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Research on PVT Solution Methods for Navigation Message of GPS Receiver

Zhou Fan
School of Information Science & Engineering, Shenyang Ligong University
Shenyang, 110159, P.R. China
e-mail: yahoo_zf@163.com

Abstract

On the basis of the analysis of PVT solution methods for navigation message, the solution procedure of evaluation algorithm of LSM and Kaman filtering evaluation algorithm is constructed. Further, based on OEM development board for data acquisition, PVT solution process of collected GPS signals is simulated, and the results show that the solution property of Kaman filtering algorithm is much better than LSM.

Keywords*: PVT solution, Kaman filtering, GPS*

1. Introduction

GPS, the Global Positioning System, is a satellite systems consisted of 24 satellites with global coverage. This system ensures that four satellites can be observed simultaneously at any time and any point on Earth. It makes the satellite can collect the longitude and latitude and the height of the observation point, in order to achieve the navigation, positioning, time service and other functions.

GPS system can provide all-weather, continuous and real-time PVT with high accuracy for global users. In the modern society with the increasing demand for information, GPS is widely applied to military and civil fields because of its ability of all-weather, continuous and real-time supply for three-dimension position, three-dimension velocity and time with high accuracy [1]. GPS, the global satellite positioning system, consists of three parts: the space part-GPS constellation; the ground control part - ground monitoring system; the user equipment part-GPS signal receiver.

PVT includes the information of position, velocity and time. In the information age, the technology of PVT information processing in GPS receiving system has gotten great development in the military and civil field. Especially, it has become the important supporting system, greatly improving the capability of command and control, the coordination with many arms and rapid response, and accuracy and efficiency of arm equipment in the high technology war. Specifically, there are mainly some following aspects about the GPS receiving system's PVT information processing technology in the military applications: firstly, the full time domain autonomous navigation. The main function of GPS is autonomous navigation, using the GPS receiver's PVT information processing system to provide users with location and time information, and the system can be combined with the electronic map to display the mobile platform track, the route planning and the travel time estimates as well, thus greatly improve the military capability of mobile warfare and rapid reaction. Secondly, the command and control of various combat platforms. With the organic combination of PVT information about navigation and positioning and digital short message communication function, and the special positioning system, transmit the moving target location information and other relevant information to the command post to complete a moving target dynamic visual display and command instruction issue, thereby achieve the command and control of a moving target in the war zone. Thirdly, the assessment of precision guided and battle damage. The PVT information guidance provided by the GPS receiver with high precision and flexible guided, has become an important guidance system of precision guided weapons. In recent several high-tech local wars, the ratio about the U.S. military using precision guided missiles and bombs has increased of nearly 100 times more

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than the Gulf War, all of them or most of them rely on the PVT information guidance provided by the GPS receiver. GPS can also assess the targets hit rate. At the detonation moment of ammunition hitting the target equipped with a GPS receiver, trigger a user machine to find a location and transmit the position and time information to the command center rapidly which can have battle damage assessment, that have been fully validated in the Iraq War. Fourthly, provide individual combat system protection in the future. The positioning and communication functions provide location information and time information for the individual soldier, at the same time the location information real-time dynamic of the individual soldier can be sent to the command structure and the structure promptly sends various commands to the individual soldier that improve their capabilities of fighting and mobility. During the Kosovo War, the U.S. military's F-117 stealth aircraft was shot down, however, the pilot's SOS device was equipped with a GPS receiver so that the U.S. Military can find and rescue the pilot within seven hours before the Yugoslav army. Fifthly, the military digital communication network time service. Use the GPS receiving system's PVT information provides high-precision time service for military communications network with a unified time scale, so that in the communication network all of digital communication devices work at the standard frequency synchronously.

Taking into account the GPS satellite almost transmits at the fixed frequency, and the emission of navigation signals is relatively weak, so that the military GPS receiver is vulnerable to enemy interference. Therefore, how to improve the positioning accuracy and anti-jamming capability of the GPS receiver is still the focus of the GPS navigation and positioning technology. The main reasons that affect the positioning accuracy and stability are that there are many errors contained in the GPS positioning process. These errors are difficult to eliminate with the traditional methods, making GPS applications have been limited in some respects. GPS positioning errors mainly include satellite measurement errors and positioning errors caused by satellite geometry position. Satellite measurement errors also include the satellite clock error, the ephemeris error, the ionized stratum additional delay error, the troposphere additional delay error, multipath effects and receiver noise.

Important ways to eliminate random errors caused by the satellite measurements are to optimize the GPS receiving system's PVT information processing technology. The PVT information processing technology refers to calculate GPS receiver system's position, velocity and time with the navigation messages. At present, the technology includes pseudo-range measurement, navigation messages decoding and navigation solvers mainly. Pseudo-range measurement is the basis of the GPS navigation and positioning, the margin of the pseudo-range measurement error directly affects the positioning accuracy. The pseudo-range correction parameter and the correct calculation of position resolution parameters need accurate information provided by navigation messages with the correct solver algorithm for processing. At the moment, these three aspects involved in the PVT information processing technology still have problems, need to be further optimized in-depth study and discussion.

PVT solution is the calculation of message information in GPS receiving system by some algorithm. LSM and Kalman filtering algorithm is used commonly. In order to satisfy the increasing demand of GPS positioning accuracy, the elimination of random errors in GPS navigation and positioning has become the focus of current research in this field through the use of various solution algorithm of navigation. At present, the general positioning solution methods of PVT information processing technology for GPS receiving system include LSM and Kalman filtering algorithm.

It is very difficult for the traditional LSM to eliminate the random errors that affect the positioning accuracy existing in navigation data received by users, but Kalman filtering algorithm applies the optimal estimation theory to models of GPS positioning solution and makes full use of all kinds of statistical information, including the motion characteristics of carriers and statistical characteristics of GPS measurement, so as to achieve the real-time and best evaluation of the real condition from the random noises for the purpose of eliminating errors. The advantage of Kalman filtering algorithm can be reflected more in dynamic positioning of high dynamic GPS receiver by Kamlan filtering algorithm. Especially, when a GPS receiver filtering prediction equation can not receive GPS signals, the position and velocity can be obtained accurately by Kalman [1-2]. It is worthwhile to note that the key of Kalman filtering algorithm is the construction of precise dynamic models and noise models, but it’s very difficult to get the accurate description of system state in a real system. Especially, it is pretty hard for a high dynamic GPS receiver to determine accurately the characteristics of dynamic noises and observed noises, and so the approximate modes should be used, which causes model errors that influence the characteristics of filtering and even bring about diffusion of filtering. At present, a great deal of study has been made on applying the best evaluation theory to GPS dynamic filtering, but many problems still exist on how to construct motion modes of carriers more reasonably and more accurately, the improvement of dynamic characteristics of filters in order to adjust to high mobility of carriers and simplify filtering models and the improvement of real-time.

2. PVT Solution Mechanization of Navigation Message

The solution of user position is to employ the observed distance between a satellite and a user receiver to determine the absolute position of the user receiver in the corresponding coordinate system relative to the origin of geodetic coordinate system. Signals of GPS satellites contain a variety of positioning information, from which different observed quantity can be obtained according to different requirements and methods. The location of PN code is to do correlative calculation by ranging code (C/A code or P code) transmitted by satellites and local PN code of receivers. The transmission time of satellites signals is calculated by measuring the maximum of correlative function, and thus the distance between the satellite and the receiver, which is called correlative measurement. The vector diagram of user position in the system of satellites navigation is given in Figure 1.

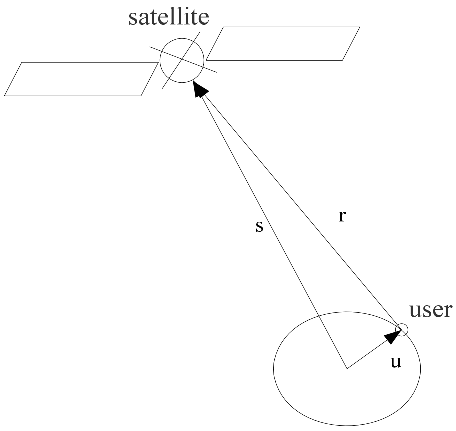

Figure 1. The Vector Diagram of User Position

From Figure 1, it’s easy to know that the vector from GPS satellite to a user is $\boldsymbol{r} = \boldsymbol{s} - \boldsymbol{u}$, the form of its scalar is $\mathrm{r} = \|\boldsymbol{s} - \boldsymbol{u}\|$. Let t_u be the divergence between the clock of a satellite and that of a receiver, and the measured pseudo range can be shown as $r_i' = \|\boldsymbol{s_i} - \boldsymbol{u}\|$ $+ct_u$.

It is easy to know that the location of a user can be calculated by a receiver which receives signals from four satellites at least. Let (x_i , y_i , z_i) how the position of a GPS satellite, let (x_u , y_u , z_u) show the position of a receiver, and the measured pseudo range can be shown as:

$$r_i^{'} = \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2} + ct_u \qquad i = 1,2,3,4 \qquad (1)$$

Let ($x_u^{'}, y_u^{'}, z_u^{'}$) show the approximate position of a receiver, demonstrate formula (1) with Taylor series at ($x_u^{'}, y_u^{'}, z_u^{'}$) , formula (2) can be obtained with the first term and the first power.

$$r_i^{'} = \tilde{r}_i^{'} + \frac{\partial r_i^{'}}{\partial x_u}\bigg|_{x_u = x_u^{'}} \cdot \left(x_u - x_u^{'}\right) + \frac{\partial r_i^{'}}{\partial y_u}\bigg|_{y_u = y_u^{'}} \cdot \left(y_u - y_u^{'}\right) + \frac{\partial r_i^{'}}{\partial z_u}\bigg|_{z_u = z_u^{'}} \cdot \left(z_u - z_u^{'}\right) + c\Delta t_u$$

$$= \tilde{r}_i^{'} - \frac{x_i - x_u^{'}}{\tilde{r}_i^{'}}\Delta x_u - \frac{y_i - y_u^{'}}{\tilde{r}_i^{'}}\Delta y_u - \frac{z_i - z_u^{'}}{\tilde{r}_i^{'}}\Delta z_u + c\Delta t_u \qquad (2)$$

In formula (2), $\tilde{r}_i^{'} = \sqrt{\left(x_i - x_u^{'}\right)^2 + \left(y_i - y_u^{'}\right)^2 + \left(z_i - z_u^{'}\right)^2}$ $i = 1,2,3,4$ is approximate pseudo range.

$$\begin{cases} \Delta x_u = x_u - x_u^{'} \\ \Delta y_u = y_u - y_u^{'} \\ \Delta z_u = z_u - z_u^{'} \end{cases} \qquad (3)$$

Formula (3) shows the difference of coordinates. It is worthwhile to note that the ignorance of some date leads to the poor accuracy of calculation in the process of linear. Meanwhile, in the above discussion, the causes of the poor accuracy also lie in the ignorance of noise in the process of measurement, the changes of the speed of light in the process of transmission and the effect of the theory of relativity.

By formula (2), $\tilde{r}_i^{'} - r_i^{'} = \frac{x_i - x_u^{'}}{\tilde{r}_i^{'}}\Delta x_u + \frac{\mathrm{y}_i - y_u^{'}}{\tilde{r}_i^{'}}\Delta y_u + \frac{z_i - z_u^{'}}{\tilde{r}_i^{'}}\Delta z - c\Delta t_u$

Let $\Delta r_i = \tilde{r}_i^{'} - r_i^{'}$, $\alpha_{xi} = \frac{x_i - x_u^{'}}{\tilde{r}_i^{'}}$, $\alpha_{yi} = \frac{y_i - y_u^{'}}{\tilde{r}_i^{'}}$, $\alpha_{zi} = \frac{z_i - z_u^{'}}{\tilde{r}_i^{'}}$,

So,

$$\Delta \boldsymbol{r} = \boldsymbol{H}\Delta \boldsymbol{u} \qquad (4)$$

In formula (4), $\Delta \boldsymbol{r} = \begin{bmatrix} \Delta r_1 \\ \Delta r_2 \\ \Delta r_3 \\ \Delta r_4 \end{bmatrix}$, $\boldsymbol{H} = \begin{bmatrix} \alpha_{x1} & \alpha_{y1} & \alpha_{z1} & 1 \\ \alpha_{x2} & \alpha_{y2} & \alpha_{z2} & 1 \\ \alpha_{x3} & \alpha_{y3} & \alpha_{z3} & 1 \\ \alpha_{x4} & \alpha_{y4} & \alpha_{z4} & 1 \end{bmatrix}$, $\Delta \boldsymbol{u} = \begin{bmatrix} \Delta x_u \\ \Delta y_u \\ \Delta z_u \\ -c\Delta t_u \end{bmatrix}$

So, the solution of formula (4) is formula (5). It contains the coordinate of a user and the offset value of the clock of a receiver [3-4].

$$\Delta \boldsymbol{u} = \boldsymbol{H}^{-1}\Delta \boldsymbol{r} \qquad (5)$$

3. Evaluation Algorithm of LSM

Evaluation algorithm of LSM is the best filtering for a series of giving data, which is utilized for the solution of navigation receivers with low speed. Formula (5) can be obtained by formula (4). The above-mentioned process is calculated again if the accuracy does not meet the requirement, and usually the realization of the accuracy can be gained with three-time or four –

time calculation. Formula (6), the solution by LSM, is deduced by formula (4) with the help of evaluation algorithm of LSM when the number of observed satellites is bigger than 4 [4].

$$\Delta u_{LS} = \left(H^T H\right)^{-1} H^T \Delta r \quad (6)$$

The solution procedure of evaluation algorithm of LSM is illustrated by Figure 2.

Step 1: Initialization of iterative increment Δu_{LS} and the value of PVT of a user u.

Step 2: Before the maximum iteration, calculating iterative increment Δu_{LS}, and substituting the result Δu_{LS} for the original u to the value of PVT of a user.

Step 3: Repeating step 2 until the iterative increment Δu_{LS} reaches the convergence threshold or the number of times of calculation is equal to the maximum iteration.

Step 4: The value of PVT of a user u is equal to the solved value of use's location only when the iterative increment Δu_{LS} is smaller than the convergence threshold. If the iterative increment Δu_{LS} is not smaller than the convergence threshold with the maximum iteration, the conclusion is made that the solution can't achieve the expected accuracy and the initialization of iterative increment should be made again.

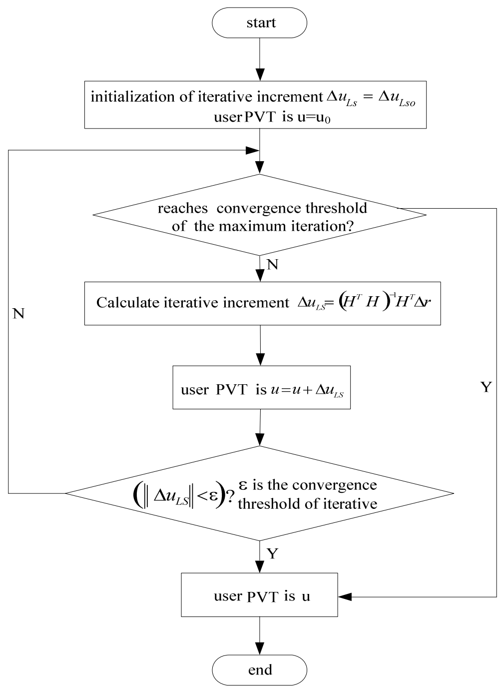

Figure 2. The Solution Procedure of Evaluation Algorithm of LSM

4. Kalman Filtering Evaluation Algorithm

The theory of the Kalman Filtering is a modern filter theory proposed in 1960 by Kalman. The Kalman filtering is a time domain method which can get the recursive least-mean-variance estimation of the system's state for the linear systems with Gaussian noise distribution. The Kalman filtering introduces the state space thought of modern control theory into the optimal filtering theory for the first time, describe the system dynamic model with the equation of state and the system observation model with equation of observation, and can handle time-varying systems, non-stationary signals and multi-dimensional signal. Due to the Kalman filtering using recursive calculation, it can be achieved by computer suitably. The Kalman filtering method is calculated on the basic of the least-mean-square-error, a extension of the Wiener filtering method. The Kalman filtering method should establish the state vector model of the applicable system in the first, and then through the recursive process seek the state vector's best estimation in the least-mean-square-error.

It is difficult for the traditional evaluation algorithm of LSM to reduce random errors of navigation data which influence location accuracy. The purpose of processing GPS navigation data lies in the reduction of effects which the errors make on the result of dynamic location as far as possible. One of the most important means is Kalman filtering. The theory of Kalman filtering, as the best real-time recursion algorithm, adopts state-space model of signals and noises, and take advantage of the previous estimate and the present observed value to renew the evaluation of state variable and get the estimate for the following moment which is suitable for real-time processing and computer operation [5-7].

The primary task of solution is the study of the following dynamic models in the system.

State equation of the studied system:

$$\mathbf{x}(n+1) = \mathbf{\Phi}(n+1, n)\mathbf{x}(n) + \mathbf{v}_1(n) \tag{7}$$

Measuring equation of the studied system:

$$\mathbf{z}(n) = \mathbf{H}(n)\mathbf{x}(n) + \mathbf{v}_2(n) \tag{8}$$

$\mathbf{x}(n)$ is M-dimension state vector of the system, to which the purpose of Kalman filtering is the best evaluation. $\mathbf{\Phi}(n+1, n)$ is M*M-dimension state transition matrix. $\mathbf{v}_1(n)$ is M-dimension noise vector of the system. $\mathbf{z}(n)$ is N-dimension measurement vector. $\mathbf{H}(n)$ is N*N-dimension measurement vector. $\mathbf{v}_2(n)$ is N-dimension measurement noise vector. $\mathbf{v}_1(n)$ and $\mathbf{v}_2(n)$ is white noise vector, and has the following properties.

$$E\{\mathbf{v}_1(n)\} = 0 \tag{9}$$

$$E\{\mathbf{v}_2(n)\} = 0 \tag{10}$$

$$E\{\mathbf{v}_1(n)\mathbf{v}_1^{\mathrm{T}}(k)\} = \begin{cases} Q_1 & n = k \\ 0 & n \neq k \end{cases} \tag{11}$$

It is known from formula (4) that the pseudo variable $\Delta\mathbf{r}$ is correspondent to the measurement vector $\mathbf{z}(n)$ of the Kalman filtering model; $\mathbf{H}$ matrix is correspondent to the measurement matrix $\mathbf{H}(n)$ of the Kalman filtering model; the value of position difference of user's receiver $\Delta\mathbf{u}$ is correspondent to the system state vector $\mathbf{x}(n)$ of the Kalman filtering model; the error of the value of position difference of user's receiver $\Delta\mathbf{u}$ is correspondent to the system noise vector $\mathbf{v}_1(n)$ of the Kalman filtering model; the value of pseudo difference $\Delta\mathbf{r}$ is correspondent to the measurement noise vector $\mathbf{v}_2(n)$ of Kalman filtering model. The Kalman filtering model of solution to the position of a user's receiver is then set up successfully [8-10].

After the construction of the Kalman filtering model, the state vector of the system (the value of position difference of a user's receiver) is calculated according to the solution process of Kalman filtering algorithm on the basis of the input measurement vector (observed pseudo received by a user's receiver) and initial condition (the value of position difference estimated by a user's receiver initially), and the present location of a user's receiver can be obtained according to the value of position difference of a user's receiver and the previous position of a receiver. The solution procedure of evaluation algorithm of Kalman filtering is illustrated by Figure 3 [10-14].

Step 1: A user's receiver calculates the initial conditions $\hat{\mathbf{x}}(1,0)$ and $\mathbf{P}(1,0)$ according to the estimated value of position difference at initial time.

Step 2: Calculating the gain matrix $\mathbf{K}(n)$, and calculating the innovation $\boldsymbol{\alpha}(n)$ according to the new observed pseudo received by a use's receiver.

Step 3: Renewing the predicted value $\hat{\mathrm{x}}(n, n+1)$.

Step 4: Obtaining the PVT value $\hat{\mathbf{x}}(n, n+1)$ of a user's receiver at the following moment according to the predicted value $\hat{\mathbf{x}}(n, n+1)$.

Step 5: If the next solution is not needed, escape directly, if not, go back to calculate $\mathbf{P}(n+1, n)$. So as to calculate the gain matrix $\mathbf{K}(n)$ of this time, the innovation $\boldsymbol{\alpha}(n)$ and the predicted value $\hat{\mathbf{x}}(n, n+1)$ of this time, and complete the calculation of $\mathbf{u}(n+1)$.

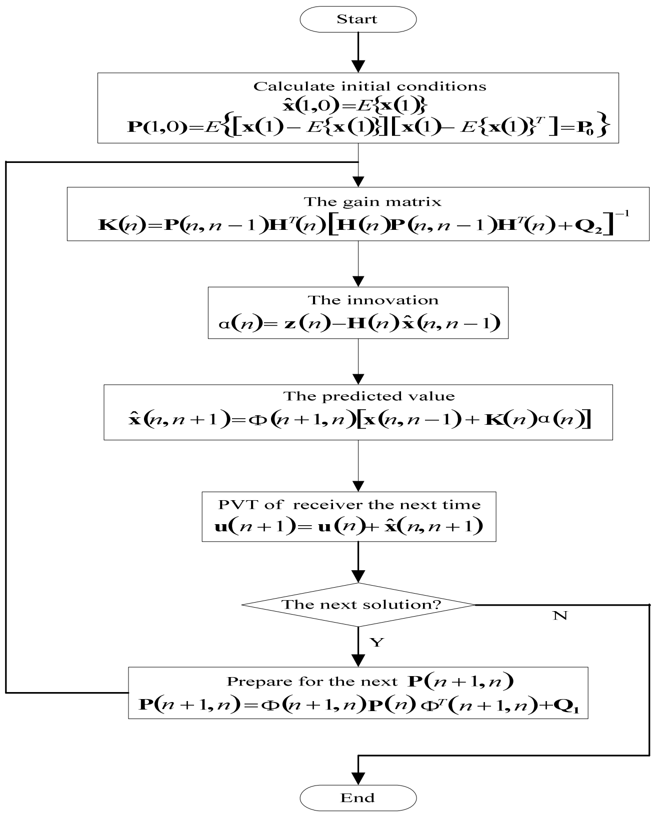

Figure 3. The Solution Procedure based on Kalman Filtering Evaluation Algorithm

5. Fuzzy Satellite Election Algorithm

The accuracy of user receiver's navigation and positioning is not only related to the navigation observations and satellite position errors like the pseudo-range measurements, but also to the numbers and the spatial location distribution of satellites. Just need 4 satellite for navigation and positioning, the positioning accuracy increases with the number of satellite monotonically, when the number of satellites is more than or equal to 6, there is few positioning accuracy improvement, however, the calculating complexity shows a geometric growth and greatly increase the receiver's implementation complexity and hardware requirements. GPS, for example, under normal circumstances, at the same time you can see the 12 GPS satellites, under the premise of a small loss of positioning accuracy, it is necessary and reasonable to choice a few satellite in the best position to locate and calculate to reduce the user receiver's implementation complexity, speed up the the positioning start time and reduce the cost of the receiver. Currently the module of satellite selection algorithm has become an important part of the user receiver. At present, satellite selection algorithm includes the following methods: firstly, the best satellite selection method. Have satellites combined orderly with the power of C_n^4 , and then GDOP values are calculated for each combination, select the smallest GDOP composition from the calculation results and that is the best geometric composition. The disadvantages of this method are the large calculated amount and taking a long time. Secondly, quasi-optimal satellite selection method. Select three satellites with largest slope distance from the visible satellites in the north, east and zenith direction; calculate a satellite's GDOP value chosen from the rest of the satellites arbitrarily. With this method you only need to calculate N-3 GDOP value, its effects rank only second to the best satellite selection method, but there is more difficulties about the selection of the first two satellites in the actual calculated process. Thirdly, geometry optimization method, according to the principle that volume is inversely proportional to the GDOP value, first select a satellite with maximum elevation from visible satellites as the first satellite, and then select two satellites which make a angle close to 109.5° with the first satellite as the second and the third satellites respectively, finally from the left satellites, arbitrarily select a satellite to form a tetrahedron and calculate volume, draw a combination of the maximum volume that is the minimum satellite combination of the GDOP [10-11].

In the fuzzy math, fuzzy comprehensive evaluation method evaluates things or phenomena affected by many factors, according to the given conditions, give an evaluation indicator to every object in all of them which is showed with a non-negative number generally. Then, select the optimal one according to the sort of evaluation indicators. Fuzzy evaluation process has the following steps:

Step 1: Structure the factor set based on the factors that impact things $A=[a_1,a_2,\cdots,a_n]$;

Step 2: Determine the remark set of fuzzy comprehensive evaluation $\Phi=[\phi_1,\phi_2,\cdots,\phi_n]$;

Step 3: Determine each element a_i on the factor set has a membership function to each element ϕ_i on the remark set $\Phi=[\phi_1,\phi_2,\cdots,\phi_n]$;

Step 4: Use f_v to give a single-element evaluation to each element a_i on the factor set, draw a fuzzy vector $v_i=[v_{i1},v_{i2},\cdots,v_{im}]$, and then use the results of the single-element evaluation structure a fuzzy matrix $V=[v_1^T,v_2^T,\cdots,v_n^T]$ that shows the fuzzy relation between these factors;

Step 5: To determine the weights of each factor, and then structure the weight of trace $P=[p_1,p_2,\cdots,p_n]$, wherein $\sum_1^n p_i=1$;

Step 6: Make a fuzzy transform $Q=P\times V$. Fuzzy vector Q is the evaluation result of the evaluated object on the remark set Φ , its component shows membership degrees of every evaluated object to each element on the remark set;

Step 7: To determine each component's weight of Q , draw the weight vectors: $\vec{P}=[\vec{P}_1,\vec{P}_2,\cdots,\vec{P}_n]$, then calculate evaluated indicators as $v=\vec{P}\times Q^T$.

Select two satellites which have the maximum and minimum elevation angle as the first and second satellites respectively and select the third and fourth satellites with the thought of fuzzy comprehensive evaluation. Show the azimuth angle and the elevation angle of the first and second satellite with A_1 and A_2, E_1 and E_2, and the rest of all visible satellites' azimuth and elevation angles show with α_i and e_i (i = 1, 2, 3 ... m). The selection of the third and fourth satellites is affected by the elevation and azimuth angles these two factors, use these two factors the angle of A_1+120° and α_i and the angle of E_i and e_i as the principle, set two angles as CA_i and CE_i to construct a fuzzy vector:

$$v_1 = [CA_1, CA_2, \cdots, CA_n]$$
$$v_2 = [CE_1, CE_2, \cdots, CE_n] \quad (12)$$

Construct a fuzzy matrix:

$$V = [v_1^T, v_2^T] \quad (13)$$

Construct the weight vectors: $P = [p_1, p_2]$, wherein p_1 and p_2 meet $p_1 + p_2 = 1$, make a fuzzy transformation: $Q = V \times P$. The satellite corresponding to the smallest element in the Q is the third satellite, the same to the fourth one.

Fuzzy satellite election theory applies the principle that tetrahedral volume is maximum. First select a satellite with the maximum elevation angle as No.1 satellite, and then select a satellite with the minimum elevation angle as No.2 satellite. Finally, according to these two satellites, draw the No.3 and No.4 satellites to make the GDOP least.

6. The Result and Analysis of Simulation

Usually, a user can observe 4-11 GPS satellites at the same time. To improve the accuracy of location, 4 satellites out of the observed ones used for solution of location on the basis of geometric optimized constellation selection algorithm. The data were collected by OEM development board in Communication and network institute of Shenyang Ligong University at 15:16-17:04 Beijing time on 30, 4, 2012. The data were collected every half of minute and 188 group of data were collected. The collected data were simulated are realized further by PVT algorithm, and so the errors of solution can be obtained. Table 1 is the measured position, azimuth and elevation of satellites that can be observed by GPS receivers.

Table 1. Position, Azimuth and Elevation of Satellites that can be Observed by Receivers

ID	X	Y	Z	elevation	azimuth
29	-23173075.2869	2240296.2301	12808312.3614	43.313	542.197
30	-3043794.7677	24945930.0716	8226588.6670	43.916	438.912
31	-7450090.2746	12860120.9836	22201826.5680	46.302	530.733
20	14277025.8485	12837584.8853	18219993.8154	49.501	215.926
23	-14995264.2880	-2692937.1015	21730965.8322	67.014	175.433
13	8531658.2683	21116541.0570	14262029.8973	50.816	236.204
16	-17295172.791100	7736797.221900	51052020.403100	69.881	185.802

Table 2. The GDOP Value of Satellite Combinations

No.	Satellite combinations	GDOP value
1	(29, 30, 23, 31)	17.047699
2	(29, 30, 16, 13)	8.26630
3	(29, 30, 13, 23)	2.852432
4	(29, 30, 31, 20)	2.82843
5	(29, 30, 16, 23)	5.729996
6	(29, 30, 20, 16)	7.328430
7	(29, 30, 20, 13)	5.219996
8	(29, 30, 31, 16)	6.125430
9	(29, 30, 23, 21)	5.296631
10	(29, 30, 13, 31)	6.430102

Take a visible satellite data, select the four satellites with the above method to calculate its GDOP value and compare the reasonability with the GDOP value calculated by four satellites selected arbitrarily.

As can be seen from Table 2, the GDOP values of different satellite combinations are a big gap. Above 10 satellite combinations, the GDOP value of the 4th combination is the smallest of all combinations. So, according to the fuzzy satellite election algorithm, we think that 4th combinations (29, 30, 31, 20) is the best satellite combination, the GDOP value is 2.828431.

After the choice of satellites by geometric optimized algorithm, satellites 29#, 30#, 31#, 20# were chosen finally to participate in PVT solution. After the PVT solution in the same conditions by evaluation algorithm of LSM and Kalman filtering evaluation algorithm respectively, the obtained errors of solution are illustrated in Figure 4 and Figure 5.

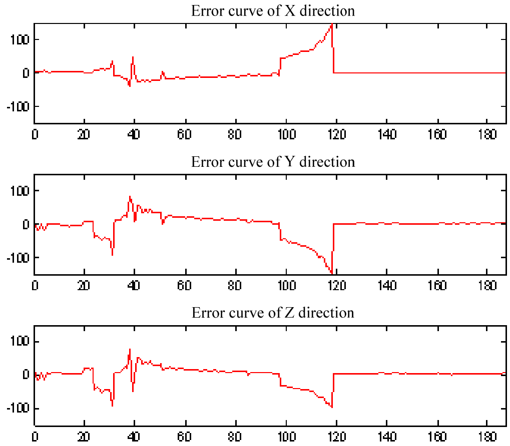

Figure 4. Errors Curve of PVT Solution of LSM Evaluation Algorithm

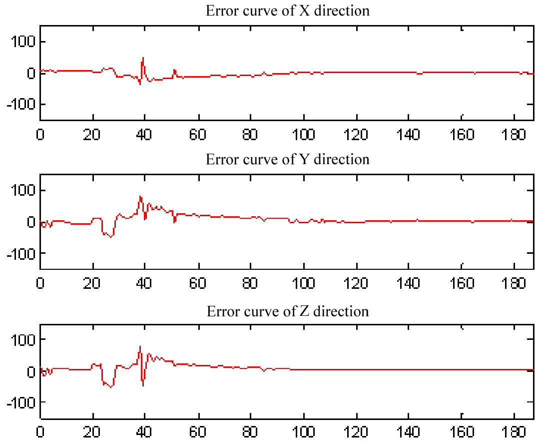

Figure 5. Errors Curve of PVT Solution of Kalman Filtering Evaluation Algorithm

With reference to Figure 4, the average accuracy of location is 6.5670m in the direction of X; the average accuracy of location is 8.1091m in the direction of Y; the average accuracy of location is 8.0277m in the direction of Z. the average accuracy of location of receivers is 7.5679m, which demonstrates the positioning performance is quite good. With reference of Figure 5, the average accuracy of location is 2.4389m in the direction of X; the average accuracy of location is 6.9746m in the direction of Y; the average accuracy of location is 7.8220m in the direction of Z. the average accuracy of location of receivers is 4.1192m, which demonstrates the positioning performance is much better than that of evaluation algorithm of LSM.

7. Conclusion

On the basis of the analysis of positioning principle of GPS system, PVT solution modes of LSM evaluation algorithm and Kalman filtering evaluation algorithm are set up. Taking OEM development board for data acquisition and VC++ as the means of simulation, PVT solution process of collected GPS signals is simulated. The results show that the two methods can accurately resolve PVT information, but Kalman filtering evaluation algorithm is more accurate and more application for solution than LSM evaluation algorithm. Taking the fact into account that PVT solution is the key to the improvement of working performance of GPS receivers, the study of the thesis promotes greatly the theoretical development of GPS receivers, which is of significance to the future development of hardware of GPS receivers.

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