.953
Mean	4.182	3.476	5.708	-11.425
RMS	2.148	1.296	1.811	5.502

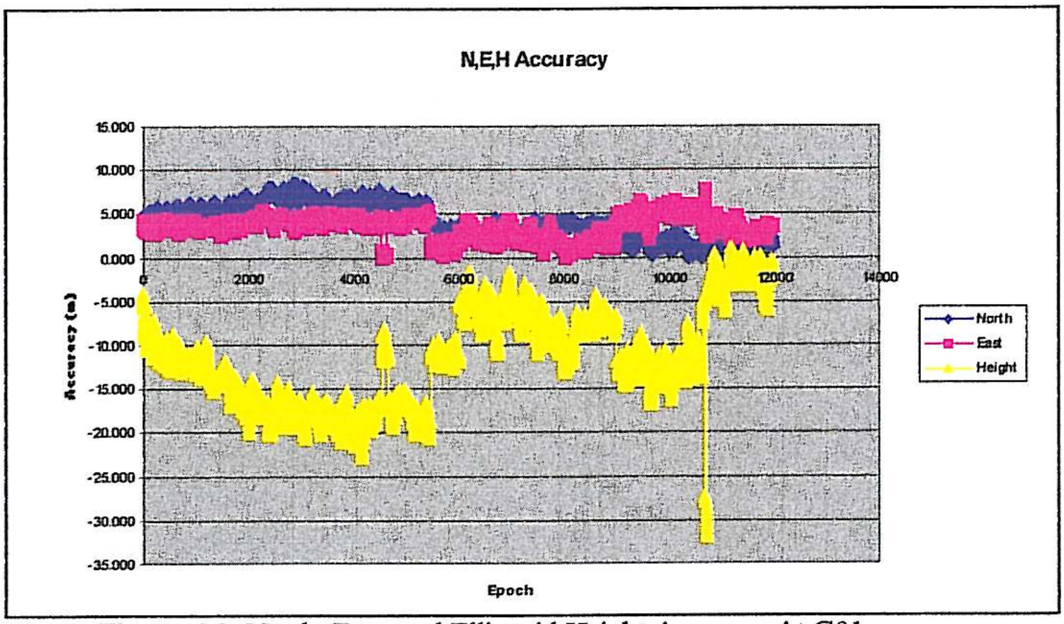

Figure 4.2: North, East, and Ellipsoid Height Accuracy At G01

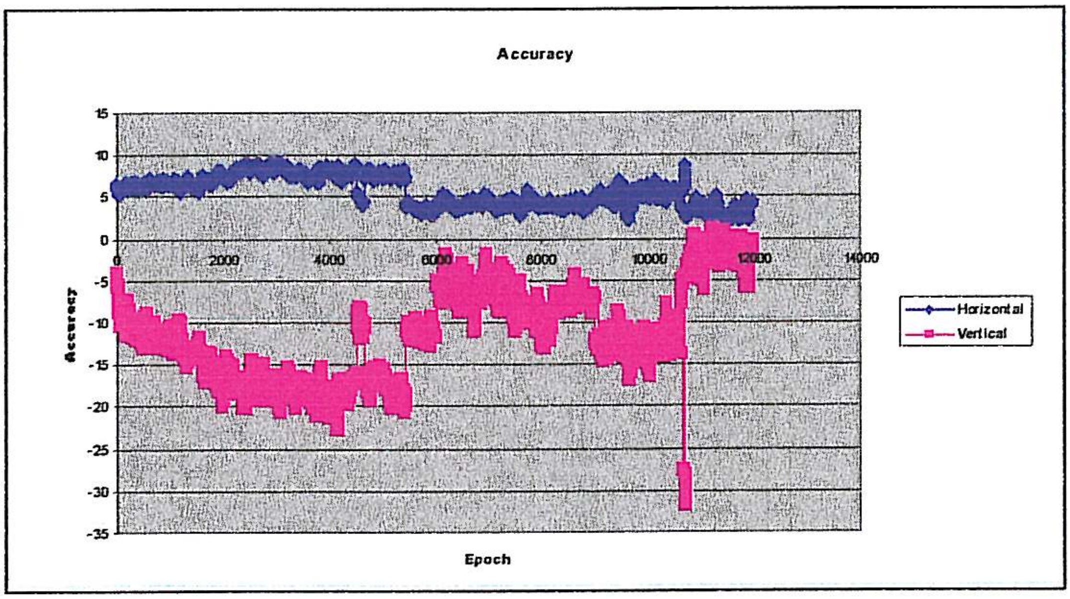

Figure 4.3: Horizontal and Vertical Accuracy At G01

The following is the table that shows the percentage of accuracy level, which can be achieved by the point positions.

Table 4.3: Percentage of The Accuracy Level At G01

Horizontal Accuracy Level	Percentage of 12000 positions
[0,1] = 0 – 1 m	0.00
(1,2] = 1< x ≤2m	0.03
(2,3]m	4.00
(3,4]m	17.71
(4,5]m	22.00
(5,6]m	11.25
(6,7]m	14.33
(7,8]m	17.85
(8,9]m	11.72
(9,10]m	1.12
Total	100

Vertical Accuracy Level	Percentage of 12000 positions
<-20m	2.23
(-20,-10]m	60.66
(-10,-5]m	22.44
(-5,0]m	13.87
(0,5]m	0.80
(5,10]m	0.00
(10,20]m	0.00
Total	100

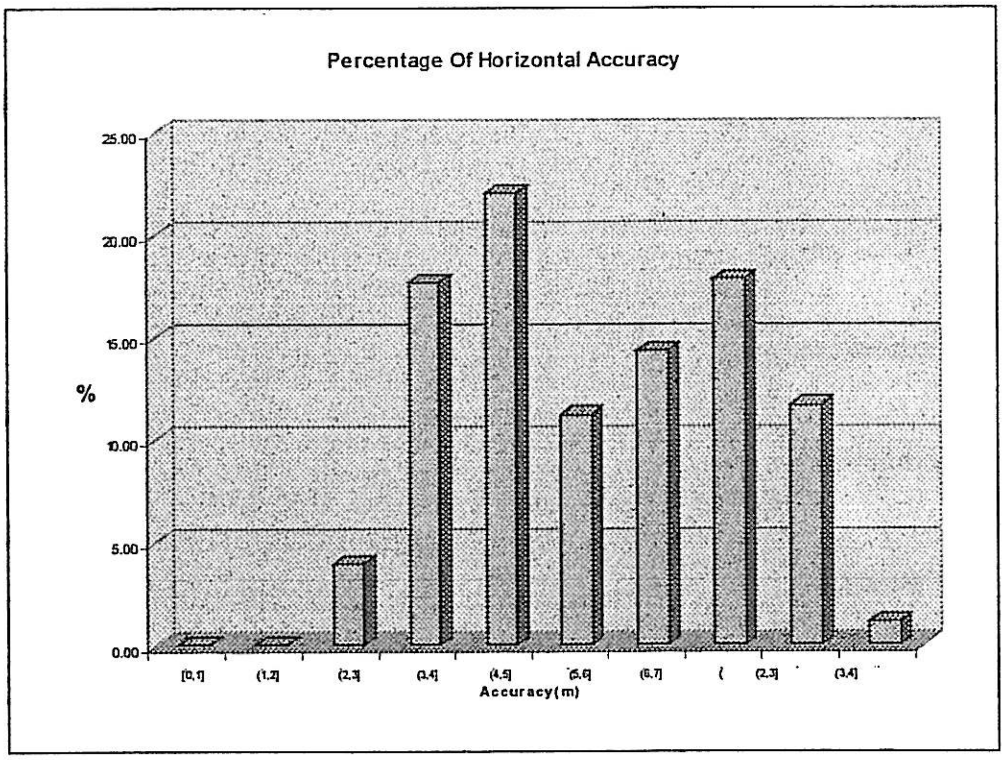

Figure 4.4: Percentage of The Horizontal Accuracy At G01

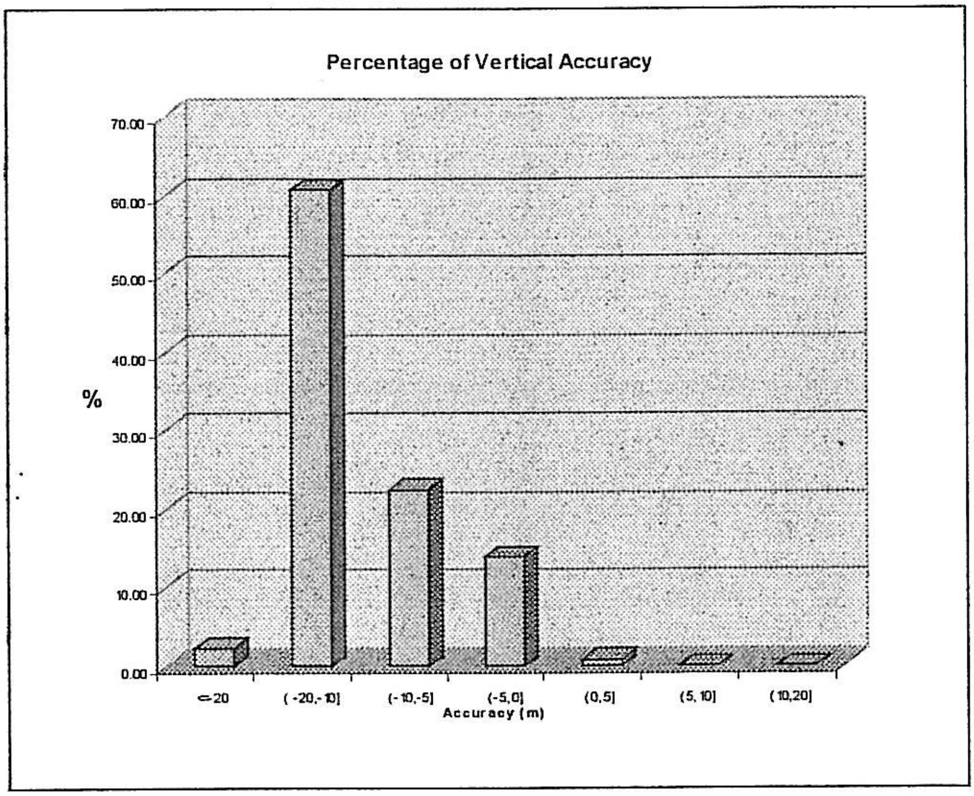

Figure 4.5: Percentage of The Vertical Accuracy At G01

4.3.1.2 Results Of G05

The results of point accuracy is obtained by comparing to the known point (G05) which is published in (Othman, 2001). Since the single point positioning is applied to obtain the point position in the latest WGS'84 then the known coordinates (G05) are first transformed into ITRF2000.

G05 coordinates are:

Latitude	: 1°33'54.40838" N
Longitude	: 103°38'02.77930" E
Ellipsoid Height	: 47.758 m.

The following is the result of data processing:

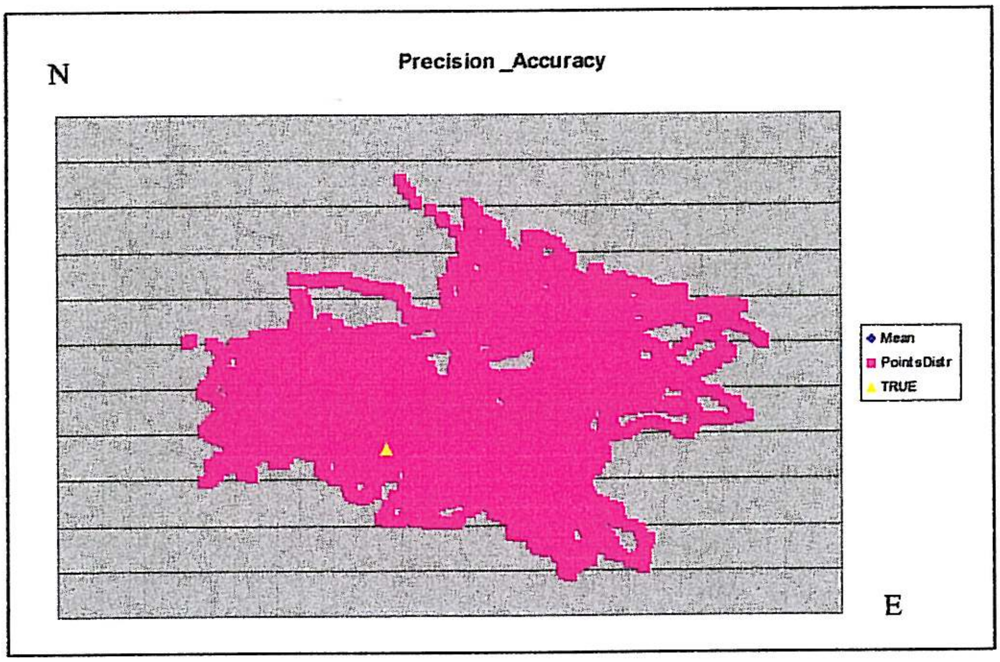

Figure 4.6: Distribution of Point Positions Results on G05

Table 4.4: Information of Data Set 1 G05

No.	Session	Epochs
1.	Morning	3000
2.	Noon	3000
3.	Afternoon	3000
4.	Evening	2929
	Total	11929

Table 4.5: Statistics of The Accuracy At G05

	North (m)	East (m)	Horizontal (m)	Vertical (m)
Maximum	13.116	13.354	14.381	31.830
Minimum	0.000	0.001	0.119	-11.293
Mean	2.885	3.631	5.021	5.724
RMS	2.375	2.565	2.918	7.188

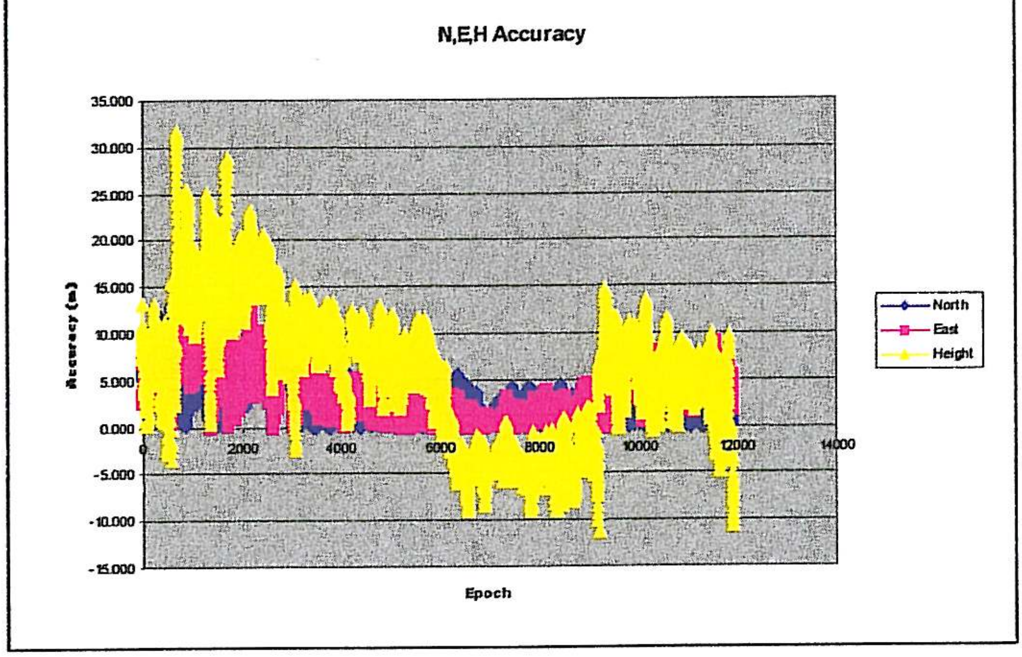

Figure 4.7: North, East, and Ellipsoid Height Accuracy At G05

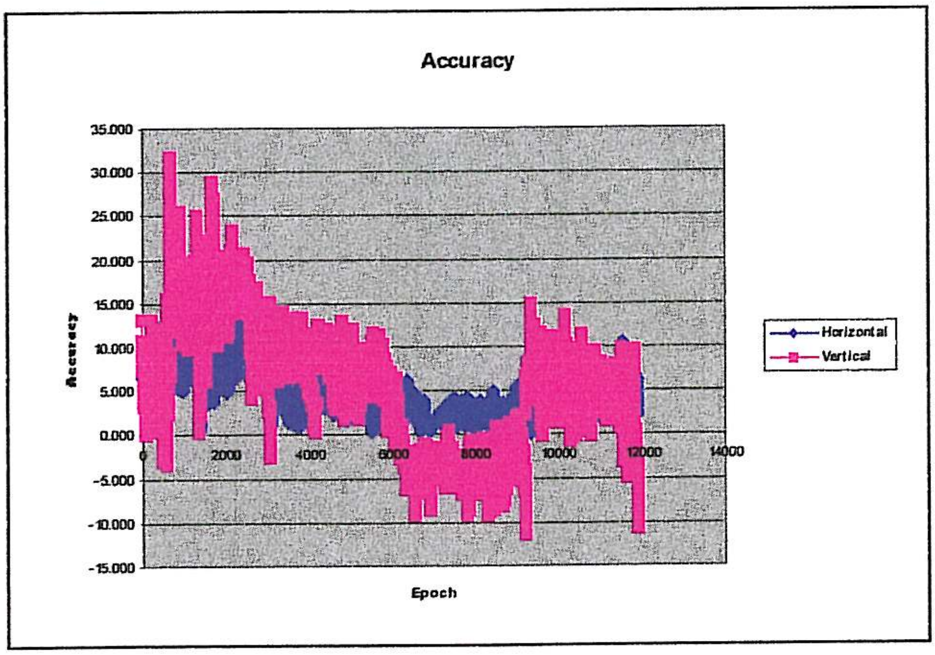

Figure 4.8: Horizontal and Vertical Accuracy At G05

The following is the table that shows the percentage of accuracy level, which can be achieved by the point positions.

Table 4.6: Percentage of The Accuracy Level At G05

Horizontal Accuracy Level	Percentage of 11929 positions
[0,1]m	2.36
(1,2]m	12.67
(2,3]m	14.02
(3,4]m	16.42
(4,5]m	11.28
(5,6]m	10.67
(6,7]m	8.11
(7,8]m	5.99
(8,9]m	5.92
(9,10]m	5.39
(10,15]m	7.18
Total	100

Vertical Accuracy Level	Percentage of 11929 positions
<-20m	0.00
[-20,-10]m	0.05
(-10,-5]m	5.74
(-5,0]m	19.93
(0,5]m	17.43
(5,10]m	30.74
(10,20]m	23.87
>20m	2.24
Total	100

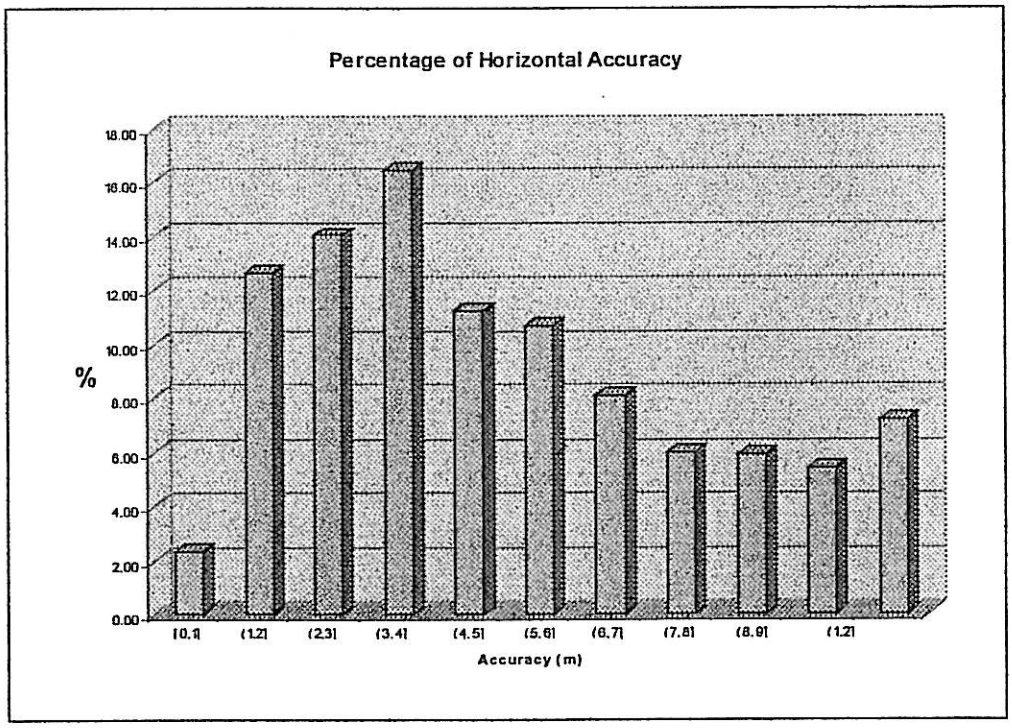

Figure 4.9: Percentage of The Horizontal Accuracy At G05

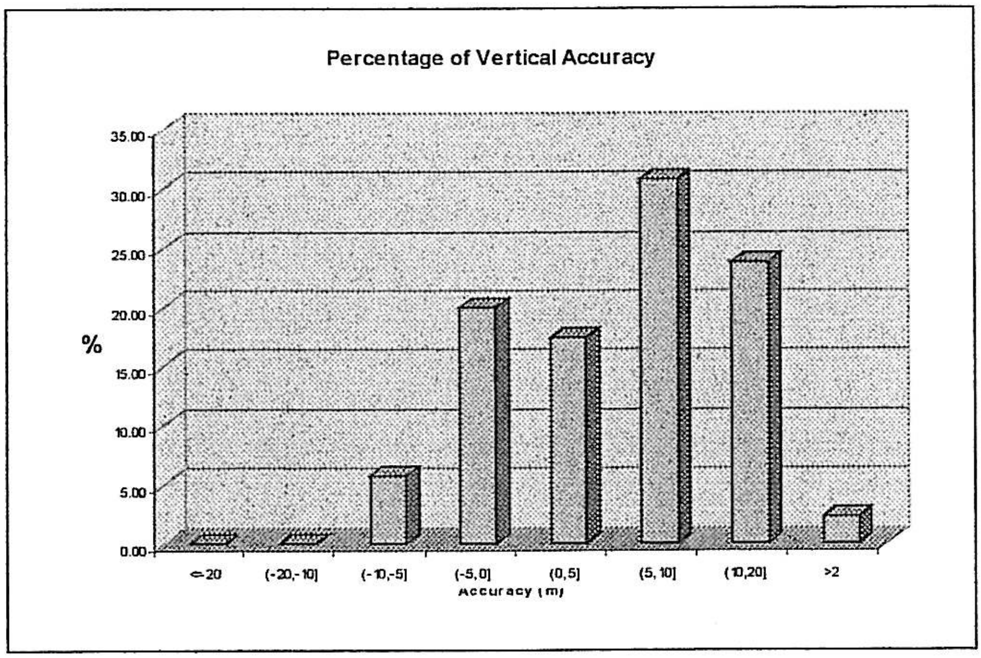

Figure 4.10: Percentage of The Vertical Accuracy At G05

4.3.1.3 Results Of G11

The results of point accuracy is obtained by comparing to the known point (G11) which is published in (Othman, 2001). Since the single point positioning is applied to obtain the point position in the latest WGS'84 then the known coordinates (G11) are first transformed into ITRF2000.

G11 coordinates are:

Latitude	: 1°33'29.60305" N
Longitude	: 103°38'13.37657" E
Ellipsoid Height	: 42.076 m.

The following is the result of data processing:

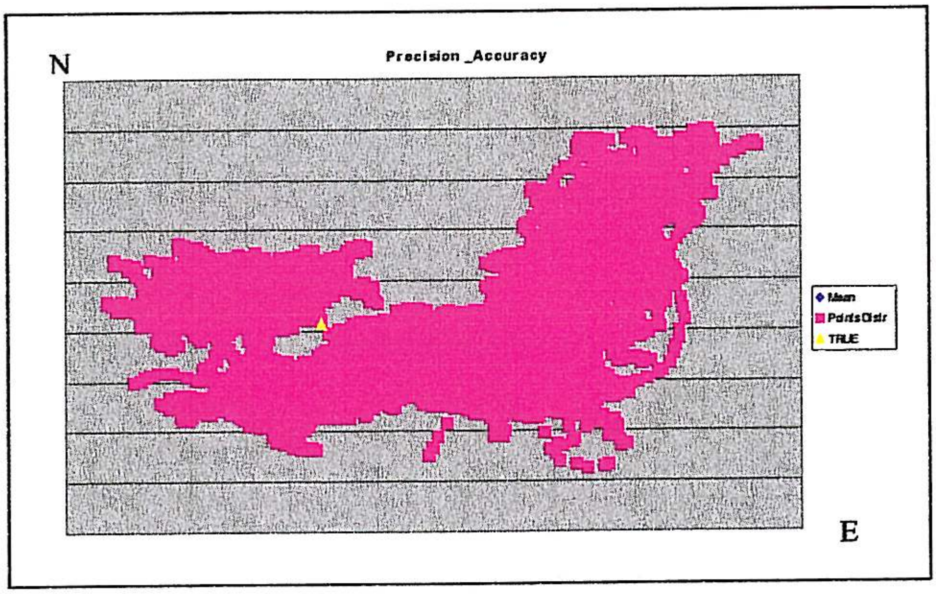

Figure 4.11: Distribution of Point Positions Results on G11

Table 4.7: Information of Data Set 1 G11

No.	Session	Epochs
1.	Morning	3000
2.	Noon	3000
3.	Afternoon	3000
4.	Evening	3000
	Total	12000

Table 4.8: Statistics of The Accuracy At G11

	North (m)	East (m)	Horizontal (m)	Vertical (m)
Maximum	8.558	9.234	12.129	29.915
Minimum	0.001	0.002	0.157	-2.648
Mean	2.108	3.115	4.005	12.860
RMS	1.462	2.001	2.062	6.186

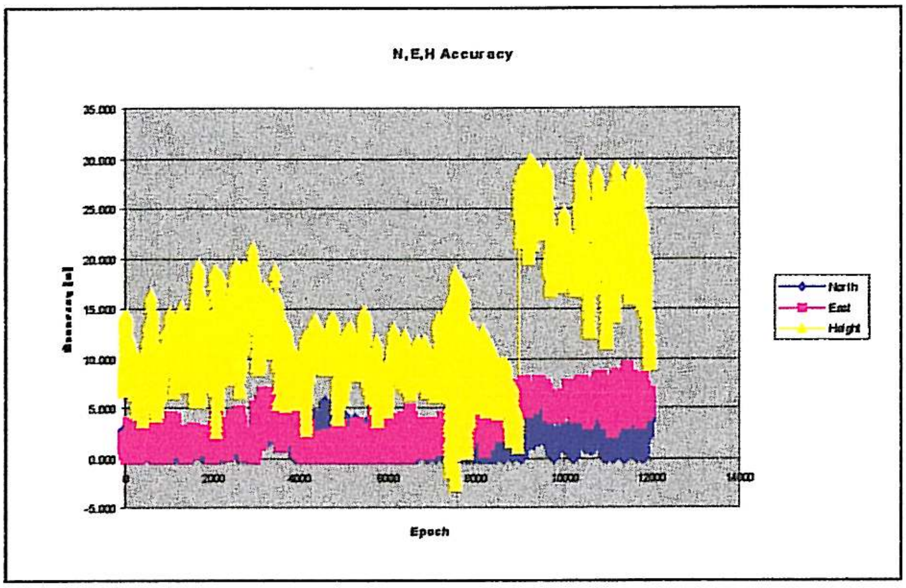

Figure 4.12: North, East, and Ellipsoid Height Accuracy At G11

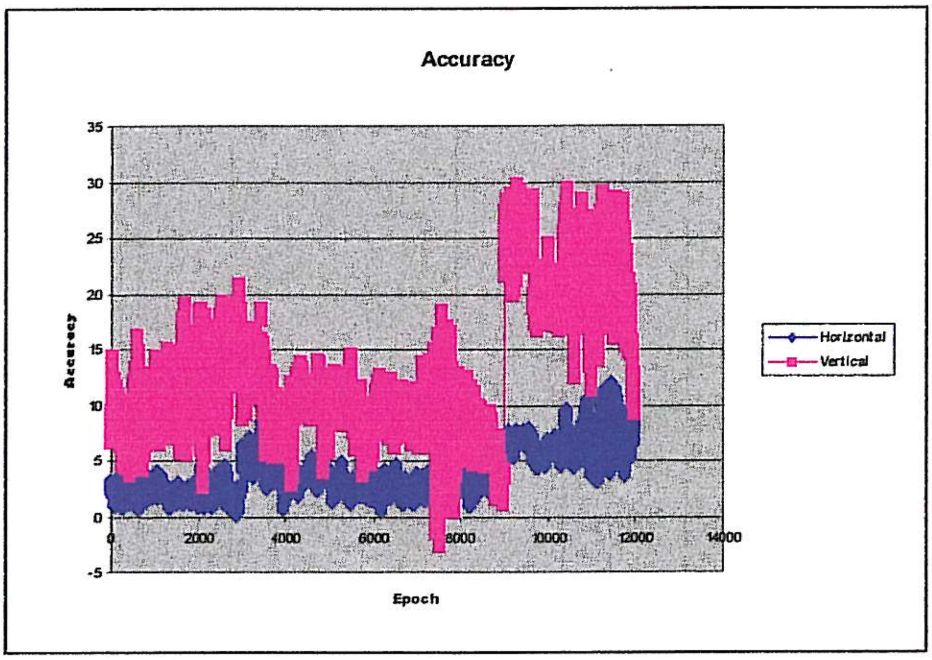

Figure 4.13: Horizontal and Vertical Accuracy At G11

The following is the table that shows the percentage of accuracy level, which can be achieved by the point positions.

Table 4.9: Percentage of The Accuracy Level At G11

Horizontal Accuracy Level	Percentage of 12000 positions
[0,1]m	1.0
(1,2]m	11.7
(2,3]m	27.2
(3,4]m	21.5
(4,5]m	10.9
(5,6]m	9.1
(6,7]m	7.8
(7,8]m	6.0
(8,9]m	2.3
(9,10]m	1.6
(10,15]m	0.9
Total	100

Vertical Accuracy Level	Percentage of 12000 positions
<-20m	0.0
[-20,-10]m	0.0
(-10,-5]m	0.0
(-5,0]m	0.2
(0,5]m	3.8
(5,10]m	36.6
(10,20]m	43.3
>20m	16.0
Total	100

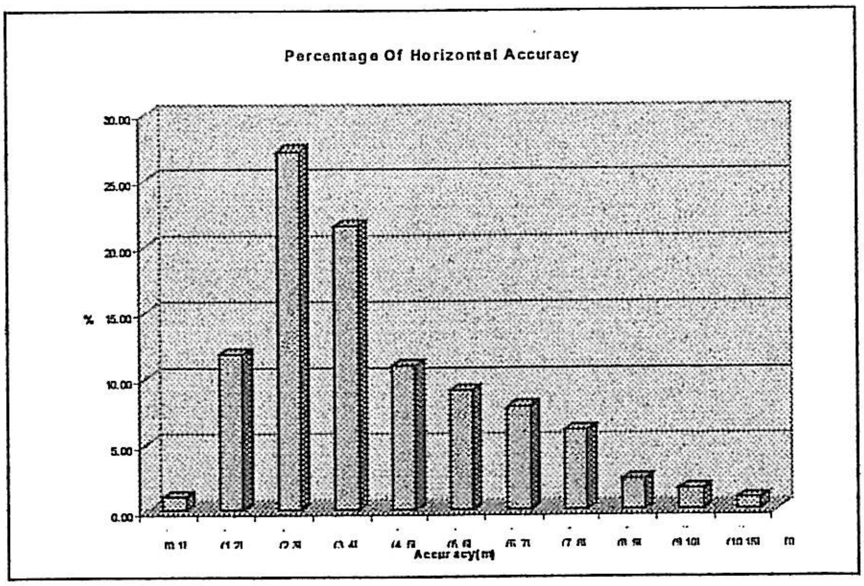

Figure 4.14: Percentage of The Horizontal Accuracy At G11

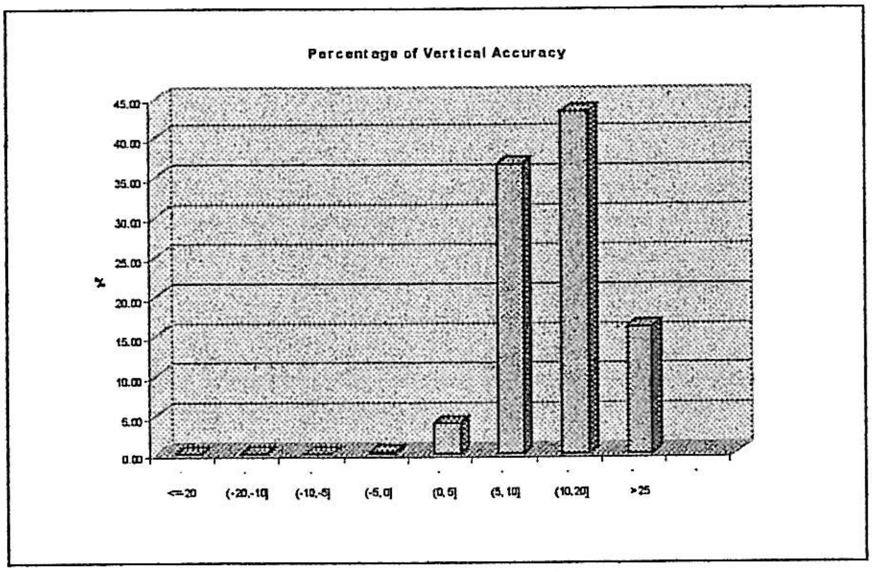

Figure 4.15: Percentage of The Vertical Accuracy At G11

4.3.2 Data Set II

Data set II is Static Mode, short occupation with epoch 10 Hz, one day for each point, 120 epochs in the morning, noon, afternoon, and evening. It means there will be 480 point positions for each test point.

4.3.2.1 Results Of G01

The following is the result of data processing:

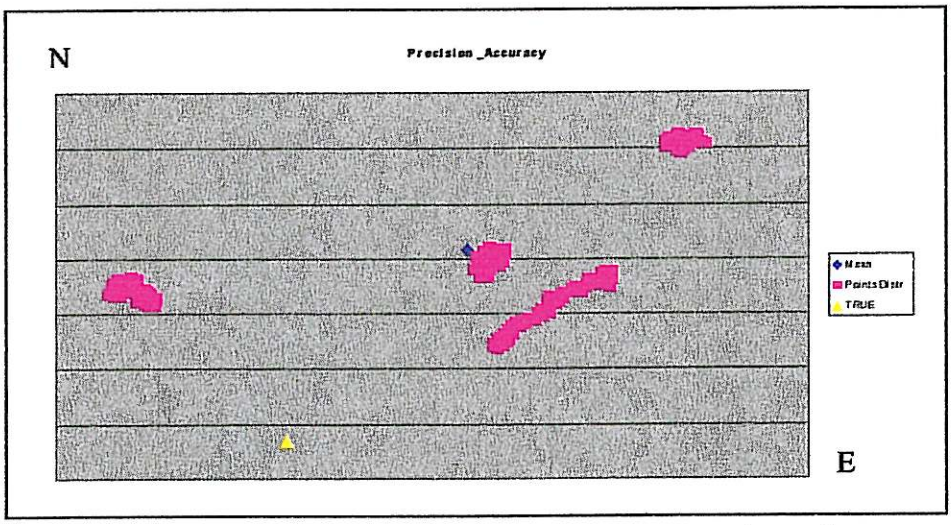

Figure 4.16: Distribution of Point Positions Results on G01

Table 4.10: Statistics of The Accuracy At G01

	North (m)	East (m)	Horizontal (m)	Vertical (m)
Maximum	6.201	5.605	8.268	-2.763
Minimum	1.875	1.705	3.229	-14.104
Mean	3.854	3.422	5.189	-9.724
RMS	1.321	1.269	1.730	3.984

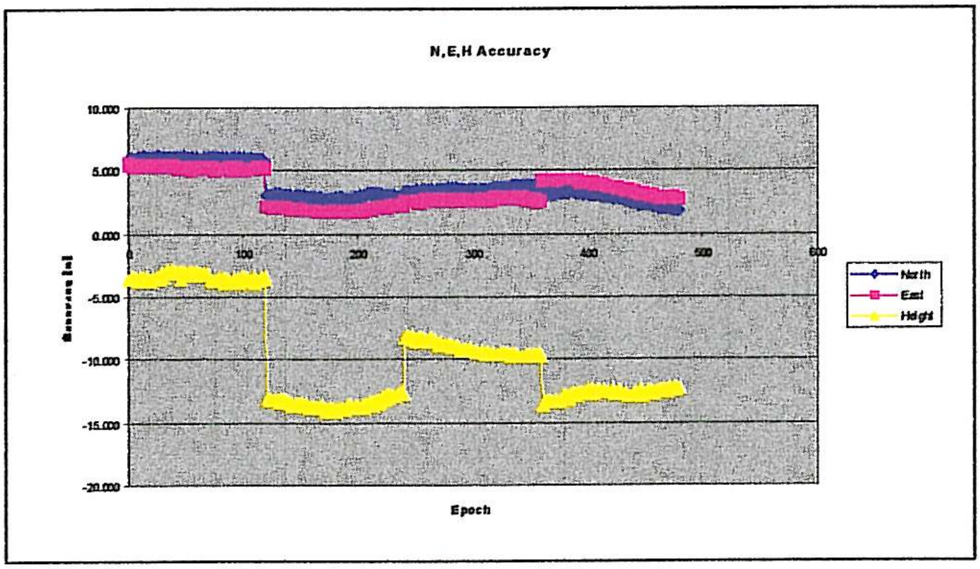

Figure 4.17: North, East, and Ellipsoid Height Accuracy At G01

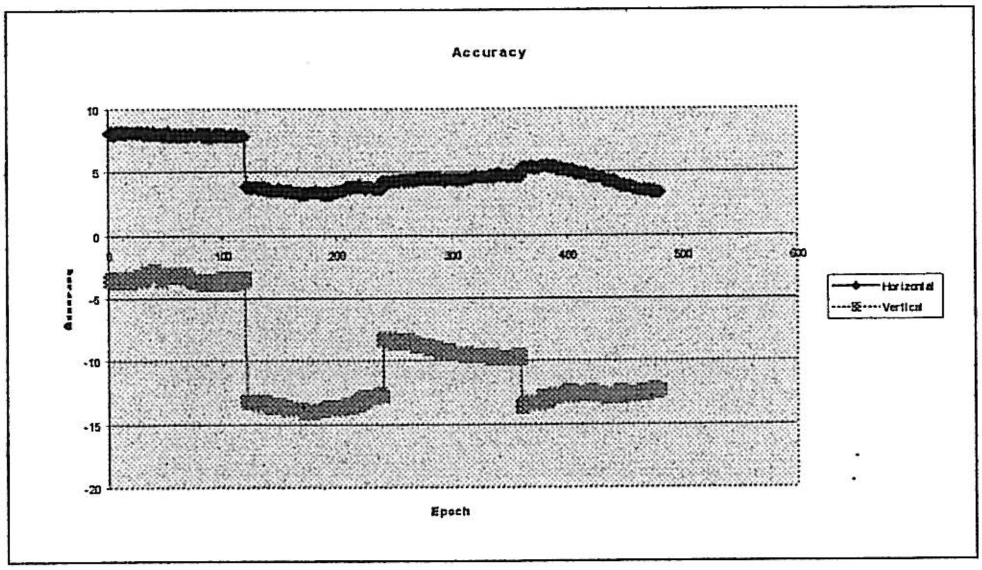

Figure 4.18: Horizontal and Vertical Accuracy At G01

The following is the table that shows the percentage of accuracy level, which can be achieved by the point positions.

Table 4.11: Percentage of The Accuracy Level At G01

Horizontal Accuracy Level	Percentage of 480 positions
[0,1]m	0.0
(1,2]m	0.0
(2,3]m	0.0
(3,4]m	32.3
(4,5]m	32.9
(5,6]m	9.8
(6,7]m	0.0
(7,8]m	10.8
(8,9]m	14.2
(9,10]m	0.0
Total	100

Vertical Accuracy Level	Percentage of 480 positions
<-15m	0.00
[-15,-10]m	50.00
(-10,-5]m	25.00
(-5,0]m	25.00
(0,5]m	0.00
Total	100

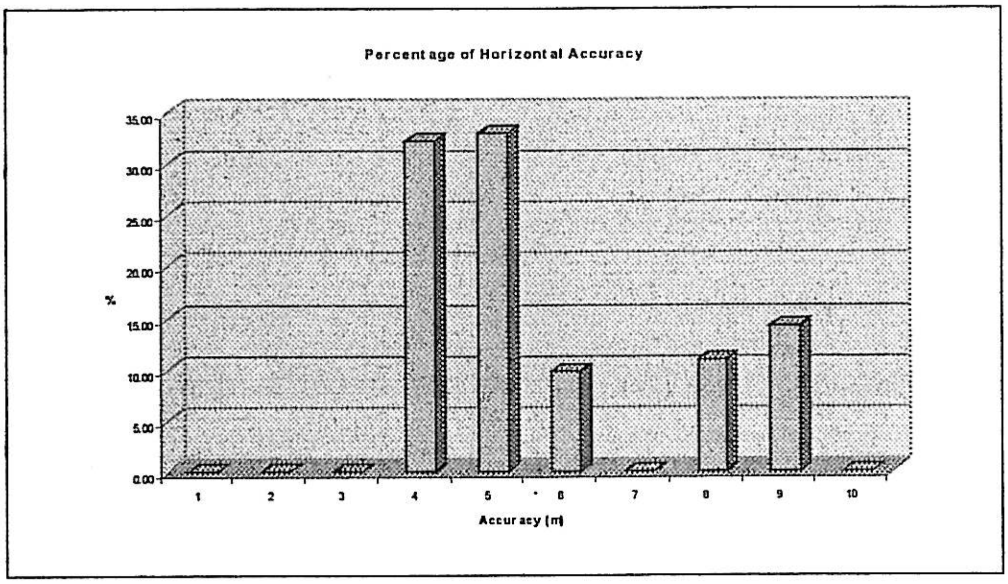

Figure 4.19: Percentage of The Horizontal Accuracy At G01

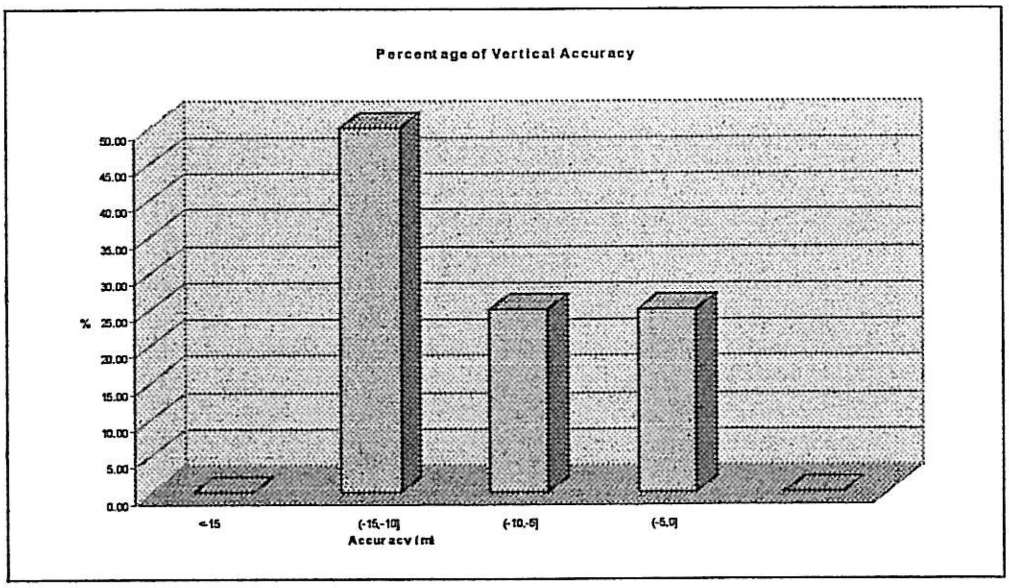

Figure 4.20:Percentage of The Vertical Accuracy At G01

4.3.2.2 Results Of G05

The following is the result of data processing:

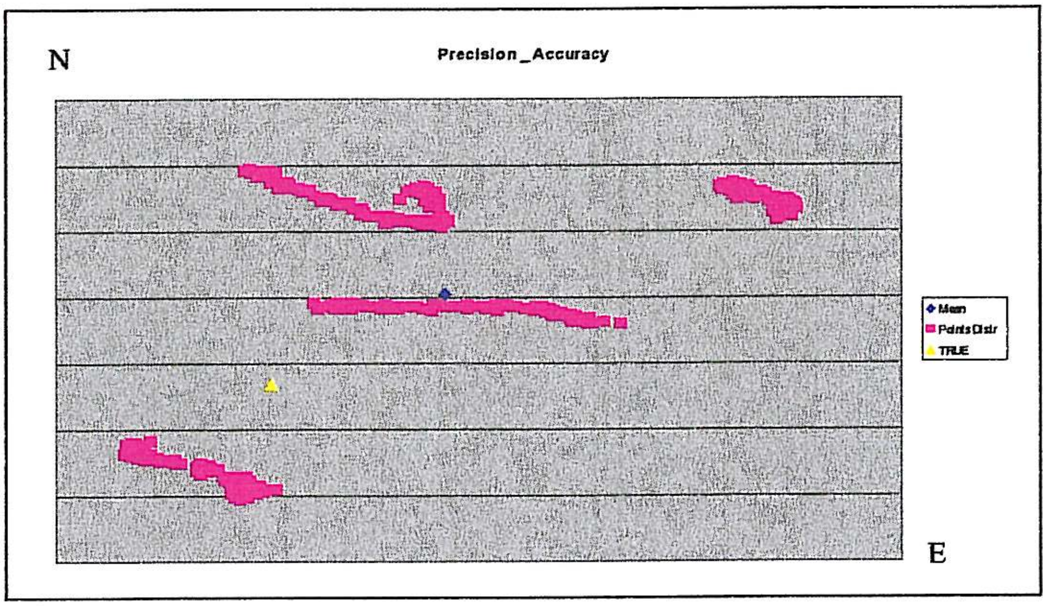

Figure 4.21: Distribution of Point Positions Results on G05

Table 4.12: Statistics of The Accuracy At G05

	North (m)	East (m)	Horizontal (m)	Vertical (m)
Maximum	7.237	4.152	7.734	18.531
Minimum	1.863	0.005	2.092	-6.822
Mean	4.481	1.670	4.908	5.318
RMS	1.839	1.364	2.005	8.005

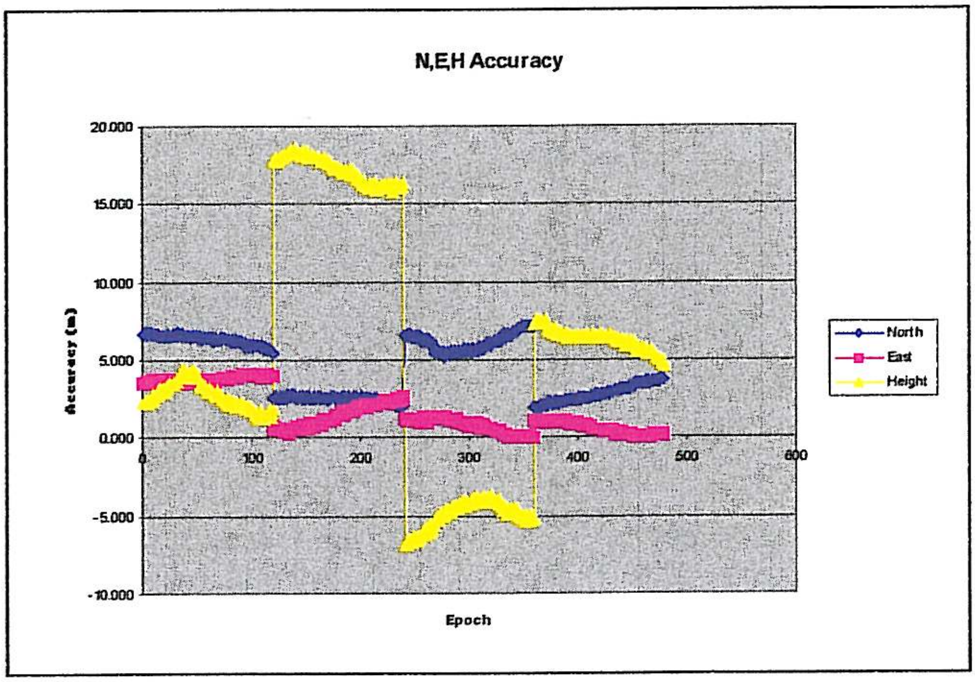

Figure 4.22: North, East, and Ellipsoid Height Accuracy At G05

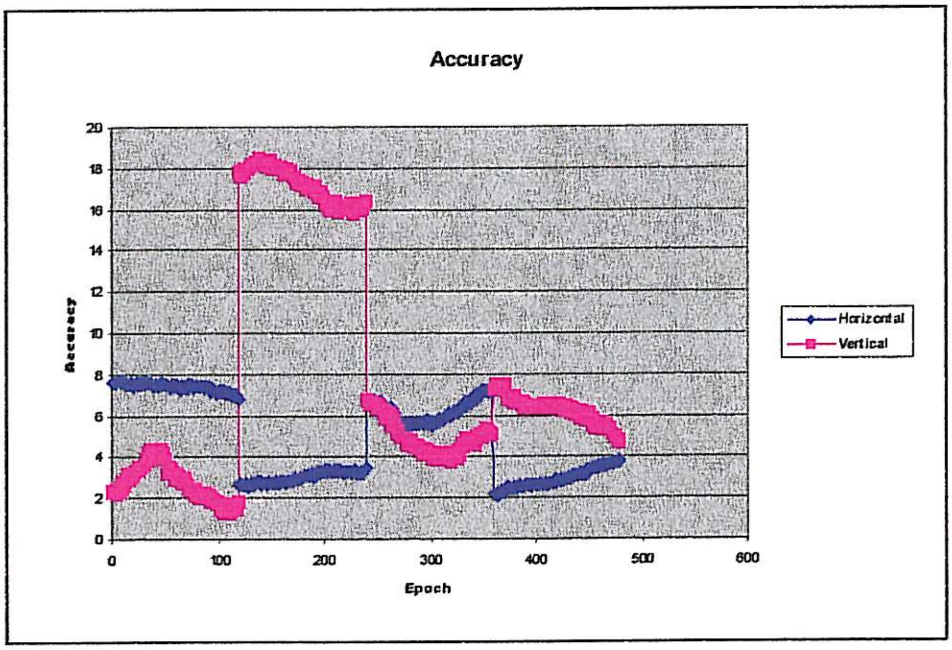

Figure 4.23: Horizontal and Vertical Accuracy At G05

The following is the table that shows the percentage of accuracy level, which can be achieved by the point positions.

Table 4.13: Percentage of The Accuracy Level At G05

Horizontal Accuracy Level	Percentage of 480 positions
[0,1]m	0
(1,2]m	0
(2,3]m	27.1
(3,4]m	22.9
(4,5]m	0
(5,6]m	10.4
(6,7]m	11.9
(7,8]m	27.7
(8,9]m	0
(9,10]m	0
Total	100

Vertical Accuracy Level	Percentage of 480 positions
<-5m	9.4
[-5,-2]m	15.6
(-2,0]m	0
(0,2]m	5.8
(2,5]m	20.2
(5,8]	24.0
(8,10]	0
(10,15]	0
(15,20]	25
Total	100

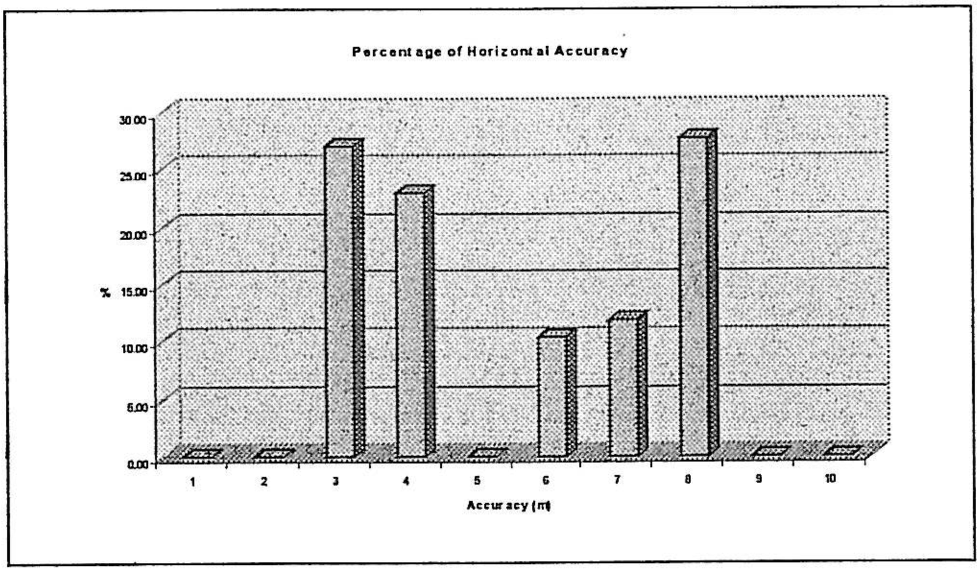

Figure 4.24: Percentage of The Horizontal Accuracy At G05

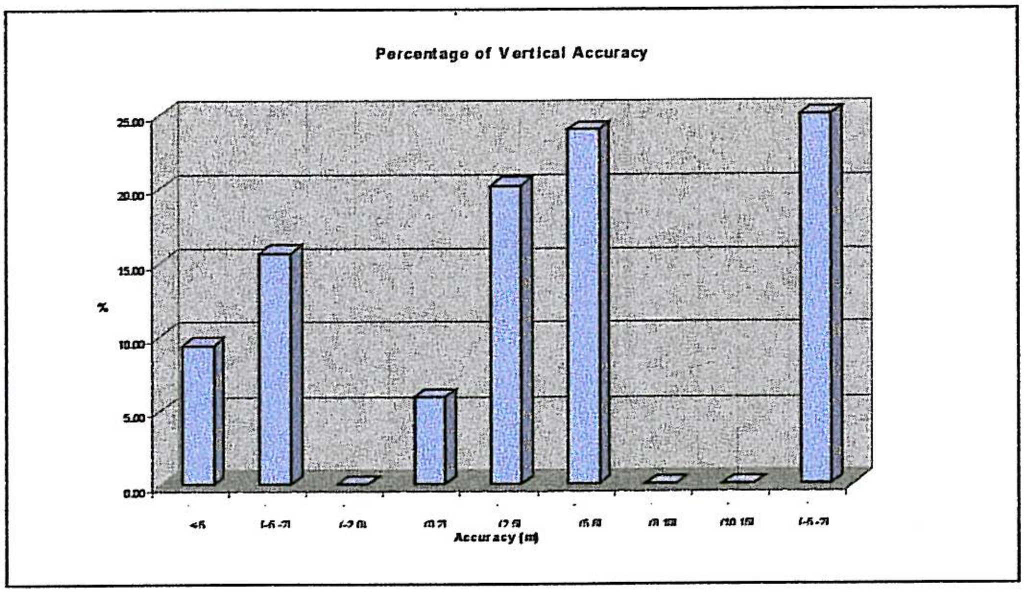

Figure 4.25: Percentage of The Vertical Accuracy At G05

4.3.2.3 Results Of G11

The following is the result of data processing:

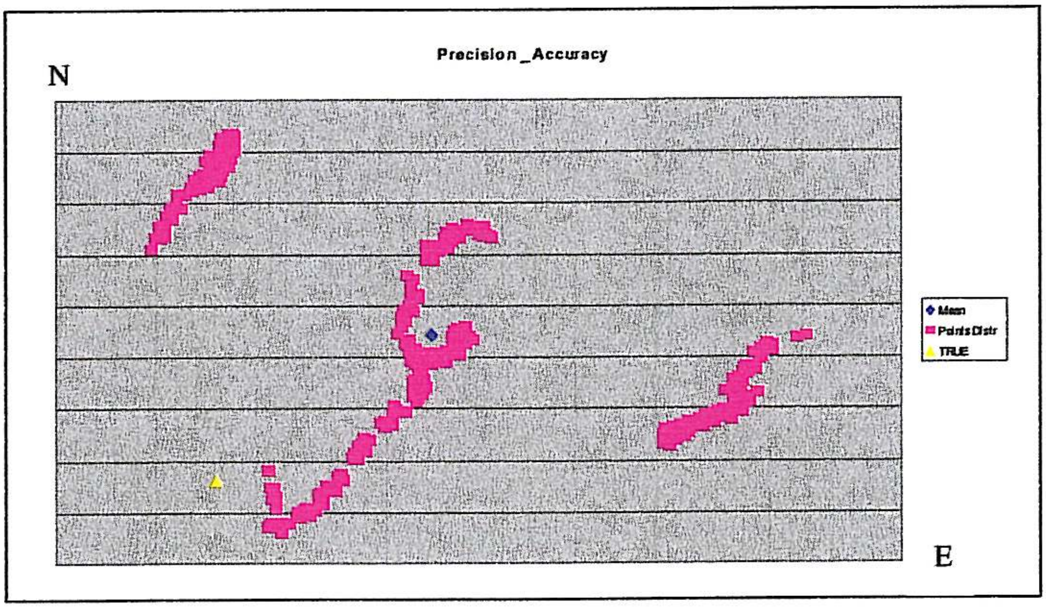

Figure 4.26: Distribution of Point Positions Results on G11

Table 4.14: Statistics of The Accuracy At G11

	North (m)	East (m)	Horizontal (m)	Vertical (m)
Maximum	3.746	7.759	7.914	15.316
Minimum	0.001	0.003	0.696	-0.769
Mean	1.637	2.902	3.861	8.829
RMS	1.143	2.412	1.820	5.070

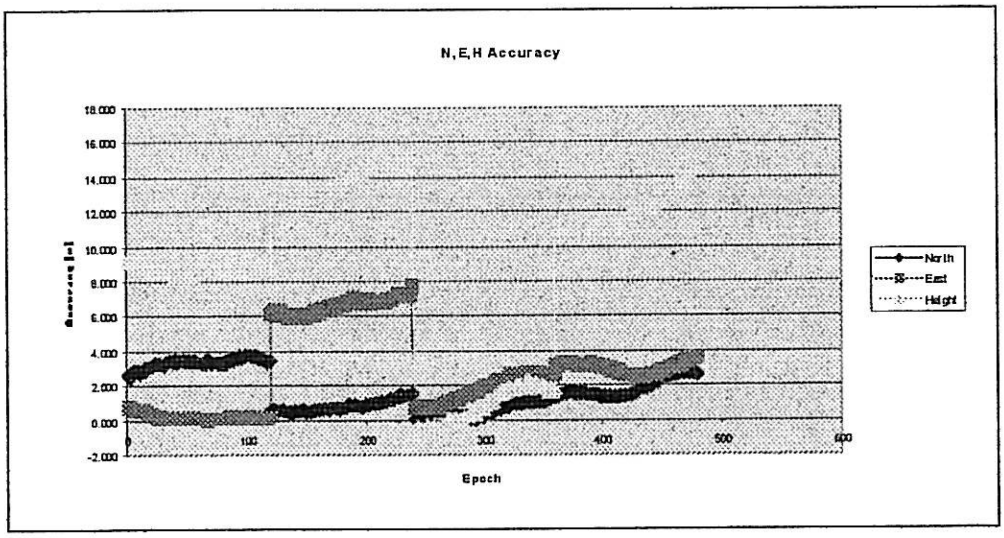

Figure 4.27: North, East, and Ellipsoid Height Accuracy At G11

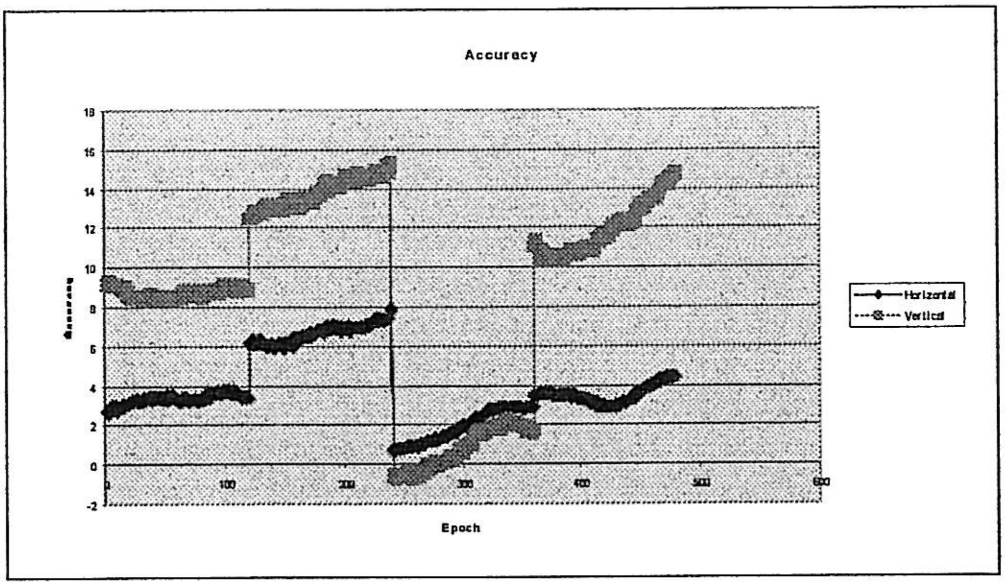

Figure 4.28: Horizontal and Vertical Accuracy At G11

The following is the table that shows the percentage of accuracy level, which can be achieved by the point positions.

Table 4.15: Percentage of The Accuracy Level At G11

Horizontal Accuracy Level	Percentage of 480 positions
[0,1]m	4.8
(1,2]m	8.9
(2,3]m	17.9
(3,4]m	39.0
(4,5]m	4.4
(5,6]m	1.7
(6,7]m	16.7
(7,8]m	6.7
(8,9]m	0
(9,10]m	0
Total	100

Vertical Accuracy Level	Percentage of 480 positions
<-5m	0.0
[-5,-2]m	0.0
(-2,0]m	6.9
(0,2]m	15.4
(2,5]m	2.7
(5,8]	0.0
(8,10]	25.0
(10,15]	49.4
(15,16]	0.6
Total	100

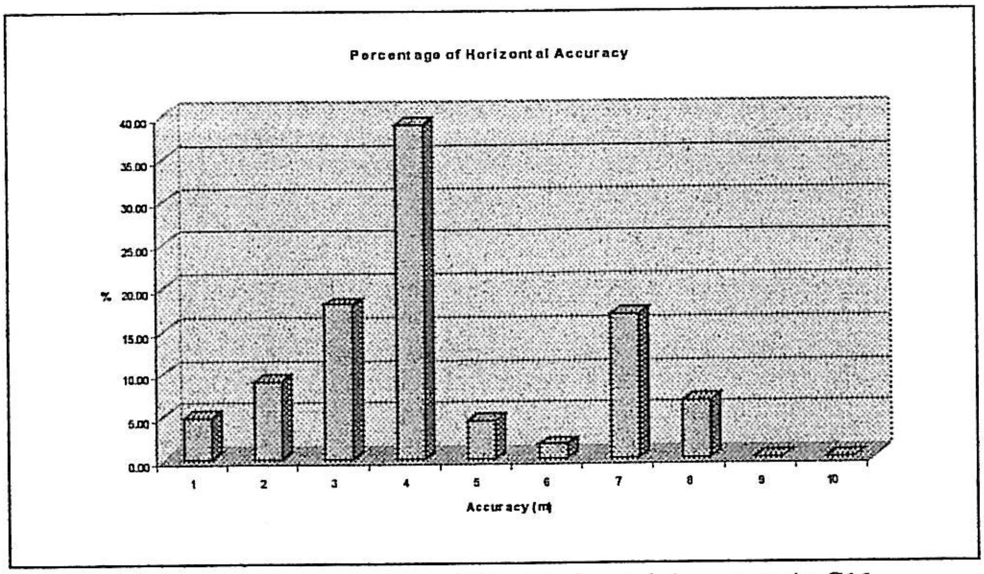

Figure 4.29: Percentage of The Horizontal Accuracy At G11

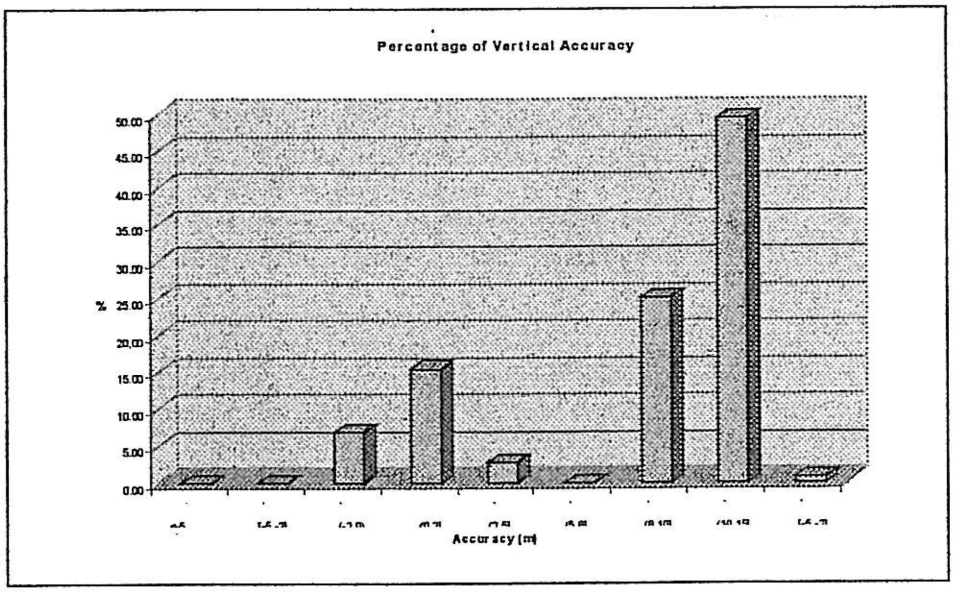

Figure 4.30: Percentage of The Vertical Accuracy At G11

4.4 ANALYSIS

Data collection, data processing and results have been performed well. The results can be read above. From the results, some analysis could be noted and all the analysis will lead to the final conclusion.

4.4.1 Analysis On Data Set I

From the result of data set I, it can be seen that:

The distribution of the point positions is random and uncorrelated. Since the epochs are so many as 12000 epochs, the uncorrelated pattern of morning, noon, afternoon, and evening session is not clearly seen. For G01, the mean of point positions and the true value is quite big compared to the ones of G05 and G11. For G01, the difference between the mean and the true value is 5.708 m, while for G05 and G11 are 5.021 m and 4.005 m respectively. Sometimes the point position accuracy will be jumped down or up then become stable. It is due to the changing of one observation session to another one such as morning session to noon session and etc. It is also most probably caused by the bad geometry of satellite whose either elevation angle or signal to ratio (SNR) value is low.

From Figure 4.1, 4.6, and 4.11, it can be seen that the point positions of G01 are not surrounding the true value while the ones of G05 and G11 are surrounding the true value. It means that there are some point positions of G05 and G11 achieve zero to 1 m accuracy, while for G01 there is none. This fact also can be further proved by referring to the table 4.2, 4.5, and 4.8 about the statistics result. From the tables, the highest accuracy obtained for G05 and G11 are 0.119 m and 0.157 m respectively while for G01 is 1.947 m.

The fact that GPS positioning in equatorial region will gives more error in the East part compared to the North part. This fact is also fit to G05 and G11 while for G01 it is not fit. The fact can be seen graphically from Figure 4.2, 4.7, and 4.12.

From the table and figure describing the percentage level of accuracy, it can be seen that all the test points i.e. G01, G05, and G11 can achieve the biggest percentage of better than 5 m accuracy level. Even for G05 and G11, the biggest percentages are for 4 m and 3 m accuracy levels respectively. The percentages of 2 m accuracy level for G01, G05, and G11 are 0.03%, 15.02%, and 12.77% respectively.

The vertical accuracy level achievement of the test points are better than 10 m. The variation of the accuracy is ranging too wide from –20 m to 20 m. It seems that the vertical aspect is still hard to be better than 5 m. Being better 10 m, it's already good enough for the single epoch observation which is still fitting the statement of Bill Clinton. He stated that the after SA set to zero, the accuracy will be ten times better which means for horizontal accuracy is 10 m and vertical accuracy is 20 m.

4.4.2 Analysis On Data Set II

From the result of data set II, it can be seen that:

The distribution of the point positions is random and uncorrelated. Since the epochs are only as many as 480 epochs, the uncorrelated pattern of morning, noon, afternoon, and evening session is clearly seen. For G01, the mean of point positions and the true value is quite big compared to the ones of G05 and G11. For G01, the difference between the mean and the true value is 5.189 m, while for G05 and G11 are 4.908 m and 3.861 m respectively. Sometimes the point position accuracy will be jumped down or up then become stable. It is due to the changing of one observation session to another one such as morning session to noon session and etc. It is also most probably caused by the bad geometry of satellite whose either elevation angle or signal to ratio (SNR) value is low.

From Figure 4.16, 4.21, and 4.26, it can be seen that no point position of the test points are surrounding the true value. It means that there is no point position of the test point achieve zero to 1 m accuracy except G11. This fact also can be further proved by referring to the table 4.10, 4.12, and 4.14 about the statistics result. From the tables, the highest accuracy obtained for G01, G05 and G11 are 3.229 m, 2.092 m and 0.696 m respectively.

The fact that GPS positioning in equatorial region will gives more error in the East part compared to the North part. This fact only fits to G11 while for G01 and G05 it is not fit. The fact can be seen graphically from Figure 4.17, 4.22, and 4.27.

From the table and figure describing the percentage level of accuracy, it can be seen that all the test points i.e. G01, G05, and G11 can achieve the biggest percentage of better than 5 m accuracy level. Even for G05 and G11, the biggest percentages are for 3 m and 4 m accuracy levels respectively. The percentages of 2 m accuracy level for G01, G05, and G11 are 0 %, 0 %, and 13.75% respectively.

The vertical accuracy level of the test points are better than 10 m. The variation of the accuracy is ranging too wide from –20 m to 20 m. It seems that the vertical aspect is still hard to be better than 5 m. Being better 10 m, it's already good enough for the single epoch observation which is still fitting the statement of Bill Clinton. He stated that the after SA set to zero, the accuracy will be ten times better which means for horizontal accuracy is 10 m and vertical accuracy is 20 m.

CHAPTER V

CONCLUSION AND RECOMENDATION

5.1 CONCLUSION

Based on the study result and analysis, it could be concluded that:

Study and investigation on the precise single point positioning using single frequency OEM GPS due to the discontinuation of SA has been done successfully.

The algorithm designed using Matlab language has been successfully performing the data processing.

The algorithm is capable of precise single point positioning which incorporates all the significant source of errors and bias such as ionospheric and tropospheric delay, satellite clock and orbit error, receiver clock error, satellite antenna phase center offset and satellite orientation, and earth rotation effect.

Satellites' position are computed by the algorithm based on the broadcast ephemeris and apply the least square adjustment to determine the point position from 6 to 12 C/A codes.

Low Cost OEM GPS CMC Allstar Single Frequency 12 Channels is the GPS receiver to collect the data for some sample of data sets.

Three data sets have been collected, processed and analyzed. They are:

1. Data set I : static mode, one day for each point, long occupation with 3000 epoch 1 Hz data in the morning, noon, afternoon, and evening session.
2. Data set II: static mode, one day for each point, short occupation with 120 epoch 10 Hz data in the morning, noon, afternoon, and evening session.

The accuracy of the point positions fits into 5 m for horizontal and 10 m for vertical. Some of the point positions could reach better than 2 m for horizontal. This statement of accuracy obtained in this study proves and agree with Bill Clinton's statement that GPS accuracy will be ten times better than before SA off which is 10 m for horizontal and 20 m for vertical. Improvement on accuracy is clearly shown in this study.

5.2 RECOMMENDATION

From this study, there are some recommendations arise:

The accuracy is still possible to be enhanced into sub decimeter level by enhancing the algorithm, better modeling especially for the ionospheric modeling, the usage of code and phase data, and using low cost but high capability of OEM GPS.

The Klobuchar ionospheric model to be claimed to reduce the ionospheric delay for 50% – 60%. Once the ionospheric delay could be removed fully, the accuracy will increase. Dual frequency and combination of code and phase could be the solution. Dual frequency receiver is far expensive than the single frequency one. In that sense, the single frequency receiver as a low cost receiver will be chosen then. Due to the advancement of receiver technology and the incoming additional frequency for GPS system, it is hoped that dual frequency receiver will be gradually cheaper. It means that ionospheric delay will be a problem any longer.

In light of receiver technology and computer and processor technology, the study could be extended to design the prototype of a home made low cost GPS receiver.

As a scientist and academician of a developing country, there is a need to study the fundamental research and experience the theory and practice despite the things have been too common and easy to use in the global market. The philosophy behind the application will play the important role and build the nation's creativity.

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