An Optimal Satellite Selection Method Based on Genetic Algorithms

Hangyu HUO*, Zheng ZHENG and Xiaolin ZHANG

School of Electronics and Information Engineering, Beihang University, Beijing, 100086, China

***Abstract* — We consider the relationship between the number of the selected satellites and geometry dilution of precision (GDOP) and navigation computation, and propose an optimal satellite selection method based on genetic algorithms. This method consists of the following steps: Firstly, the number of selected satellites and GDOP threshold are decided according to the precision requirements of the user. Secondly, the initial population of satellite selection solutions is constructed, and the initial solution is obtained through the selection, crossover and mutation operations. Thirdly, according to the least GDOP principle, the optimal satellite is selected from other visible satellites, and the final solution is obtained. The experimental results show that under the premise of meeting the user's location accuracy requirement, the method can effectively reduce the complexity of satellite selection algorithm, compared with optimal GDOP method, where in the case of losing about 10.6% of GDOP value, 99.6% less number of calculations, at the same time can effectively reduce more than 62% of the navigation computation.**

Keywords-satellite navigation; genetic algorithm; geometric dilution of precision; satellite selection

I. INTRODUCTION

Currently, the US GPS and Russian GLONASS have developed into the second-generation satellite navigation system, the European Galileo and China's COMPASS are also built actively. With a large increase in the number of visible satellites, the multi-constellations navigation will become the main trend in future due to the benefits in positioning accuracy. At the same time, the navigation computation will grow rapidly, which will seriously affect the real-time performance of navigation solver and greatly increase the difficulty and cost of receiver hardware design for high dynamic users.

Therefore, how to select visible satellites in real time to reduce excessive redundant information and improve the real-time performance of multi-constellations navigation receiver under the premise of meeting user's positioning accuracy requirement is essential. The best visible satellites selection method in single navigation system is generally optimal GDOP method [1] or optimal volume method [2], which will cause a great amount of computation in multi-constellations navigation due to the satellites number increasing. At present, a series of methods to reduce the amount of calculation are designed for satellite selection [3, 4, 5, 6]. However, these methods still have some limitation in conditions of large visible number of satellites or high positioning accuracy requirements.

This paper proposes an optimal satellite selection method, which named Genetic Optimization Satellite Selection Method (GOSSM), by analyzing the relationship between the number of the selected satellites and geometry dilution of precision (GDOP) and navigation computation. The method is premised on the user's location accuracy requirement. And the experiment results show that, in the case of small number of selected satellites, which means we can significantly reduce the navigation computation, GOSSM achieves fast satellite selection with a small loss of GDOP.

II. BETWEEN THE NUMBER OF SELECTED SATELLITES AND GDOP AND NAVIGATION COMPUTATION

A. *Relationship between the Number of Selected Satellites and GDOP*

Positioning accuracy of satellite navigation systems can be expressed as the product of GDOP and user equivalent range error.

$$\sigma_p = GDOP \cdot \sigma_{UERE} \tag{1}$$

Where σ_p denotes the standard deviation of positioning accuracy, GDOP is geometry dilution of precision, σ_{UERE} denotes the standard deviation of user equivalent range error. GDOP reflects amplification of user equivalent range error made by the positioning satellite constellation topology. Without loss of generality, we suppose that equivalent range error of each navigation system is approximately consistent. So that GDOP can reflect positioning accuracy, which means user's requirements for positioning accuracy can be embodied by GDOP threshold.

GDOP of multi-constellation navigation system is as follows:

$$\mathrm{H}=\begin{bmatrix} a_x^1 & a_y^1 & a_z^1 & 1 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_x^{A_{s1}} & a_y^{A_{s1}} & a_z^{A_{s1}} & 1 & 0 \\ a_x^{A_{s1}+1} & a_y^{A_{s1}+1} & a_z^{A_{s1}+1} & 0 & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_x^{A} & a_y^{A} & a_z^{A} & 0 & 1 \end{bmatrix} \quad (2)$$

Where a_x^i, a_y^i and a_z^i ($i=1,\cdots,A_{s1},A_{s1}+1,\cdots,A$) represent the direction vector of the i^{th} satellite; A_{s1} and $A-A_{s1}$ denote the number of visible satellite in system-I and system-II from the integrated navigation system.

Basing on ephemeris parameters of GPS/COMPASS navigation satellites, we build the simulation platform and choose observation stations from twenty-seven stations of Crustal Moment Observation Network of China. The elevation angle is 5°. The simulation time for 24h. The sampling interval is 60s. Select satellite with optimal GDOP method. The relationship between the number of selected satellites and GDOP in SUIY (most northeast), TASH (most west), YONG (most south) and XIAA (middle part) at t=12h is listed in Table 1. Fig.1 shows when the proportion of selected satellites is 0.5, the statistical probability of ratio of GDOP obtained before and after satellite selection, which is represented as $\overline{\Delta \mathrm{GDOP}}$.

TABLE 1. RELATIONSHIP BETWEEN THE NUMBER OF SELECTED SATELLITES AND GDOP

Number of selected satellites	GDOP			
	SUIY	TASH	XIAA	YONG
5	2.04	2.06	2.12	2.16
6	1.90	1.90	2.03	2.04
7	1.77	1.79	1.98	1.95
8	1.67	1.72	1.94	1.88
9	1.65	1.68	1.91	1.81
10	1.59	1.64	1.84	1.77
11	1.52	1.60	1.79	1.73
12	1.47	1.56	1.76	1.69
13	1.42	1.52	1.73	1.67
14	1.40	1.49	1.70	1.65
15	1.38	1.47	1.68	1.64
16	1.37	1.45	1.67	1.62
17	/	1.44	1.65	/
18	/	1.43	1.64	/

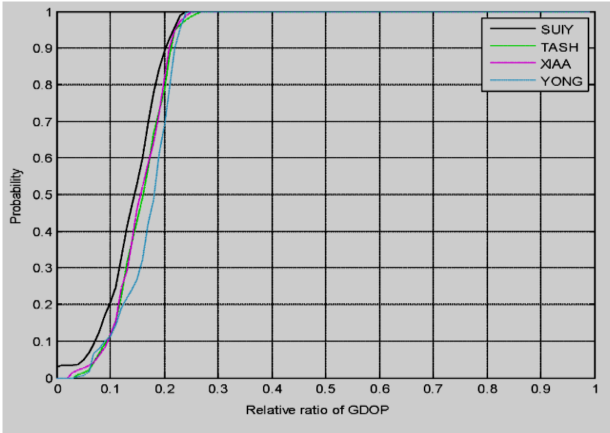

Figure 1. Statistical probability of $\overline{\Delta \mathrm{GDOP}}$ when proportion of selected satellites is 0.5.

From Table1 and Fig.1, the following conclusions can be drawn:

With the increasing of the number of selected satellites, the GDOP of each observation station after satellite selection decreases in a nonlinear way.

When the number of selected satellites is small, GDOP decrease rapidly, however, when the number of selected satellites is large, GDOP decrease slowly.

When the proportion of selected satellites is 0.5, the mean value of $\overline{\Delta \mathrm{GDOP}}$ n each observation station is not greater than 0.17. The maximum of $\overline{\Delta \mathrm{GDOP}}$ in each station during the simulation is not greater than 0.27. And $\overline{\Delta \mathrm{GDOP}}$ is less than 0.2 in at least 70% of the simulation time.

B. Relationship between the Number of Selected Satellites and Navigation Computation

In satellite navigation system, the equation of pseudo range measurement is as follows [1]:

$$\Delta\rho = H \cdot \Delta x + \varepsilon \quad (3)$$

Where $\Delta\rho \in R^B$ is the difference between measured value and predicted value of pseudo range, B is the number of selected satellites for positioning, $H \in R^{m\times I_{sys}}$ is measurement matrix, $I_{sys}=3+sys$ is state variable dimension, sys is the number of navigation system, $\Delta x \in R^{I_{sys}}$ is the increment of state variable, $\varepsilon \in R^{I_{sys}}$ is measurement noise.

The solving formula with least square method is as follows [1]:

$$\Delta x = \left(H^{\mathrm{T}} H\right)^{-1} \cdot H^{\mathrm{T}} \cdot \Delta \rho \tag{4}$$

The computation of each iteration is listed in Table 2. Where I_{sys} denotes state variable dimension and B stands for the number of selected satellites. The inversions of matrixes in Table 2 are computed with Gaussian Elimination [7]. For GPS/COMPASS dual-constellations navigation systems, $I_{sys} = 5$. During the simulation time, the average number of visible satellites in twenty-seven observation stations is 18. The relationship between the number of selected satellites and navigation computation is shown in Fig.2.

TABLE 2. COMPUTATIONS IN LEAST SQUARE METHOD

Multi-plication	$(1/3) I_{sys}^3 + (B+1) I_{sys}^2 + \left(B^2 + B - (1/3)\right) I_{sys} + 3B$
Addition	$(1/3) I_{sys}^3 + \left(B + (1/2)\right) I_{sys}^2 + \left(B^2 + B - (11/6)\right) I_{sys} + 3B$

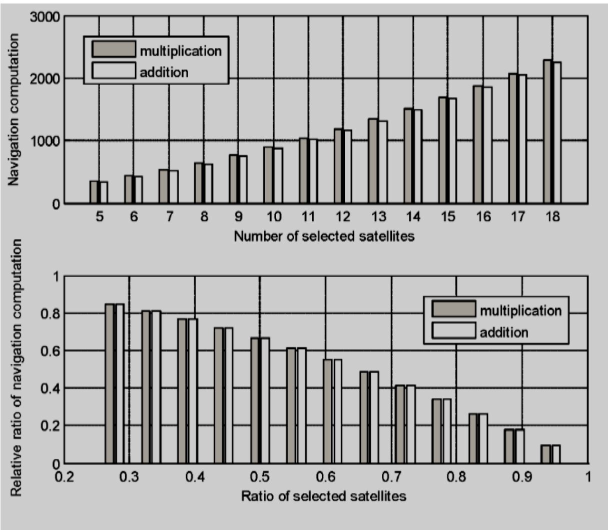

Figure 2. Topographic and geological map of bias tunnel.

From Fig.2, we can draw the conclusion that the navigation computation is decreased rapidly with the decreasing of the number of selected satellites, and when the proportion of selected satellites is 0.5, the reduction ratio of navigation computation is more than 60%.

The following satellite selection method searches for the balance between positioning accuracy, navigation computation and satellite selection computation instead of getting optimal GDOP. The method proposed in this paper significantly reduces navigation computation with less GDOP loss while completing satellite selection quickly to reduce the load of receiver processor and the difficulty of receiver hardware design.

III. GENETIC OPTIMIZATION SATELLITE SELECTION METHOD

A. The Mathematical Description of the Satellite Selection Problem

In the multi-constellations integrated navigation system, the satellite selection, that is to say, from all visible by selecting a certain number of satellites, make the precision of its topology structure to meet user needs. Then, the mathematical description of the satellite selection is as follows.

(1) $\exists A \in N$, $\exists B \in N$, and $A \geq B$.

(2) $\exists Z_j = \left[z_A \quad \cdots \quad z_1 \right]$, $j = 1, \ldots, k$, $z_i = \begin{cases} 1 \\ 0 \end{cases}$, $i = 1, \ldots, A$, and $\sum_{i=1}^{A} z_i = B$.

(3)To find $Z_0 \in \left\{ Z_j \right\}$, $GDOP\left(Z_0\right) = \min\left\{GDOP\left(Z_j\right)\right\}$, meeting

$GDOP\left(Z_0\right) \leq GDOP_T$.

Where A is the number of visible satellites, B is the number of selected satellites, k is the number of B-satellite subset, Z_j is the selected satellite scenario, $x_i = 1$ means the i^{th} satellite is selected, and $x_i = 0$ means the i^{th} satellite is not selected, $GDOP\left(Z_j\right)$ is GDOP of Z_j , Z_0 is the selected satellite solution, $GDOP_T$ is the GDOP threshold, which meets positioning accuracy requirement.

Obviously, this is a single objective optimization problem.

B. Genetic Optimization Satellite Selection Method

By designing coding scheme and evolution operators, the initial solution of satellite selection will be obtained, and then the initial solution with optimal GDOP principle will be optimized to get the final solution of satellite selection. The specific steps are as follows.

Step 1：Determine the number of selected satellites m, GDOP threshold $GDOP_T$, and elevation angle threshold. The number of selected satellite B is determined based on the consideration of the total number of receiver channels, positioning accuracy requirement, and fault detection requirement and receiver processor performance. GDOP threshold $GDOP_T$ depends on the user's positioning accuracy requirement. Generally, $GDOP_T = 6$ [1]. The elevation angle threshold depends on the environment in which the receiver is.

DOI 10.5013/ IJSSST.a.17.25.40 ISSN: 1473-804x online, 1473-8031 print

Step 2： According to the number and positions of visible satellites obtained in satellite ephemeris, exclude the satellites whose elevation angles are less than the threshold.

Step 3: Construct the initial population with m-1 satellites selection scenario.

Binary coding is used for satellite selection scenario. Each visible satellite was treated as a gene, used to indicate whether the satellite is selected. In satellite selection scenario $Z_j = [z_A \quad \cdots \quad z_1]$, which meets $\sum_{i=1}^{A} z_i = B-1$. All visible satellites are sequentially arranged, and the least significant bit represents the i^{th} satellite.

Step 4: Solve the fitness value of each satellite selection scenario in the population.

Objective function.

$$f_0(Z) = GDOP(Z) \tag{5}$$

Where Z represents the satellite selection scenario.

Fitness function.

$$f(Z) = \frac{GDOP_{\max} - f_0(Z) + \varepsilon}{GDOP_{\max} - GDOP_{\min} + \varepsilon} \tag{6}$$

Where $GDOP_{\max}$ denotes the maximum of GDOP of current population, and $GDOP_{\min}$ denotes the minimum of GDOP of current population, $\varepsilon \in (0,1)$, is a constant.

Step 5: Determine whether the initial population meets the termination principle of GOSSM, if not, do selection operator, crossover operator and mutation operator to obtain the new population. Repeat step 4 and 5 until getting the initial solution of satellite selection.

Termination principle. When the GDOP of the individual of which the fitness value is the biggest one meets the constraint $\min\{GDOP(Z_j)\} \le GDOP_T$, the evolution will be terminated. At the same time, in order to ensure the effectiveness of the iteration, the evolution will also be terminated if the maximum of fitness is constant or equivalent to the maximum evolutional generation.

Selection operator. In order to avoid the optimal constellation be eliminated, the roulette wheel selection method is adopted. To guarantee parents and offspring's have equal competition opportunities, a bigger sample space can obtained.

Crossover operators. The number of selected satellites is a constant determined by user's positioning accuracy requirement, which means the satellite selection scenario meets the constraint $\sum_{i=1}^{A} z_i = B-1$. To guarantee that the satellite the satellite selection which has better GDOP will not be eliminated when the crossover offspring is legal, a crossover operator is proposed.

The operation steps are as follows.

(1)Two individuals (parents) are selected with the crossover probability pc. And then two random integers A_1 and A_2 of $1 \sim (B-1)$ are generated to determine the range and number of gene '1' to be crossed.

(2)The original offspring is produced by interchanging the gene '1' which is in the range of A_1 to A_2.

(3)Determine whether the crossover offspring meets the constraint.

(4)If the crossover offspring doesn't meet the constraint, randomly select gene '0' in original offspring mutate into gene '1' according to the quantity of gene '1' to legalize offspring.

Mutation operator. To guarantee that the number of selected satellites of individual has exactly the same quantity in satellite selection, a dual gene '01' which is relative mutation operator is proposed.

The operation steps are as follows.

(1)Randomly select an individual c_p with the mutation probability p_m.

(2)Generate a random integer g_1 between 1 to A.

(3)Generate another random integer g_2 ($g_2 \neq g_1$) between 1 to n, of which the corresponding gene of individual c_p is 1 if the g_1^{th} gene of individual c_p is 0. Otherwise the corresponding gene of integer g_2 should be 0 when the g_2^{th} gene is 1.

(4)Interchange the g_1^{th} and g_2^{th} genes of individual c_p (convert 0 to 1, and vice versa).

Step 6: Select the B^{th} satellite in the rest of visible satellites with optimal GDOP principle to obtain the final solution of satellite selection.

Fig.3 shows the flowchart of GOSSM.

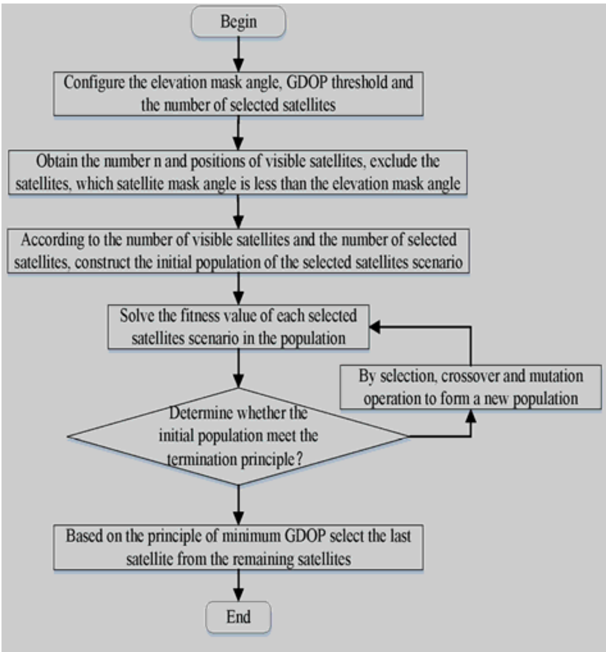

Figure 3. The flowchart of GOSSM.

IV. SIMULATION RESULTS

The validity and complexity of GOSSM proposed in this paper are analyzed and studied based on the GPS/COMPASS simulation platform. And we compare this method with the optimal GDOP method.

A. Simulation Environment

Referring to RTCA DO-2229D standard, the elevation angle is 5°. Based on twenty-seven stations of Crustal Moment Observation Network of China, we build the simulation platform of the GPS and COMPASS dual-constellation navigation system. The simulation time is 24h, and the sampling interval is 10s.

B. Performance Analysis of GOSSM.

During the simulation time, the average number of visible satellites of GPS/COMPASS dual-constellation navigation system in twenty-seven observation stations is 18. In order to analyze the performance of GOSSM when the number of selected satellites is small, and to meet the system fault detection requirement, the number of selected satellites is taken as 8 and 9. And we take $GDOP_T$ as 2.5,3,4 and 6 to analyze the performance of GOSSM under different positioning accuracy.

Analysis of validity. Fig.4 ~ Fig.7 show the variation of $GDOP$ and $GDOP_T$ respectively, in TASH and XIAA station after satellite selection under different thresholds.

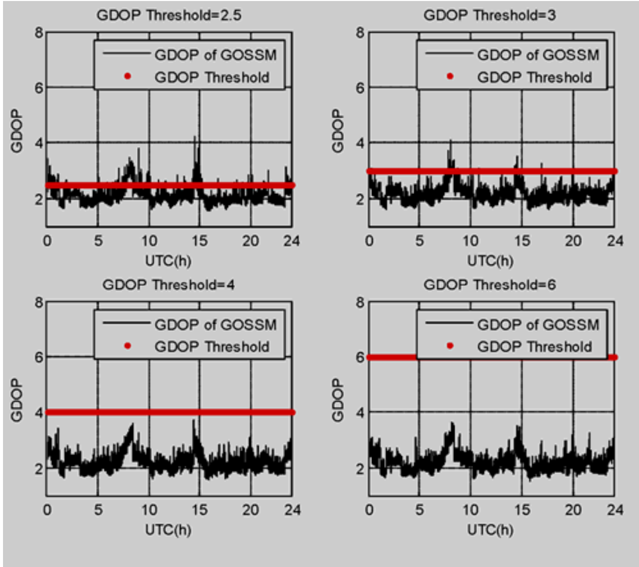

Figure 4. Variation of $GDOP$ and $GDOP_T$ under 8 selected satellites in TASH station

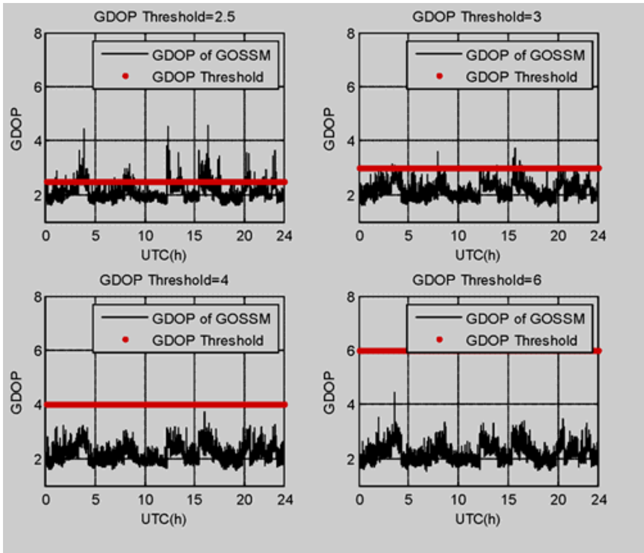

Figure 5. Variation of $GDOP$ and $GDOP_T$ under 8 selected satellites in XIAA station

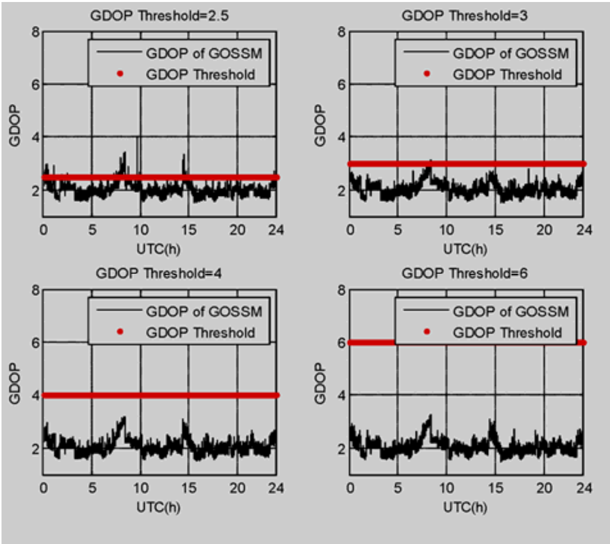

Figure 6. Variation of $GDOP$ and $GDOP_T$ under 9 selected satellites in TASH station.

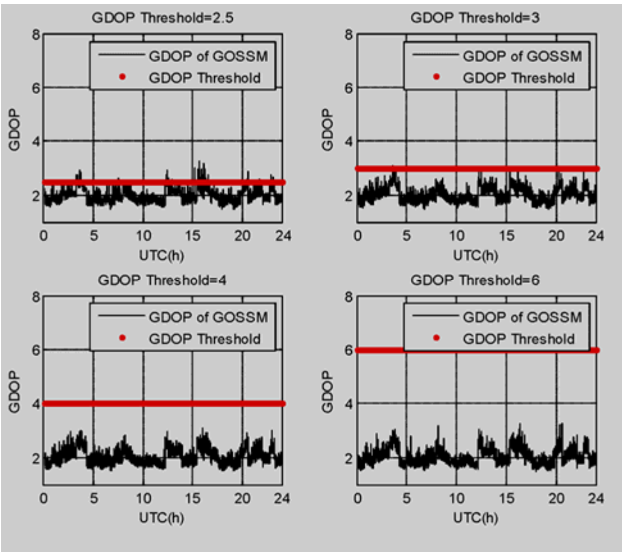

Figure 7. Variation of $GDOP$ and $GDOP_T$ under 9 selected satellites in XIAA station.

Table 3 ~ Table 4 are the statistical analysis of $GDOP$ in Fig.4 ~ Fig.7, where $P_{GDOP} = p\left(GDOP \le GDOP_T\right)$ stands for the probability of $GDOP$ which is not more than $GDOP_T$.

The average of $GDOP$ after satellite selection is below the threshold for each observation station. When $GDOP_T$ is between 2.5 and 4, no less than 94.43% of $GDOP$ meets the threshold requirement, and when $GDOP_T$ is between 4 and 6, no case is failed. And the validity and accuracy of GOSSM can be proved.

TABLE 3. $GDOP$ STATISTICS UNDER SELECTING 8 SATELLITES

station \ $GDOP_T$		2.5	3	4	6
TASH	$GDOP_{\min}$	1.57	1.58	1.58	1.52
	$GDOP_{\max}$	4.21	4.10	3.73	3.62
	$\overline{GDOP}$	2.073	2.142	2.170	2.170
	$GDOP_{\mathrm{var}}$	0.060	0.065	0.085	0.085
	P_{GDOP}	94.43%	99.02 %	100%	100%
XIAA	$GDOP_{\min}$	1.60	1.57	1.58	1.54
	$GDOP_{\max}$	4.56	3.70	3.74	4.42
	$\overline{GDOP}$	2.032	2.107	2.143	2.143
	$GDOP_{\mathrm{var}}$	0.059	0.062	0.090	0.091
	P_{GDOP}	95.64%	99.77 %	100%	100%

TABLE 4. $GDOP$ STATISTICS UNDER SELECTING 9 SATELLITES

station \ $GDOP_T$		2.5	3	4	6
TASH	$GDOP_{\min}$	1.53	1.51	1.52	1.50
	$GDOP_{\max}$	3.99	3.14	3.18	3.24
	$\overline{GDOP}$	1.989	2.019	2.027	2.025
	$GDOP_{\mathrm{var}}$	0.052	0.061	0.069	0.069
	P_{GDOP}	96.86%	99.84%	100%	100%
XIAA	$GDOP_{\min}$	1.48	1.49	1.51	1.50
	$GDOP_{\max}$	3.24	3.08	3.09	3.24
	$\overline{GDOP}$	1.944	1.987	1.997	1.997
	$GDOP_{\mathrm{var}}$	0.044	0.061	0.070	0.071
	P_{GDOP}	98.58%	99.97%	100%	100%

From Fig.4 ~ Fig.7 and Table 3 ~ Table 4, it can be concluded:

The temporal variation of $GDOP$ after satellite selection is smooth, for each observation station. And the feasibility and robustness of GOSSM can be proved.

The simulations for other observation stations have the similar conclusions.

Analysis of complexity. Fig.8 ~ Fig.11 show the simulation results of evolution algebra EA in TASH and XIAA station.

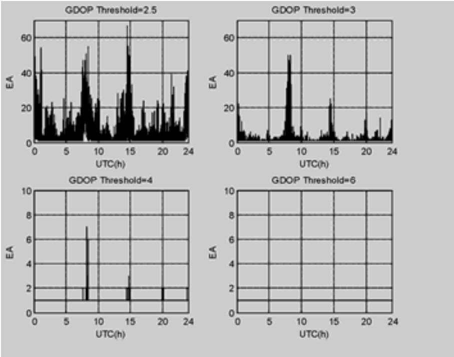

Figure 8. Variation of EA under 8 selected satellites in TASH station.

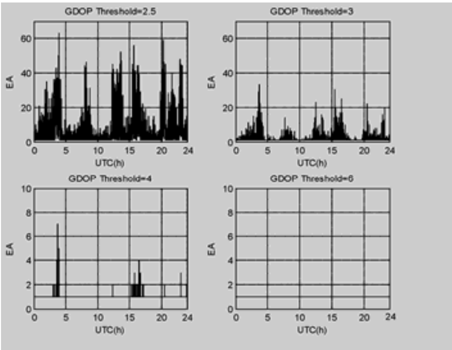

Figure 9. Variation of EA under 8 selected satellites in XIAA station.

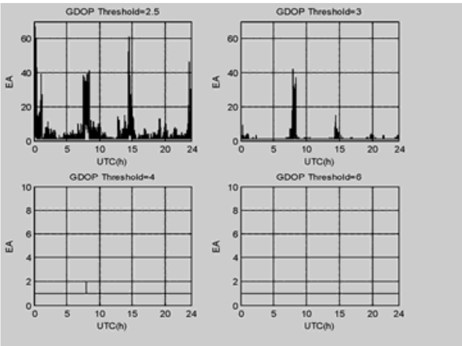

Figure 10. Variation of EA under 9 selected satellites in TASH station.

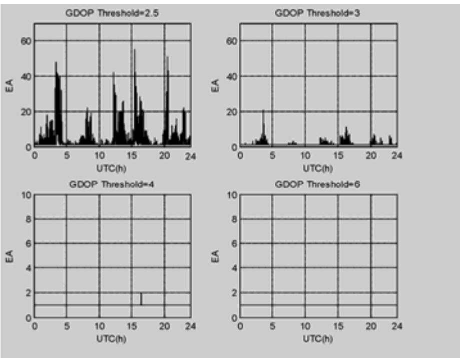

Figure 11. Variation of EA under 9 selected satellites in XIAA station.

Table 5 and Table 6 are the statistical analysis of Fig.8 ~ Fig.11, where $EA_{0.95}$ stands for the minimum EA that meets $p\left(GDOP \le GDOP_T\right) \ge 0.95$, and $P_{EA} = p\left(EA\right) \le 10$ stands for the probability of EA which is no more than 10.

TABLE 5. *EA* STATISTICS UNDER SELECTING 8 SATELLITES

$GDOP_T$		2.5	3	4	6
TASH	$EA_{\min}$	1	1	1	1
	$EA_{\max}$	50	25	2	1
	$\overline{EA}$	2.77	1.15	1	1
	$EA_{0.95}$	11	2	1	1
	P_{EA}	82.80%	96.91%	100%	100%
XIAA	$EA_{\min}$	1	1	1	1
	$EA_{\max}$	57	16	1	1
	$\overline{EA}$	2.20	1.07	1	1
	$EA_{0.95}$	7	1	1	1
	P_{EA}	76.97%	98.33%	99.97%	100%

TABLE 6. *EA* STATISTICS UNDER SELECTING 9 SATELLITES

$GDOP_T$		2.5	3	4	6
TASH	$EA_{\min}$	1	1	1	1
	$EA_{\max}$	50	7	2	1
	$\overline{EA}$	1.78	1.02	1	1
	$EA_{0.95}$	4	1	1	1
	P_{EA}	91.74%	98.09%	100%	100%
XIAA	$EA_{\min}$	1	1	1	1
	$EA_{\max}$	66	7	1	1
	$\overline{EA}$	1.60	1.01	1	1
	$EA_{0.95}$	3	1	1	1
	P_{EA}	90.64%	99.91%	100%	100%

From Fig.8 ~ Fig.11 and Table 5 ~ Table 6, it can be concluded:

When $GDOP_T$ is between 4 and 6, satellite selection can be finished with only one evolution.

When $GDOP_T$ is between 3 and 4, 95% satellite selection can be finished with 5 evolutions at most, and 96.91% satellite selection with 10 evolutions at most.

When $GDOP_T$ is between 2.5 and 3, more than 76.97% satellite selection can be finished with 10 evolutions at most under 8 selected satellites, and more than 90.64% satellite selection can be finished with10 evolutions at most under 9 selected satellites.

The simulations for other observation stations have the similar conclusions.

Analysis of computation. The relative ratio of navigation computation before and after satellite selection in XIAA station is shown in Fig.12. And the statistical analysis is shown in Table 7.

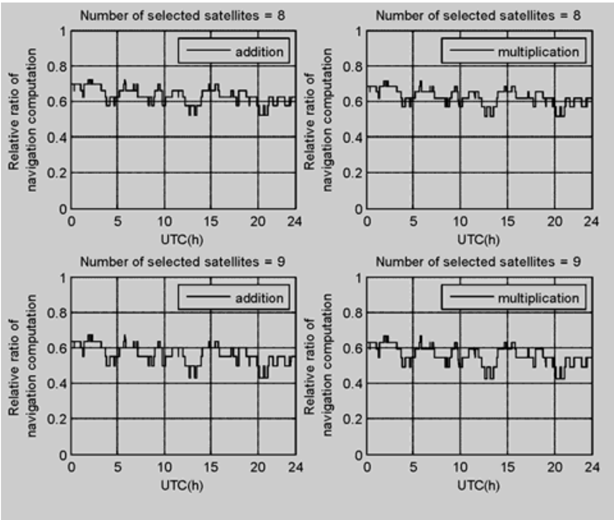

Figure 12. Ratio of navigation computation before and after satellite selection.

TABLE 7. STATISTICAL OF THE RATIO OF NAVIGATION COMPUTATION

	ratio(8 selected satellites)			ratio(9 selected satellites)		
	min	max	mean	min	max	mean
Multi-plication	51.5%	71.5%	62.5%	42.7%	66.3%	55.7%
addition	52.3%	72.2%	63.2%	43.4%	66.9%	56.3%

From Fig.12 and Table 7, it can be concluded:

The amount of addition decreases by 62.5% and the amount of multiplication decreases by 63.2% when 8 satellites were selected with least square method under meeting positioning accuracy requirement. When 9 satellites selected, the amount of addition and multiplication decreased by 55.7% and 56.3%, respectively.

The simulations for other observation stations have the similar conclusions.

The decrease of navigation computation in weighted least square method with GOSSM can be more significant.

Performance compared with GOSSM and optimal GDOP method. In order to analyze the performance of GOSSM further, we focus on the comparative study of GOSSM and optimal GDOP method in two aspects: GDOP after satellite selection and computation for satellite selection under $GDOP_T = 3$.

Comparison of GDOP after satellite selection. The statistical results of GDOP after satellite selection with optimal GDOP method in TASH and XIAA station are listed in Table 8.

TABLE 8 GDOP STATISTICAL AFTER SATELLITE SELECTION WITH OPTIMAL GDOP METHOD

station	number of selected satellites	$GDOP_{\min}$	$GDOP_{\max}$	$\overline{GDOP}$	$GDOP_{\mathrm{var}}$
TASH	8	1.47	2.69	1.936	0.049
	9	1.39	2.54	1.867	0.045
XIAA	8	1.46	2.52	1.909	0.050
	9	1.42	2.40	1.836	0.039

Comparing Table 8 with Table 2~ Table 4, it can be concluded:

The average of GDOP after satellite selection with GOSSM increases by 10.64% compared with the optimal GDOP method in TASH station and increases by 8.14% in XIAA station when 8 satellites selected.

The average of GDOP after satellite selection with GOSSM increases by 10.37% compared with the optimal GDOP method in TASH station and increases by 8.22% in XIAA station when 9 satellites selected.

The simulations for other observation stations have the similar conclusions.

Comparison of navigation computation for satellite selection. The statistical results of computation for satellite selection with GOSSM and optimal GDOP method in TASH and XIAA station are listed in Table 9. N_{GDOP} is the times of calculating GDOP.

TABLE 9 GDOP STATISTICAL AFTER SATELLITE SELECTION WITH OPTIMAL GDOP METHOD

station	Number of selected satellites	N_{GDOP} of Optimal			N_{GDOP} of GOSSM		
		min	max	mean	min	max	var
TASH	8	1287	43758	12870	33	572	43
	9	715	48620	11440	33	484	38
XIAA	8	1287	43758	12870	33	385	42
	9	715	48620	11440	33	253	35

From Table 9, it can be concluded:

The average of N_{GDOP} with GOSSM decreases by 99.67% compared with the optimal GDOP method in TASH station and by 99.67% in XIAA station when 8 satellites selected.

The average of N_{GDOP} with GOSSM increases by 99.67% compared with the optimal GDOP method in TASH station and by 99.69% in XIAA station when 9 satellites selected.

The simulations for other observation stations have the similar conclusions.

V. CONCLUSIONS

Under the analysis of the relationship between the number of the selected satellites and GDOP and navigation computation, this paper proposes a Genetic Optimization Satellite Selection Method (GOSSM) premised on meeting positioning accuracy requirement. Operational rule and flowchart are given in the paper. The simulation results show that, a solution of satellite selection with small satellite selecting proportion, which meets positioning accuracy requirement, can be given quickly by GOSSM. GOSSM has good accuracy and robustness, and reduces navigation computation significantly. GOSSM can help improve the real-time performance of receiver and reduce the difficulty of hardware design, and can be a reference for the development of multi-mode navigation receiver.

ACKNOWLEDGMENTS

The authors thank the reviewers who gave a through and careful reading to the original manuscript. Their comments are greatly appreciated and have help to improve the quality of this paper. This work is supported in part by the National Defense (bureau) civil aerospace major project and the Beijing Key Discipline Foundation (No.XK100070525).

.

REFERENCES

[1] E. D. Kaplan and C Hegarty, “Understanding GPS: principles and applications, 2nd edition,” Translated by Y. H. Kou, Publishing House of Electronics Industry, pp. 240-268, 2007.

[2] Y. Q. Bai and D. Chen, “The calculation of geometric dilution of precision and satellite selection method for satellite navigation,” Navigation, vol. 42, pp. 88-94, 2006.

[3] Z. Yan and Z. M. Ding, “Satellite radio navigation,” Defense Industry Press, pp. 227-231, 1989.

[4] Q. Zhang, X. L. Zhang, H. W. Li, et al, “Satellite selection algorithm for combined satellite receivers,” Journal of Beijing University of Aeronautics and Astronautics, vol. 33, pp. 1424-1427, 2007.

[5] L. Jin, Z. G. Huang, R. Li, et al, “Study on fast satellite selection algorithm for integrated navigation,” Acta Electronica Sinica, vol. 37, pp. 1931-1936, 2009.

[6] C. H. Chen and X. L. Zhang, “A new fast satellite selection approach for satellite navigation system,” Acta Electronica Sinica, vol. 38, pp. 2887-2891, 2010.

[7] Q. J. Yan, “Numerical Analysis, 3nd edition,” Beihang University Press, pp. 14-17, 2006.