Chapter 53
Improved Satellite Selection Algorithm Based on Carrier-to-Noise Ratio and Geometric Dilution of Precision

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Abstract Based on the traditional fuzzy arithmetic and concerned about the influence of carrier-to-noise ratio (C/N0) to positioning accuracy, this paper proposes an improved satellite selection algorithm based on C/N0 and geometric dilution of precision (GDOP). Positioning accuracy is mainly influenced by GDOP and the error of pseudo range measurement, and C/N0 is one of the primer factors influence the latter one. Both the error of pseudo range measurement and GDOP should be concerned in order to decrease the positioning error, instead of separate consideration. Traditional satellite selection algorithms, such as the algorithm of minimum GDOP, the algorithm of max volume of tetrahedron and so on, they just concentrated on the influence of GDOP and ignore the error of pseudo range measurement. This paper chooses the first two satellites with the highest and lowest elevation angle based on the principle of minimum GDOP, and then consider C/N0 and the satellite geometric distribution both when choosing the others. Use fuzzy satellite selection algorithm based on entropy method to weight the two factors. Pick out the satellite combination with smaller GDOP and higher C/N0 in the end. Compare and analyze the two results separately get from the method proposed in this paper and the traditional one, the simulation result shows that the improved satellite selection algorithm that considered GDOP and C/N0 both, compared to the traditional ones, can lead to smaller positioning error and better positioning result.

Keywords C/N0 · GDOP · Positioning error · Entropy method · Fuzzy arithmetic

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53.1 Introduction

Global Positioning System is radio navigation system based on satellite, characterized by pluripotency, globalization, all-weather, continuity and instantaneity, which has been widely used in both military and civil fields.

By the end of 1994, the layout of GPS consisted of 24 satellites had been completed, which can reach up to 98 % of global covered ratio; at present, receiver can use ephemeris of 32 satellites to accomplish positioning. So, if use all these ephemeris to calculate, not only the accuracy of positioning would not improve obviously but the consumption of time would increase largely, influence the performance of fast positioning. How to choose the combination of satellites which has the highest accuracy of positioning fast and effectively, makes a lot sense to improve the whole performance of software receiver.

There are mainly two factors that influence the accuracy of positioning: measurement error of pseudo range and GDOP. Traditional algorithm of satellite choosing, such as the algorithm of minimum GDOP, the algorithm of max volume of tetrahedron and so on, they just concentrated on the influence of GDOP and ignore the error of pseudo range measurement. This paper chooses the first two satellites with the highest and lowest elevation angle based on the principle of minimum GDOP, and then consider C/N0 and the satellite geometric distribution both when choosing the others. Use fuzzy satellite selection algorithm based on entropy method to weight the two factors. Pick out the satellite combination with smaller GDOP and higher C/N0 in the end.

53.2 Factors Influenced the Accuracy of Positioning

53.2.1 Geometric Dilution of Precision (GDOP)

GDOP measures the geometric distribution of the satellites, it represents space geometric distribution performance between users and satellites. If see the pseudo range measurement error factor as an independent and constant error, variances are all σ_0, then the positioning error can be expressed as: $\delta_{PVT} = GDOP * \sigma_0$, so GDOP plays a part in magnifying δ_{PVT}.

In order to improve the accuracy of positioning, we should choose the combination of satellites with lower GDOP, that means the satellite with larger space distribution range and better geometric distribution with users is better.

Document [1] proves that with the increase of satellites used in the calculation of positioning, GDOP decreased largely, and this trend tends to be un-conspicuous when the sum of satellites comes to 6.

53.2.2 Measurement Error of Pseudo Distance

In order to analyze the influences of all kinds of errors to the accuracy of positioning, a basic assumption is usually made: attribute the errors to the pseudo distances of every satellite and see them as equivalent error of pseudo distance values. The main error source include: the delay caused by atmosphere, noise and disturbance of receiver, deviation of multipath and hardware. Typical estimation of UERE listed in Table 53.1.

The error sources listed above influence the accuracy of positioning directly in different degree, the errors from user are much larger than that from space and control, and that would badly influence C/N0, which is the ratio between the power of receiver and noise, the bigger C/N0 is, the better signal received. This paper is mainly discussed the influence to the accuracy of positioning that C/N0 made.

Document [2] proves that the bigger SNR is, the smaller error of positioning is; on the contrary, the same conclusion can be got. On the other hand, document [3] gives a relation between C/N0 and SNR:

$$SNR = C/N0 * T_{coh}$$

Here, T_{coh} is coherent integration time. So the conclusion is: the bigger C/N0 is, the smaller error of positioning is, the higher accuracy is; the smaller C/N0 is, the bigger error of positioning is, the lower accuracy is.

53.3 Algorithm of Choosing Satellites Based on Entropy

53.3.1 Analysis of Algorithm

Based on the number of satellites of GPS that can be seen in BUPT, which mostly ranges from 6 to 12, according to the conclusion made before, 6 is the best choice.

From document [4] we can see that, the higher the top satellite (with biggest elevation) is, the smaller GDOP is; the lower the bottom satellite (with lowest elevation) is, the higher accuracy of positioning is. So, at first, we choose the

Table 53.1 Typical estimate of UERE of standard positioning service

Section source	Error source	1σ error (m)
Space/control	Broadcast clock	1.1
	L1 P(Y)-L1 C/A group delay	0.3
	Broadcast ephemeris	0.8
User	Ionospheric delay	7.0*
	Tropospheric delay	0.2
	Noise of receiver	0.1
	Multipath	0.2
System UERE	Total (RSS)	7.1*

satellite with biggest elevation to be the first one and the one with second biggest elevation be the next, the third satellite is the one with lowest elevation. After that, we use entropy method to balance the ratio among elevation, azimuth and C/N0 in order to choose the next three satellites.

53.3.2 Using Entropy Method to Weight

(1) Make sure the factors:

$$\text{Factors set}: E = [\,x1 \quad x2 \quad x3\,]$$

Here, $x1$ represents azimuth angle Al, $x2$ represents elevation angle E and $x3$ represents C/N0.

(2) Make sure the judges:

$$F = [f_1 \quad f_2 \quad \cdots \quad f_m\,]$$

Here, $f_i = [\,Al_i \quad E_i \quad C/N0_i\,]^T$, m represents the number of satellites that can be seen.

(3) Judge every factors and get fuzzy vectors:

$$R_1 = [\,CAl_1 \quad CAl_2 \quad \cdots \quad CAl_m\,]$$

$$R_2 = [\,CE_1 \quad CE_2 \quad \cdots \quad CE_m\,]$$

$$R_3 = [\,CN0_1 \quad CN0_2 \quad \cdots \quad CN0_m\,]$$

$$R = \left[\,R_1^T \quad R_2^T \quad R_3^T\,\right]^T$$

$$CAl_i = Al_3 + 90^\circ * (i-3) - Al_i,\ CE_i = E_i - E_3,\ CN0_i = C/N0_i - C/N0_{\min}, \quad i \in (4,5,6).$$

$CAl_i\,(i = 4,5,6,)$ represents adding 90°, 180° and 270° respectively to the third azimuth that had been chosen before. Then minus it with last azimuths, choose the one with bigger difference which means more uniform distribution. For the index which is the bigger the better:

$$R_1 = \frac{Al_{1j} - \min\{Al_{1j}\}}{\max\{Al_{1j}\} - \min\{Al_{1j}\}}$$

$CE_i\,(i = 4,5,6,)$ represents the minus difference between the last elevations and the third one, the smaller the value is, the little elevation for chosen is. For the index which is the smaller the better:

$$R_2 = \frac{\max\{E_{2j}\} - E_{2j}}{\max\{E_{2j}\} - \min\{E_{2j}\}}$$

$CN0_i\ (i = 4, 5, 6,)$ represents the minus difference between the last values of C/N0 and the smallest one, the bigger the value is, the better signal the satellite owns. So the same as above, for the index which is the bigger the better:

$$R_3 = \frac{CN0_{3j} - \min\{CN0_{3j}\}}{\max\{CN0_{3j}\} - \min\{CN0_{3j}\}}$$

(4) Define entropy

In the case of n evaluated objects and m indexes, the entropy of the index ranked I is defined:

$$H_i = -k\sum_{j=1}^{n} f_{ij} \ln f_{ij}, \quad i = 1, 2, \ldots, m$$

Here, $f_{ij} = r_{ij} \Big/ \sum_{j=1}^{n} r_{ij}$, $k = 1/\ln n$, when $f_{ij} = 0$, let $f_{ij} \ln f_{ij} = 0$.

(5) Use "Entropy Method" to stricter weight set:

$$P = [\,w_1 \quad w_2 \quad w_3\,]$$

Here, $w_i = \frac{1-H_i}{m-\sum_{i=1}^{n} H_i}$, $0 \le w_i \le 1, \sum_{i=1}^{n} w_i = 1$

(6) Fuzzy change:

$$Q = P \bullet R$$

Choose the one with bigger Q value in the end.

53.4 Analysis of Simulated Results

On the basis of theoretical analysis above, this paper uses the simulated tool of MATLAB to test and verify the data got from satellite signal simulator in the two different conditions: results got from traditional and modified method on the condition that the C/N0 value of every satellite differs less than 2db; use satellite signal simulator to minus 5db from one of the satellites chosen from the smallest GDOP combination, then compare the performances of two different method again.

53.4.1 Result of Un-Conspicuous Difference of C/N0 Values

At the observed point, the number of satellites that can be seen is 12, the elevations, azimuths and C/N0 values are listed below:

PRN	Elevations	Azimuths	C/N0
1	7.100574	317.1562	45.6889
5	68.42472	249.8318	45.1346
9	14.60859	53.85035	45.2436
10	51.12814	174.5211	44.9057
12	41.17076	64.32487	44.7321
15	59.03869	81.71412	45.4117
18	31.44686	162.0777	44.4217
25	53.54906	131.2996	45.5653
27	78.37755	340.0934	45.6102
28	50.48001	131.3614	45.7455
31	34.85086	245.0932	45.6404
32	5.120772	319.7330	45.6319

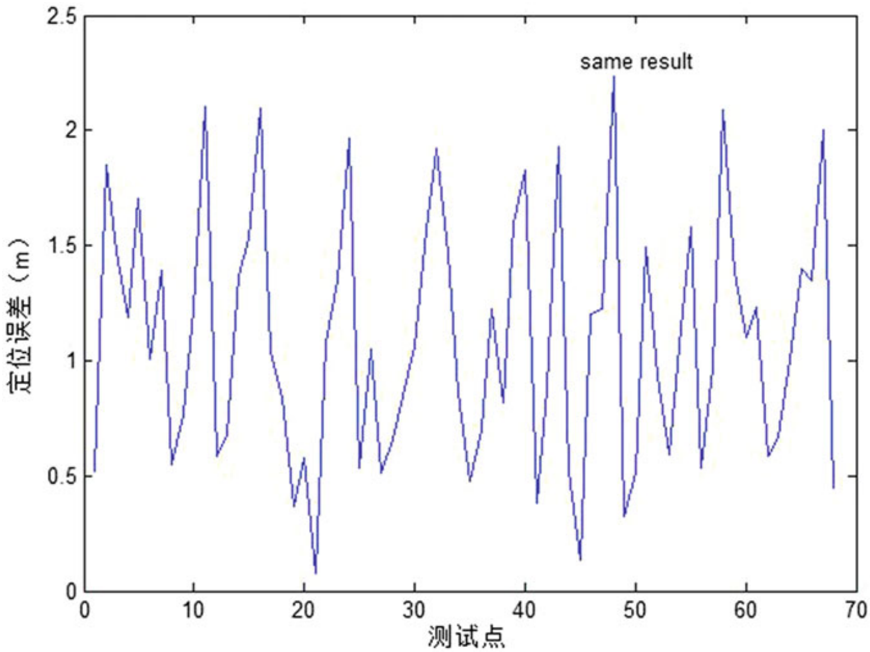

Fig. 53.1 Error line of positioning

Make simulation of the method mentioned in document [5], we can get the combination of satellites with smallest GDOP, this method cut down the cost of calculation, results are listed below, which are the same to the results got from the method mentioned in this paper (Fig. 53.1):

Satellite combination (PRN)	GDOP	Mean value of C/N0	Error of positioning (m)
1, 5, 18, 27, 31, 32	2.54576	45.3546	1.0914

53.4.2 Result of Conspicuous Difference of C/N0 Values

Use satellite signal simulator to minus 5db from one of the satellites chosen from the smallest GDOP combination (here, we choose PRN 18), data and the simulation listed below:

PRN	Elevations	Azimuths	C/N0
1	7.100574	317.1562	45.6889
5	68.42472	249.8318	45.1346
9	14.60859	53.85035	45.2436
10	51.12814	174.5211	44.9057
12	41.17076	64.32487	44.7321
15	59.03869	81.71412	45.4117
18	31.44686	162.0777	39.4217
25	53.54906	131.2996	45.5653
27	78.37755	340.0934	45.6102
28	50.48001	131.3614	45.7455
31	34.85086	245.0932	45.6404
32	5.120772	319.7330	45.6319

	Satellite combination (PRN)	GDOP	Mean value of C/N0	Error of positioning (m)
Traditional method	1, 5, 18, 27, 31, 32	2.5457	44.5212	1.8428
Modified method	1, 5, 9, 27, 31, 32	3.0927	45.4916	1.2916

In Fig. 53.2, red-real line represents the errors of positioning got from the traditional algorithm, blue-broken line represents the errors of positioning got from the modified method. We can see that use the modified method, which blends C/N0 in the index that valued by entropy, to choose the combination of satellites can lead to bigger mean C/N0 value and better effect of positioning which improved by about 30 %, although GDOP is bigger than the traditional one.

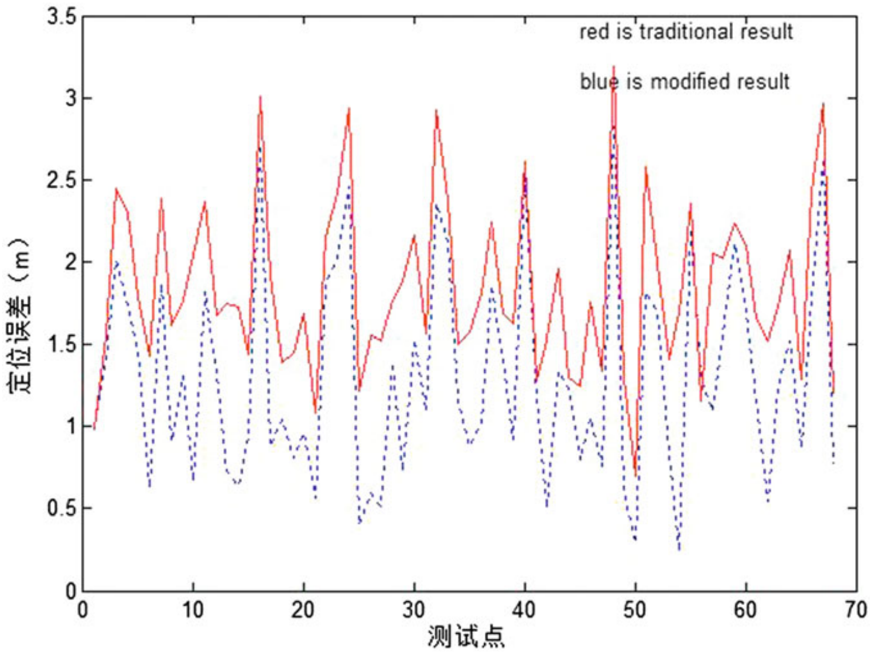

Fig. 53.2 Error line of positioning

53.4.3 Compare and Analyse

Compare and analyze the results above, we can get the conclusions:

(1) The final result of two methods are the same under the condition that the C/N0 value of every satellite differs less than 2db;
(2) When C/N0 value of one or more satellites differs largely (>2db) than the others, although the GDOP still is the smallest got from the traditional method, if the combination contains the satellite of low C/N0 value, the final error of positioning would be large. On the contrary, the accuracy of positioning calculated through the satellites chose by the modified method is the highest even if the GDOP is not the smallest, because the C/N0 value is higher.

For the case of multi-system, the number of satellites grows bigger, if spreading this method mentioned here to this situation, not only the cost of calculation would be definitely cut down, the accuracy of positioning would be guaranteed powerfully as well.

53.5 Conclusion

This paper mainly discussed the influence of GDOP and C/N0 on positioning accuracy respectively from the angel of positioning error, and proposed a modified method of choosing satellites, which used entropy method to weight both GDOP and C/N0, on the basis of traditional fuzzy method. The simulated result proves that: this modified method not only owns the traditional advantage of lower cost of calculation, but also the final effect of positioning is improved obviously.

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