IMPROVED GPS SINGLE POINT POSITIONING USING WEIGHTED LEAST SQUARE METHOD

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Tajuk Projek : Improved GPS Single Point Positioning using Weighted Least Square Method

Sesi Pengajian :

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ABSTRACT

Global positioning system (GPS) is a satellite-based system used for navigation purpose. The exact location of a receiver on Earth can be determined by using this system. In order to estimate the position of the receiver, the receiver is required at least four satellites view on the space with the observed pseudo-range or carrier phase from each satellite has been detected. However, the accuracy of the location on the earth is depending on the satellite views and the elevation angle of the satellite to the ground receiver. In addition, the accuracy also affected by the time delay from receiver clock bias, ionospheric delay and the tropospheric delay. In order to improve the accuracy of GPS single point positioning, the weighted least square method is proposed. Analysis was done for the accuracy improvement brought by this method. In this project, the weighted least square algorithm is written in MATLAB software to calculate the exact position of receiver on earth by using the Receiver Independent Exchange (RINEX) file as the input raw data. In addition, another method which is ordinary least square method is also written in MATLAB software to make a comparison with the weighted least square method. Based from the simulation result, all weighted least square provided the promising results with smaller standard deviation value compared to ordinary least square method. There are 3 different parameters were used as weight for weighted least square method which is sinusoidal function, zero-difference pseudo-range sinusoidal function and tangent function.

ABSTRAK

Sistem kedudukan global (GPS) adalah satu sistem berasaskan satelit yang digunakan untuk tujuan navigasi. Lokasi yang tepat seorang penerima di bumi boleh ditentukan dengan menggunakan sistem ini. Untuk menganggarkan kedudukan penerima, penerima diperlukan sekurang-kurangnya empat satelit melihat pada ruang dengan fasa pseudo-range atau pembawa yang diperhatikan dari setiap satelit telah dikesan. Walau bagaimanapun, ketepatan lokasi pada bumi ini bergantung kepada paparan satelit dan sudut ketinggian satelit kepada penerima tanah. Di samping itu, ketepatan juga dipengaruhi oleh kelewatan masa daripada berat sebelah jam penerima, kelewatan ionosfera dan kelewatan tropospheric. Dalam usaha untuk meningkatkan ketepatan GPS titik kedudukan, kaedah kuasa dua terkecil wajaran adalah dicadangkan. Analisis telah dilakukan untuk penambahbaikan ketepatan yang dibawa oleh kaedah ini. Dalam projek ini, algoritma persegi kurangnya wajaran ditulis dalam perisian MATLAB untuk mengira kedudukan sebenar penerima di bumi dengan menggunakan Penerima Exchange Bebas (RINEX) fail sebagai data mentah input. Di samping itu, satu lagi kaedah yang biasa kaedah kuasa dua terkecil juga ditulis dalam perisian MATLAB untuk membuat perbandingan dengan kaedah-kurangnya persegi wajaran. Berdasarkan daripada hasil simulasi, semua wajaran kurangnya persegi dengan syarat keputusan yang menjanjikan dengan lebih kecil nilai sisihan piawai berbanding kaedah kuasa dua terkecil biasa. Terdapat 3 parameter yang berbeza telah digunakan sebagai berat untuk kaedah kuasa dua terkecil wajaran yang merupakan fungsi sinusoidal, sifar perbezaan pseudo-range fungsi sinusoidal dan tangen fungsi.

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LIST OF ABBREVIATIONS

CA	-	Coarse Acquisition or Clear Acquisition
DOP	-	Dilution of Precision
DRMS	-	Distance Root Mean Square
ECEF	-	Earth Center Earth Fixed
GDOP	-	Geometrical Dilution of Precision
GNSS	-	Global Navigation Satellite System
GPS	-	Global Positioning System
HDOP	-	Horizontal Dilution of Precision
LLA	-	Latitude Longitude Altitude
MATLAB	-	Matrix Laboratory
MEO	-	Medium Earth Orbit
OLS	-	Ordinary Least Square
PDOP	-	Position Dilution of Precision
RINEX	-	Receiver Independent Exchange
SA	-	Selective Availability
TDOP	-	Time Dilution of Precision
VDOP	-	Vertical Dilution of Precision
WGS84	-	World Geodetic System 1984
WLS	-	Weighted Least Square

CHAPTER 1

INTRODUCTION

1 OVERVIEW

This chapter is discussed the introduction to the project. The project background is briefly introduced the GPS and the important of the GPS system. Next, the project problem statement is stated clearly and proposed the solution. In order to achieve the objectives, the scope of project is fixed and carried the methodology the to achieve the objective of project.

1.1 Project background

In this era, Global Positioning System (GPS) plays the important role among the civilians and the military applications. For civilians, it is always useful in the navigation system. The users can go everywhere by using a low cost GPS receiver in car even through a smartphone for route navigation purpose.

However, the accuracy of navigation is not that critical compared to the rescue and life-saving application. Nowadays the most important role for GPS development is the emergency solution which is the critical application for rescue and life-saving [1]. In addition, the GPS applications also including the agriculture control, aerospace and marine navigation.

Moreover, the military also use the GPS to control the nuclear weapons and the GPS surveillance system. Those critical applications need a very high accuracy and sophisticated GPS receiver used in the system. For emergency solution in rescue and life-saving, the position provided by a 2G and 3G mobile network in very low accuracy. Hence, it has possibility located to a position which is inaccurate from the actual position. In this situation, the position provided by a GPS is better than the mobile network. However, the accuracy of GPS also depends on the quality of GPS receiver, the signal loss and time delay in the free space propagation. A best approximation algorithm is needed for a low cost GPS receiver in order to calculate better accurate position for critical application.

In this project, weighted least square method is proposed to improve accuracy of a low cost GPS receiver for single point positioning. This weighted least square method is compared to the ordinary least square method in order to know the improvement brought by weighted least square method.

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1.2 Problem statement

Nowadays, Global Positioning System (GPS) is play an important role in space–based navigation system. The GPS single point positioning is often used in the critical application such as rescue and life-saving. The accuracy of the coordinate of the user or receiver is very important for the saving and rescue mission to positioning search victim accurately and take the action plan immediately.

However, the accuracy for user's receiver is affected by the satellite views in the space. Since the Selectivity Availability is switch off on 1 May 2000, the error correction is only including the satellite clock offset, ionospheric delay and tropospheric delay [2][3][4]. The path of the GPS signal affects the accuracy of user position due to the ionospheric delay and tropospheric delay. If the GPS satellite signal from the longer path will affected more on the ionospheric delay and tropospheric delay.

In order to improve the accuracy position of the user, weighted least square method is proposed to overcome this problem by defining the weight compared the shorter path to each satellite path. The algorithm is written in MATLAB software, and using the least square method with the RINEX data from observation and navigation file were post processing to estimate the position of user.

1.3 Objectives

The main objectives of this project is to analyze the improvement GPS single point positioning by using weighted least square method. The GPS single point positioning is using the L1 frequency (1575.42 MHz).

- To develop the ordinary least square and weighted least square algorithm in MATLAB for GPS positioning computation.
- To analyze and study the improvement of accuracy brought by weighted least square method.

1.4 Score of project

This project is focused on L1 frequency of GPS single point positioning to determine the receiver coordinate in Earth Center Earth Fixed (ECEF) coordination. The algorithm tested in this project is written in MATLAB software with the RINEX v2.11 navigation and observation file as the input data to estimate the approximation location of GPS receiver by using ordinary least square and weighted least square method. The single point positioning model is based on world geodetic system 1984 (WGS84) datum and the errors correction are included for satellite offset clock error, satellite relativistic clock error, ionospheric delay based on Klobuchar model and tropospheric delay based on Hopfield model.

1.5 Report outline

This report is divided into 5 chapters. In chapter 1, the introduction of the project is explained clearly with the problem statement, objectives of project, score of project and the project methodology which is discussed the entire work flow of this project. In chapter 2, the introduction to the GPS is discussed in theoretical and provide the previous researchers' works to compare the work flow and improvement from their proposed models and method in order to determine the approximation receiver coordination. In chapter 3, the methodology of this project is explained clearly with the work flow of algorithm as written in MATLAB software. Next, chapter 4 is demonstrated the output result of the algorithm and analyzed the results based on the approximation position from the RINEX observation file, ordinary least square and weighted least square method. The discussion on the analysis is included at the last part of chapter 4. Followed by chapter 5, the conclusion of the project and the future work for this project improvement.

CHAPTER 2

LITERATURE REVIEW

2 OVERVIEW

This chapter is briefly explained the GPS constellation and the basic concept for single point positioning. Then, the degradation of GPS signal that caused by the source of errors in signal propagation from space segment to ground segment is discussed. Next, there will be a short introduction to the raw data of GPS which is the RINEX file format. Lastly, least square methods are discussed in detail and comparing the previous work of others researchers.

2.1 Introduction to GNSS

Global Navigation Satellite System (GNSS) is the infrastructure that allows users with a compatible device to determine their position, velocity and local time by processing signals from satellites in space. There are 4 common satellite constellation under GNSS which is GPS developed by US, GLONASS developed by Russian, Galileo developed by European Union and BEIDOU developed by China [1].

2.1.1 Important of GNSS

GNSS is used in many applications including the professional and the safety-critical applications such as safety of life, search and rescue services. However, this is depending on the need of users to declare the important of the GNSS performance. The performance including availability, accuracy, continuity, integrity and indoor penetration [1][5][6].

2.2 Global Positioning System

Global Positioning System (GPS) is the utility owned by US Department of Defense. The main purpose of having this system is to provide the users with positioning, navigating and timing services at all the time. Basically, GPS is divided into 3 segment which is space segment, control segment and users segment to control and monitor the satellite vehicles in the space. In addition, the orbits design of GPS is different from other satellite constellation [5][6].

2.2.1 Space segment

Figure 2.1 shows the full satellite constellation for the GPS is 24 satellites divided into 4 satellites in 6 orbital planes. Each of the orbital plane has inclination angle is 55 degrees from equatorial plane. The GPS satellites is fly at Medium Earth Orbit (MEO), so its altitude is 20200 km from the surface of Earth and each satellite circle is twice in a day. In general, this system constellation consists 24 satellite vehicles in the space. However, the Air forces want to maintain the coverage of satellites by increased the number of satellites more than 24. So the effective operation is 27 slot constellation to improve the coverage around the world [5][6][7].

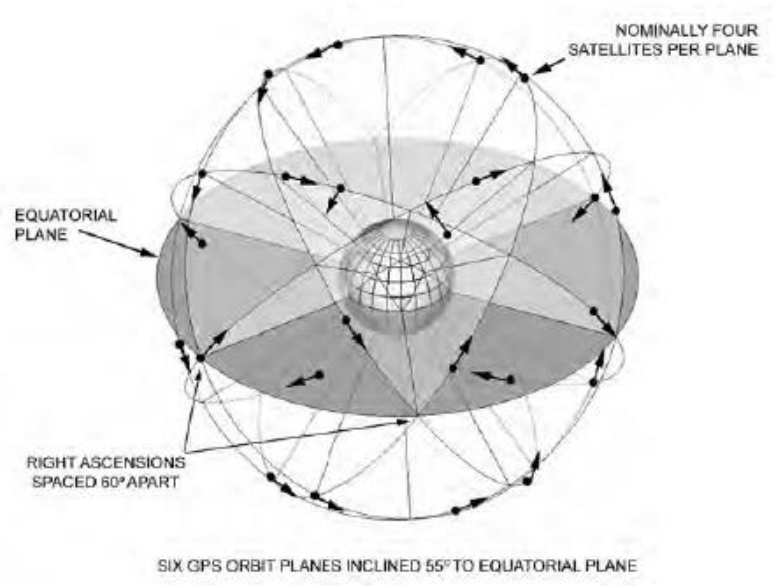

Figure 2.1: Basic GPS satellite constellation

2.2.2 Control segment

Figure 2.2 shows the location of control segment. The control segment consists of ground facilities in global network to track, control and monitor the location of the satellite vehicles and its transmission, perform analyses and send commands and data to the constellation. This segment is divided into several station such as a master control station, an alternative master control station, twelve command and control antennas and sixteen monitoring station. The master control station is set at Colorado which is main system control directly to each satellite vehicle to set their navigation message in order to have the accurate information of ephemeris data [5][6][7].

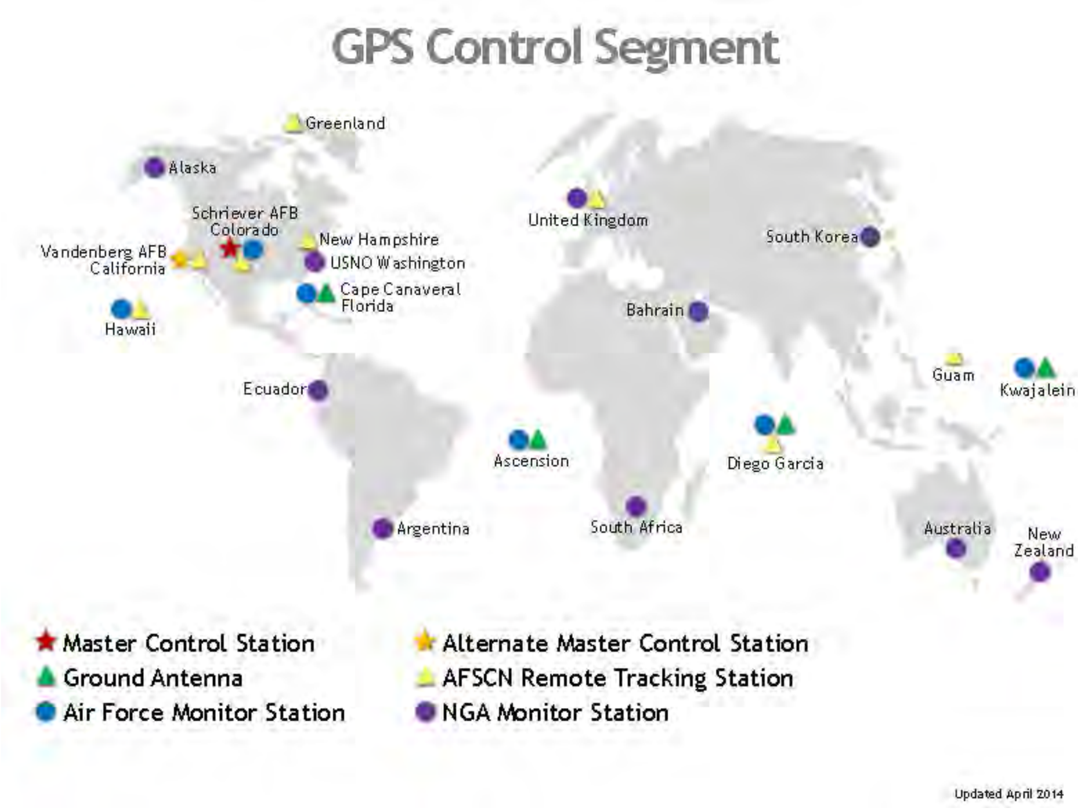

Figure 2.2: GPS control segment

2.2.3 User segment

User segment is the GPS compatible devices which is used to receive the GPS signal and determine the position of the users. Beside, these devices also can be used in navigation and timing calculation [8]. But, the accuracy of the GPS receiver is depended on the type of receiver. A low cost receiver is using the standard positioning service (SPS) so that the Coarse Acquisition (C/A) code is used to determine the position of receiver. For the precise positioning service (PPS) is more accurate but it is needed an authorized GPS receiver. The GPS signal for PPS is encoded as p-code or sometime is called Y-code [6][9]. Figure 2.3 shows the three dimensional positioning method. A GPS receiver uses triangulation to determine its position on the surface of earth by using the angle and intersection points between 4 satellites in Global Positioning System (GPS).

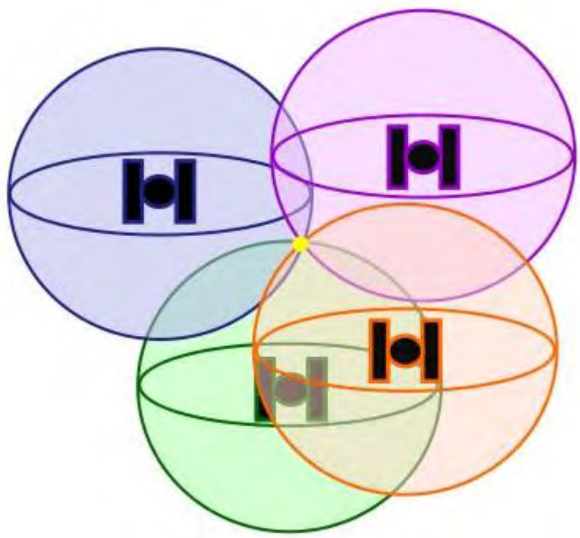

Figure 2.3: 3D Positioning

Figure 2.4 shows the trilateration positioning method. A GPS receiver uses trilateration to determine its position on the surface of the earth by timing signals from four satellites in the Global Positioning System (GPS).

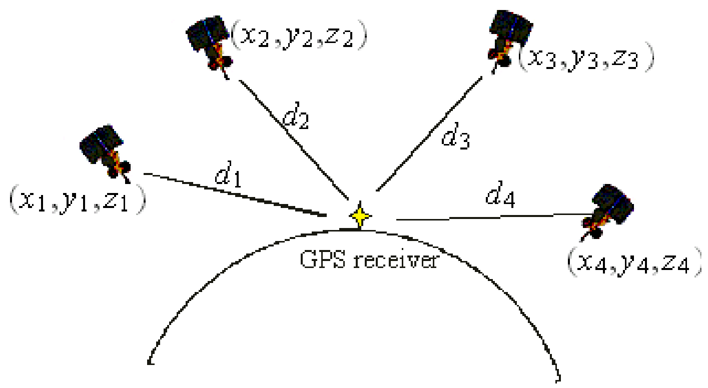

Figure 2.4: Trilateration Positioning

In two dimensional case, the position of receiver is determined by using three satellites. The trace of a point with constant distance to a fixed point is a circle in the two-dimensional case. Two satellites have two intersection point for the user's position. Hence, the third satellite is used to determine the exact user's position. In three dimensional case, the position of receiver is determined by using four satellites. Three satellites are used to determine the latitude, longitude and altitude. The equal-distance trace to a fixed point is a sphere in a three-dimensional case. Two spheres intersect to make a circle. This circle intersects another sphere to produce two points. In order to determine which point is the user position, one more satellite is needed[10].

2.3 Basic GPS positioning

The basic of GPS positioning to be establish is at least to have 4 satellites to determine the position of a GPS receiver [8][11]. However, a 2D positioning is required 3 satellites to determine the location in latitude and longitude. But 3D positioning is required minimum 4 satellites to determine the location in latitude, longitude and altitude. The basic positioning for 4 satellite is shown in equation (2-1) to (2-4):

$$\rho_1 = \sqrt{(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2} + \varepsilon_1 \tag{2-1}$$

$$\rho_2 = \sqrt{(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2} + \varepsilon_2 \tag{2-2}$$

$$\rho_3 = \sqrt{(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2} + \varepsilon_3 \tag{2-3}$$

$$\rho_4 = \sqrt{(x - x_4)^2 + (y - y_4)^2 + (z - z_4)^2} + \varepsilon_4 \tag{2-4}$$

where ρ_i is pseudo-range in meters, and x, y, and z is the ECEF coordinate of receiver in meters, the x_i, y_i and z_i are the ECEF coordinate of satellite. The i indicates the number of satellites. The ε_i is the clock bias error [9].

Equation (2-1) to (2-4) is the equation for 1 satellite pseudo range relative to the earth station receiver. For a 3D positioning, there is at least 4 satellites, so that it need 4 equations to determine the location of receiver. This equation is a non-linear equation which is required the Taylor's series method to linearize the equation in (2-1) to (2-4) and solve the equation in least square method. The method proposed to solve this equation is using the ordinary least square and weighted least square methods to determine the value of x, y and z by assuming the initial value of Δx, Δy and Δz are 0. If the x, y and z are the coordinate from the receiver, x_i, y_i and z_i is the coordinate of the satellites view in the space and $\varepsilon = ct$, c is the speed of light, t is the clock bias of user receiver. The value i is the number of satellites view. Pseudo-range is the sum of the actual range and the offset due to the user clock bias. In order to calculate the coordinate of user, receiver is using a linear equation to solve the 4 unknown value. Hence, the value of x, y and z are

$$x = x_n + \Delta x$$

$$y = y_n + \Delta y$$

$$z = z_n + \Delta z$$

$$t = t_n + \Delta t$$

$$\rho_i = \rho_{ni} + \Delta\rho_i$$

The equation (2-1) to (2-4) is simplified as in equation (2-5)

$$\left[\frac{X_n - X_i}{\rho_{ni} - ct_n}\right](\Delta x) + \left[\frac{Y_n - Y_i}{\rho_{ni} - ct_n}\right](\Delta y) + \left[\frac{Z_n - Z_i}{\rho_{ni} - ct_n}\right](\Delta z) + c\Delta t = \Delta\rho_i \tag{2-5}$$

This equation is represented one satellite. There are at least 4 satellites are detected, the equation is formed with the 4 x 4 matrix. Then, the solution of Δx, Δy, Δz and Δt are determined by using the least square method as in equation (2-6) and (2-7).

2.4 GPS signaling

GPS signaling is the electromagnetic wave which is propagated from space to earth station. This EM signal is generated by atomic clock in satellite vehicle which is used to transmit PRN code to the receiver in L1 or L2 frequency. L1 is 1575.42 MHz and L2 is 1227.6 MHz but the fundamental frequency for both L1 and L2 are 1023Mbit/s the navigation data the code from each satellite is modulated into GPS signal and transmit signal to the ground receiver. There are two types of code is transmitted which is C/A code and P-code[12].

Coarse Acquisition or Clear Acquisition (C/A) code is the standard GPS PRN codes. It also known as the Civilian Code or S-Code. This code is only modulated with the L1 carrier frequency and it is used to acquire and decode the L1 satellite signals so that L1 pseudo-range measurements can be made (the Block IIR-M satellites add another civil code on the L2 frequency). GPS receivers internally generate the PRN string of bit code of for each GPS satellite and align the code to lock on to each signal. The 1.023 MHz chip C/A code repeats every 1 milliseconds giving a code chip length of 300 m which, is very easy to lock onto[13]. The Precise or Protected code with a pseudorandom string of bits that is used by GPS receivers to determine the range to the transmitting GPS satellite on the GPS L1 and L2 carrier at a chip rate of 10.23MHz (approximately 10 times the resolution of the C/A code), which repeats about every 267 days. Each week segment of this code is unique to a GPS satellite and is reset each week. Under the policy of the DoD, the P-code is replaced by an encrypted Y-code when Anti-Spoofing is active. Y-code is intended to be available only to authorized (primarily military) users.

2.5 Sources of error

This section will discuss the sources of error. The error is introduced by the GPS signals that travel a long distance from space to earth. So, there will be consists of error on delay and the required mitigate the effect to obtain the better accurate position. Since the SA is removed, the atmosphere layer is the dominant issue that affect the signal propagation path.

2.5.1 Denial of accuracy

Denial of accuracy is the selective availability (SA) which is introduced by US government intentionally degrade the autonomous position capability of GPS for civilian use. This intentionally degradation is done by artificially make the clock error in the satellites and truncating the satellite ephemeris data. SA is activated on March 1990 and was turned off on May 2000 until now [2][3][4]. So that, the majority of accuracy error of GPS navigation and positioning is caused by SA before May 2000. Since the selective availability is removed, the majority error on accuracy nowadays is introduced by atmosphere of earth which is ionosphere and troposphere effect.