The Analysis for the Movement Characteristics of the Flying Object with Genetic Algorithms

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Abstract

Issues such as multiobjective optimization, time-series prediction, the analysis from noisy observation data, and the solution of implicit functions are all crucial in the consideration of real world problems, and research into the applicability of evolutionary computer techniques to these problems has already begun [1–9,13]. However, there are only a few examples of studies where evolutionary computer techniques have been applied to problems that involve all of these issues at the same time. One such examples are previous studies in which we reported on the effectiveness of genetic algorithms (GA) as a tool for tracking objects as they move towards a destination while making evasive maneuvers in order to avoid pursuit or attack. In another study, we reported on the effectiveness of GA as a tool for tracking objects in the earth orbit. All our previous reports are based on the active observed data. In this paper, we verify the applicability of GA to the problem of analyzing the movement characteristics of flying objects based on only passive observed data. **Key words:** Tracking, Analysis based on observed passive data, Analysis from noisy data.

1 Introduction

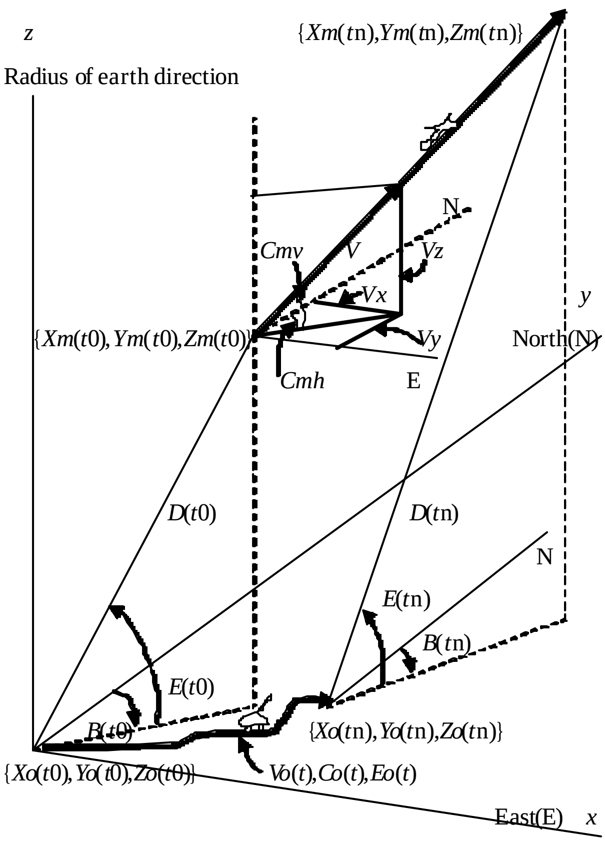
In previous reports, we considered the two dimensional movement of an object whose evasive motion was assumed to consist of constant-velocity straight-line, simple sinusoidal and sawtooth motion [10, 11]. In another previous report, we considered the three dimensional path elements of the moving objects in a earth orbit whose motion consists of circles, ellipses [12]. These previous analysis are based on active observed data gathered by radar, laser or active sonar. In this paper, we report the three dimensional movements analysis for the flying object like a fighter in the air, from passive observed data without the active observed data. The passive observed data means that they can be gathered by the observation equipment in its surveillance mode without radiation of electric-magnetic wave(EMW), only by observation of the EMW radiated by the flying object. The passive observed data consist of the bearing and elevation angles from observer. Active observed data means that they can be gathered by the observation equipment in its radiation mode of the EMW. Active observed data contain distance component.

The movement characteristics to be analyzed based on the passive observed data must contain the distance components. If the flying object is enemy aircraft for the observer, the observer should not radiate the EMW for concealing the existence of observer itself, because the enemy aircraft may starts counter attack operation to the observer. Therefore, the analysis for the movement characteristics of the flying object based on the passive observed data has the tactical meanings. The movement characteristics are the present distance, the velocity and the three dimensional proceeding course of the flying object. The other hand, to analyze the movement characteristics of the flying object rightly from only the passive observed data, it is necessary that the removal observer changes the velocity or course of itself at least one times during the analysis, because there are infinite solutions in case of no changing of the velocity and course of observer. This can be took the place by the plural foxed position observers arranged different places. Even though, the movement of the flying object has constant velocity and course in short period, this analysis has the problems such as described in the beginning of abstract.

2 Tracking of a Flying Object in the Air

2.1 Earth Surface coordinates and Movement Characteristics of the Flying Object

The relationship between the earth surface coordinates *xyz* and the movement characteristics is illustrated in Figure 1. This shows a flying object is proceeding to the destination. Its velocity and course are assumed as constant in the period of analysis. The velocity is V. East-West(x) components of velocity V is Vx. North-South(y) components is Vy. Radius direction of the earth component(y) is Vz. Proceeding horizontal course measured clockwise from the north direction (y) of the flying object is Cmh, vertical course measured upward from surface is Cvm. Initial position of the observer is $Xo(t0)$,$Yo(t0)$,$Zo(t0)$. This point is the origin of the earth surface coordinates. Exact values of them are 0, 0, 0. The position of the observer at time tn is $Xo(tn)$, $Yo(tn)$, $Zo(tn)$. Initial position of the flying object is $Xm(t0)$, $Ym(t0)$, $Zm(t0)$ and position of time tn is $Xm(tn)$, $Ym(tn)$, $Zm(tn)$. The observer observes the bearings and elevations of flying object intermittently as removing on the ground. This removal observer must change its velocity or course at least one times during the analysis because there are infinite solutions in case of no changing. This can be took



Xo(*t*n):observer X position of time *t*n
Yo(*t*n):observer Y position of time *t*n
Zo(*t*n):observer Z position of time *t*n
Xm(*t*n):mover X position of time *t*n
Xm(*t*n):mover Y position of time *t*n
Xm(*t*n):mover Z position of time *t*n
B(*t*n):bearing of time *t*n
E(*t*n):elevation of time *t*n
D(*t*n):distance of time *t*n
V:velocity of mover
Vx:East(*x*) component of *V*
Vy:North(*y*) component of *V*
Vz:Radius of earth(*z*) component of *V*
Cmh:mover horizontal course
Cmv:mover vertical course
Vo(*t*): observer velocity of time *t*
Co(*t*): observer horizontal course of time *t*
Eo(*t*): observer vertical course of time *t*

Figure 1: The movement of the flying object and the observer at time from *t*0 to *tn* in the coordinates *xyz*.

the place by the plural fixed position observers arranged different places. Initial bearing is *B*(*t*0) and bearing at time *tn* is *B*(*tn*). Initial elevation is *E*(*t*0) and elevation at time *tn* is *E*(*t*n). Intial dis tance from observer to the flying object is *D*(*t*0) and distance at time *tn* is *D*(*tn*).

2.2 Formulation of Analysis for the Movement Characteristics of the flying object

In the following, we show the relationship between the inferred values of the movement characteristics——initial distance *D*(*t*0), East-West components of velocity *Vx*. North-South components of velocity *Vy*. Radius direction of the earth component velocity *Vz* ——and flying object's bearing *B*(*tn*) and elevation *E*(*t*n) at time *tn*.

Position of the observer at time *tn* is expressed by equation (1).

$$\left.\begin{aligned} Xo(tn) &= \int_{t0}^{tn} Vo(t)\cos Eo(t)\cos Co(t)\,dt \\ Yo(tn) &= \int_{t0}^{tn} Vo(t)\cos Eo(t)\sin Co(t)\,dt \\ Zo(tn) &= \int_{t0}^{tn} Vo(t)\sin Eo(t)\,dt \end{aligned}\right\} \quad \ldots\ldots(1)$$

Position of the flying object at time *t*0 is expressed by equation (2) as the function of initial distance *D*(*t*0).

$$\left.\begin{aligned} Xm(t0) &= D(t0)\cos E(t0)\sin B(t0) \\ Ym(t0) &= D(t0)\cos E(t0)\cos B(t0) \\ Zm(t0) &= D(t0)\sin E(t0) \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots(2)$$

Position of the flying object at time *tn* is expressed by equation (3) as the function of *x,y,z* component of flying object's velocity.

$$\left.\begin{aligned} Xm(tn) &= Xm(t0) + Vx*(tn - t0) \\ Ym(tn) &= Ym(t0) + Vy*(tn - t0) \\ Zm(tn) &= Zm(t0) + Vz*(tn - t0) \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots(3)$$

Distance *x,y,z* components of the flying object from the observer at time *tn* is expressed by equation (4).

$$\left.\begin{aligned} Dx(tn) &= Xm(tn) - Xo(tn) \\ Dy(tn) &= Ym(tn) - Yo(tn) \\ Dz(tn) &= Zm(tn) - Zo(tn) \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Distance at time *tn* is expressed by equation (5).

$$D(tn) = \sqrt{(Xm(tn) - Xo(tn))^2 + (Ym(tn) - Yo(tn))^2 + (Zm(tn) - Zo(tn))^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Bearing at time *tn* is expressed by equation (6).

$$B(tn) = \tan^{-1}\frac{Xm(tn) - Xo(tn)}{Ym(tn) - Yo(tn)} \quad \text{.........................(6)}$$

Elevation at time *tn* is expressed by equation (7).

$$E(tn) = \tan^{-1}\frac{Zm(tn) - Zo(tn)}{\sqrt{(Xm(tn) - Xo(tn))^2 + (Ym(tn) - Yo(tn))^2}} \quad \text{....(7)}$$

Velocity of the flying object is expressed by equation (8).

$$V = \sqrt{Vx^2 + Vy^2 + Vz^2} \quad \text{.................(8)}$$

Horizontal course of the flying object is expressed by equation (9).

$$Cmh = \tan^{-1}\frac{Vx}{Vy} \quad \text{.........................(9)}$$

Vertical course of the flying object is expressed by equation (10).

$$Cmv = \tan^{-1}\frac{Vz}{\sqrt{Vx^2 + Vy^2}} \quad \text{...................(10)}$$

Accordingly, the problem addressed in this paper — i.e., that of analyzing the three dimensional movement of a flying object — can be formulated as an inverse problem involving complex implicit functions where it is necessary to find the four characteristics—initial distance *D*(*t*0), velocity x component *Vx*, *y* component *Vy*, *z* component *Vz*—of a flying object by working backwards from noisy time-series observations of its bearing and elevation obtained from the observer. The present distance *D*(*tn*), velocity *V*, horizontal course *Cmh*, vertical course *Cmv* of the flying object are calculated from *D*(*t*0), Vx, Vy, Vz by equation (5), (8), (9), (10).

3 Method to Apply Genetic Algorithms

3.1 The Movement Characteristics Determined by Genetic Algorithms

Four movement characteristics — initial distance *D*(*t*0), flying object velocity *x* component *Vx*, *y* component *Vy*, *z* component *Vz* — constitute a complex implicit function, so we will try to use genetic algorithms to determine their values. Initial distance *D*(*t*0) can be biased by offset value because observer can detect the existence of the flying object before it approach to certain minimum area of distance to the observer. If bias value is *Dbias*, GA operation value for initial distance *Dga* is *D*(*t*0)-*Dbias*.

3.2 Chromosome Coding Method

We defined chromosomes respectively corresponding to the characteristics—initial distance *Dag* and flying object velocity *x* component *Vx*, *y* component *Vy*, *z* component *Vz*. And we expressed a single individual as a set of these characteristics as sub chromosomes. But the sub-chromosome of the initial distance *Dga* and the velocity Vx,Vy,Vz consist of different length bits according to range of its value and necessary resolution. The initial distance *Dga* consists of integer 18 bits, velocity of *Vx*,*Vy*,*Vz* consists of integer 17 bits.

The physical range over which each sub chromosome are expressed are set considering the possible range of distance and velocity of flying object, analysis period of time and the observation precision of passive observations. Assumed range of initial distance is 50,000m~200,000m, assumed range of velocity is ±500m/sec and assumed bearing and elevation error is less than 0.1degree. Analysis period of time to get effective accuracy should be less than 100sec.

The minimum units of these sub chromosome are set as follows by considering above conditions: initial distance *D*(*t*0) is 1m, flying object velocity component *Vx*, *Vy*, *Vz* is 1/100m/sec. In exact physical calculation of this simulation, initial distance *D*(*t*0) is biased by constant value *Dbias*=50,000m (*Dga*= *D*(*t*0)-*Dbias*).

3.3 Fitness Function

We determine the angles error between the observed angles(bearing and elevation) data of the moving object and the angles data inferred by GA, and we defined the fitness of an individual based on the reciprocal of the square root of the sum of these errors. The fitness function is shown in Equation (11).

$$f = k(n+1)/\{\sum_{i=0}^{i=n}\sqrt{dB(ti)^2 + dE(ti)^2}\} \quad \text{..................(11)}$$

Where

$$dB(ti) = esB(ti) - oB(ti), \quad dE(ti) = esE(ti) - oE(ti)$$

Here, *esBti*, *esEti* are the bearings and elevations estimated by GA at time *ti*, *oBti* and *oEti* are the bearings and elevations observed at time *ti*, *n*+1 is the number of observations, and *k* is a suitable constant. For example, case of *k*=1, it is set so that *f*=1.0 when the average angle difference is 1.0 degree.

3.4 Genetic Operation

The method for selecting the group of individuals carried forward to the next generation from the current generation is shown in Figure 2. All individual (the total number of chromosomes)*P* sent from the previous generation is evaluated by calculation of fitness and sorted in descending order. Fixed proportion *E* from the highest fitness individual is retained as elite, and the number of discarded individuals are supplemented by roulette selection to preserve the original population *P*. *M* (=*P*-*E*) is the number of discarded individuals. Making up of the deficit for *M* is done as follows. One pair of individual is chosen as parent by roulette selection from all individual *P* of the current generation. The sub chromosomes *Dga*, *Vx*, *Vy*, *Vz* of this one pair of individual is then subjected to single point crossover between each of the same kind of sub chromosomes independently (i.e. crossover between *Dga* and *Dga*, *Vx* and *Vx*, *Vy* and *Vy*, *Vz* and *Vz*,of both individual) to produce one pair of child individual.

After crossover operation, all sub chromosome of produced one pair child individual is subjected to spontaneous mutation independently. Through the crossover and spontaneous mutation processes, one pair of new individual is produced and carried forward to the

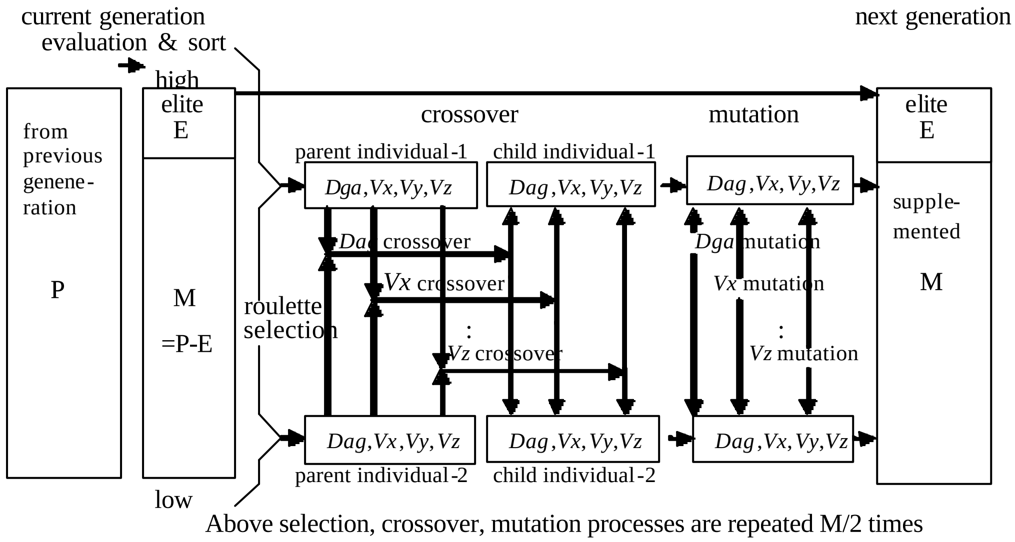


Figure 2: Flowchart of genetic operation. 1 pair of chromosome is selected by roulette selection, and crossover and spontaneous mutation are done for each sub-chromosome respectively.

next generation. Above processes are repeated until the making up of the deficit for M is completed (M/2 times). In preliminary trials we found two phenomena.

The first of those phenomena is that the solution starts to converge around the 20th generation, so for subsequent generations we reduced the spontaneous mutation rate for all sub chromosomes. We did those to avoid destroying the sub chromosome that had already approached convergence. In the exact simulation, the spontaneous mutation rate is changed from the 20th generation onwards as described in Section 4.2 Simulation Data. The results of the reducing the spontaneous mutation rate is described in Section 4.3 Results of Simulation.

The second phenomenon is as follows. From the 10th generation onwards, new two type individuals (chromosome) are effective for the earlier convergence. One of them is calculated as much 2% uniform random numbers of the sub chromosomes contained in the fittest individual of the current generation. The other is calculated as much 2% uniform random numbers of the sub chromosomes contained in the roulette selected individuals from the current generation. The number of these new two type individual are 10% for total number of individual. The results of the supplement the modified sub chromosomes is described in Section 4.3 Results of Simulation.

4 Evaluation Tests

4.1 Evaluation Method

We made a software system shown in Figure 3 for the evaluation of this research. This system consists of three modules of software, Observed data Generator, Estimated value Generator and Estimated value Evaluator. They do cooperative works for evaluation.

Observed data Generator

Based on the theoretical movement characteristics of a flying object provided by the operator, the observed data generator calculates the theoretical values of the object's, bearing (Bti) and elevation (Eti) at time ti for 1-second intervals from the time $t0$ at which the observation starts. It then adds normal random number errors εbti and εeti to the calculated theoretical values to simulate the errors produced by an observation system, such as electric magnetic wave beam fluctuations, instrumentation errors, and conversion errors, to produce the observed bearing ($oBti$) and observed elevation ($oEti$).

As the observation time ti is increased, the observed data generated for experimental use are stored along with the observation time ti in the database for observed data. This observation data gathering cycle is continued until simulation ends.

Estimate value Generator

The Estimated value Generator generates the estimated bearing ($esBti$) and estimated elevation ($esEti$) based on estimated sub chromosomes in the chromosomes. The initial values of the sub chromosomes are set randomly to values in the defined ranges by using uniform random numbers. and uses genetic algorithms to renovate the estimated values of sub chromosomes. The values of $esBti$ and $esEti$ ($t0 \leq ti \leq tn$) are calculated by Equations (6), (7) based on the renovated values of sub chromosomes. These renovated $esBti$ and $esEti$ are sent to the Estimated value Evaluator.

Next, we will describe how the GA is used to renovate the estimated values of the sub chromosome. In the Estimated value Generator, the values of $esBti$ and $esEti$ corresponding to each individual are sent to the Estimated value Evaluator.

Next, based on the received fitness values, the method described in section 3.4 is used to select the fittest individuals and perform crossovers and spontaneous mutations, thereby updating the generation i.e., renovating the estimated values of the sub chromosomes.

Here, the renovating of the estimated values of the sub chromosomes using a genetic algorithm is started at the point when a certain set of observed data is stored into the

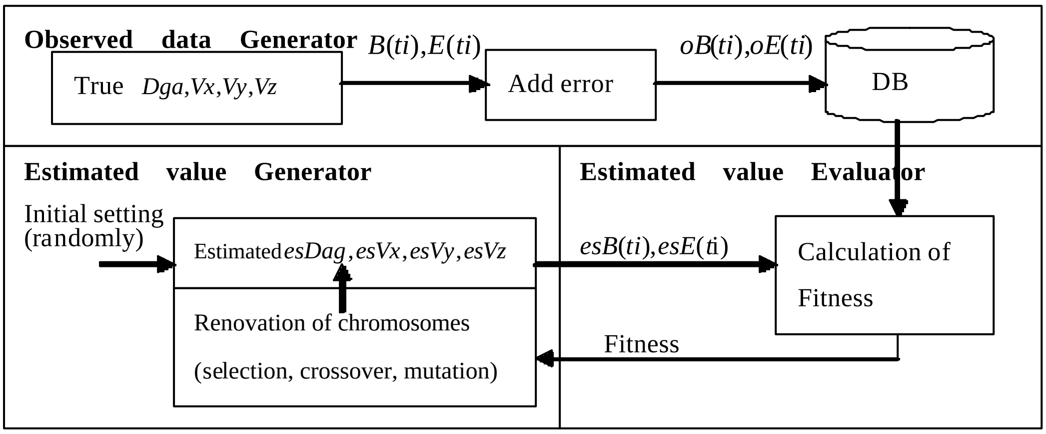


Figure3: The flowchart of GA evaluation system. The GA evaluation system consists of Observed data Generator, Estimated value Generator and Estimated value Evaluator.

database for observed data. Spontaneous mutation rate are changed at around convergence generation of the analysis in order to broaden the search space before convergence and to avoid destroying the solution after convergence.

Estimated value Evaluator

For every observation time, the Estimated value Evaluator calculates the fitness of each individual according to Equation (11) based on the values of the observed bearing ($oBti$) and elevation ($oEti$) input from the database for observed data and the estimated bearing ($esBti$) and estimated elevation ($esEti$) input from the Estimated value Generator. These calculated fitness values are sent to the Estimated value Generator, where they are used for genetic manipulation. The above processes of generating observed values, generating estimated values and performing evaluation are repeated until a stopping criterion is met. The stopping criterion was taken to be the fulfillment of either of two conditions: that an individual appears whose fitness exceeds a preset standard fitness, or that the number of generations of genetic manipulation becomes greater than a certain value.

4.2 Simulation Data

In this simulation, the parameters of genetic operation were set as follows:

(1)maximum genetic manipulation generation:50 (2) observed data set prior to GA start: 60 (3) number of total individuals: 6000 (4)number of elite:60 (5)crossover ratio: 0.8 (6)spontaneous mutation rate: 0.00001 before the 20th generations, and 0.000005 from the 20th generation onwards.

The physical parameters are as follows:

(1) Initial distance : 150000m (2) Initial bearing : 5.0deg
(3) Initial elevation : 5.0deg (4) Velocity of flying object : 340m/s (5): Horizontal-course of flying object:110.0deg
(6) Vertical-course of flying object : 5.0deg (7)observing: by two observers arranged 5km apart. (8) observation error (maximum) : 0.004 deg, 0.020deg, 0.100deg

4.3 Results of Simulation

Figure 4 shows how the best fitness for three kinds of error of the observation vary with the number of generations in cases where the movement of the flying object is assumed to be linear movement. To obtain a maximum fitness value of 1.0, the fitness fg on the vertical axis in this figures is the normalized value obtained from the relationship $fg = 1 - 1/f$, where f is the fitness defined in Equation (11). The observations are made at 1-second intervals by the observer having an bearing and elevation observation errors. At the time of

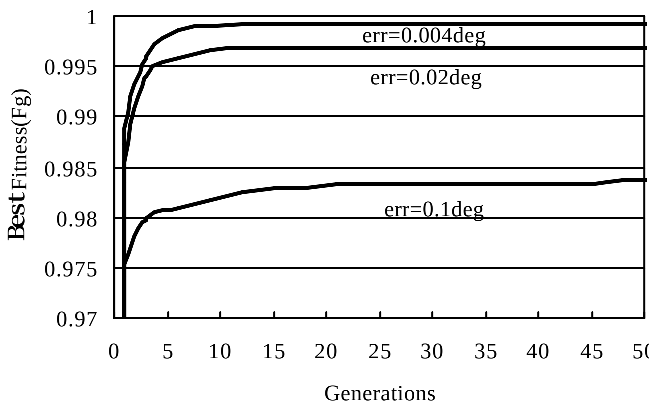


Figure4: The maximum and average fitness for generations.

Table1: The accuracy of analyzed initial distance $D(t0)$, velocity component Vx, Vy, Vz, velocity V, horizontal course Cmh and vertical course Cmv.

sub-chromo	$D(t0)$(m)	Vx(m/s)	Vy(m/s)	Vz(m/s)
theory	150000	333.6	-58.8	29.6
err=0.004o	37	0.1	0.1	0.1
err=0.020o	155	0.6	1.2	0.2
err=0.100o	522	0.8	4.0	0.3

out put	V(m/s)	Cmh(deg)	Cmv(deg)
theory	340.0	100.0	5.0
err=0.004o	0.1	0.0	0.0
err=0.020o	0.5	0.2	0.1
err=0.100o	0.6	0.7	0.2

the 60th observation (i.e., 60 seconds after the observations are started), the first generation of GA starts. Figure 4 shows the best fitness (Fg) of three kinds of observation error grow up sharply and they converge around at 7~15th generation. The fitness of the observation error 0.004deg grows up at the earliest generation. The fitness of observation error 0.1deg grows up last. Table 1 shows the accuracy of the analyzed movement characteristics (sub chromosomes) for the three kinds observation error at the 50th generation. The accuracy of the observation error 0.004deg is the best and the accuracy of observation error 0.1deg is the worst among three kinds of error. Reducing the spontaneous mutation described in Section 3.4 Genetic Operation is effective for the early convergence by several %. New two type chromosomes described in Section 3.4 effects to make the convergence generation earlier by more than 10%. These data are average values of 20 trials.

4.4 Discussion

From the above experimental results, it can be judged that by applying GA to the analysis for the movement characteristics of a flying object whose four characteristics are all unknown, it is possible to analyze these values only from time-series values of the observed bearing and elevation of the flying object obtained from observation equipment. Since the analysis results are all based on observation data, it can be judged that the necessary time for the completion of analysis is effected by the errors contained in observed bearing and elevation. The smaller the errors contained in observed data are, the faster and the more accurately the analysis completes. However, even though, the errors contained in the bearing and elevation extend to around 0.1 degrees, the accuracies of the results and the completion time of the analysis are still in effective range.

To shorten the analysis time, we must do furthermore investigation for the effect of the parameters of GA. These parameters are number of stored data prior to analysis start, number of chromosome, number of elite, crossover rate and mutation rate. Also, we must deepen the quantitative analysis of the effectiveness of reducing spontaneous mutation and new two type chromosome described in Section 4.3 Results of simulation.

5 Conclusion

As a problem including various issues such as multiobjective optimization, time-series prediction, the analysis from noisy observation data, and the solution of implicit functions, we have investigated the applicability of genetic algorithms to the analysis of the three dimensional and dynamic linear movement of a flying object in the air based on the passive observed data. In the future ,we aim to demonstrate that genetic algorithms are suitable for solving three dimensional and non linear movement analysis problems for objects moving in the air and seawater by expanding this technique in a practical amount of time and practical level of precision. Also, we aim to demonstrate that genetic algorithms are suitable for the more wide and complex analysis for the facts in the noisy data.

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