Multiobjective Asynchrone Parallel Genetic Algorithm for Reentry Trajectory Optimization

S.Timchenko[1,2*], V.Bimatov[1], P.Kuznecov[2], Yu.Sidorenko[1]

[1]Tomsk State University,
634050, Lenina 36, Tomsk, GSP-14, Russia

[2]Tomsk State University of Control Systems and Radioelectronics

The multiobjective optimization problem of the reentry trajectory in the Earth atmosphere with respect to the integral heat flux to the stagnation point of the blunt body with heat-conducting surface and body shell thickness and properties is considered. This problem is solved with the physical restrictions for the body acceleration along trajectory and for the equilibrium temperature on the outer and inner body surfaces. As an objective function the integral convective heat flux Q along the trajectory is considered and the value Q is computed on the basis numerical solution of the multicomponent nonequilibrium thin viscous shock layer equations (TVSL) (for the gas) jointly with heat conductivity equation (for the body shell).

This problem are solved by means of the floating-point multiobjective asynchrone parallel Genetic Algorithm (MAPGA) with the arithmetical crossover operator and the nonuniform distance-dependent mutation operator.

Problem description

Let us consider the space vehicle moving along trajectory at Earth atmosphere. The vehicle entry is beginning from altitude H_0=100 km with V_0 = 7.8 km/s, the acceleration is absent, the vehicle mass is constant. We assume that Earth is the sphere, its swirling is absent and the gravity force does not depend on altitude.

For formulation of the optimization problem let us suppose that t_1 is the total time of the vehicle moving along trajectory. In this case the total convective heat flux to the stagnation point of the body surface Q along trajectory can be calculated using the following relation:

$$Q(W,H) = \int_0^{t_1} q_w^0\left(H(t),V(t),R^*,k,k_{wi},...\right)dt \qquad (1)$$

Here $q_w^0\left(H(t),V(t),R^*,k,k_{wi},...\right)$ is the heat flux to the stagnation point of the space vehicle body surface, *V(t)* is the velocity flight, *H(t)* is the altitude flight, k is equal the ratio of the body surface main curvatures at the stagnation point, R^* is the character linear size of the problem, k_{wi} ($i=1,...,N-1$) are the known parameters of the heterogeneous chemical reactions proceeding at the body surface.

Let us consider the following multiobjective optimization problem: to find the smooth functions *V(t)* and *H(t)* ($0 \le t \le t_1$) which have the following following properties:

1. The value Q has the minimum.
2. Termal protective shell thickness is the minimum.
3. The equilibrium temperature of the outer termal protective shell surface at the stagnation point $T_{wo}(t)$ does not exceed the preassigned limit value T_{w0}^* and one of the inner shell surface $T_{wi}(t)$ does not exceed the preassigned limit value T_{wi}^*

This problem is solved with the following restrictions:

* Corresponding author. E-mail: tsv@ftf.tsu.ru

$$V(0) = V_0,\ H(0) = H_0,\ V(t_1) = V^*, H(t_1) = H^*$$

$$\left|\dot{V}(t)\right| < ag, \left|\dot{V}\right| \le \frac{S^*}{m}\frac{\rho_\infty(t)V^2(t)}{2}$$

Here S^* is the character square of the Termal protective body surface, *m* is the mass of the vehicle.

Unlike the single objective optimization, the solution to this problem is not a single point, but a family of points known as the Pareto-optimal set. Each point in this set is optimal in the sense that that no improvement can be achived in one objective component that doesn't lead to degradation in at least one of the remaining component.

As initial mathematical model for calculating the integral (1) we will use the thin (hypersonic) viscous shock layer equations. The analysis demonstrates that this model has a good accuracy for our range of the velocity and the altitude of the flight TVSL equations is calculated jointly with heat conductivity equation for the body shell [2].

Method of solution

For solution of the above listed optimization problems we used the variant of the floating-point Genetic Algorithms. We used ordinary single point, uniform or arithmetical crossover operator and the nonuniform mutation operator defined by Michalewicz.

One of the main problems that arises in GAs is premature convergence. For solution of this problem we used the Distance-Dependent Mutation approach [1]. This approach consists in using the distance between the two mates in order to compute the mutation rate: the mutation rate is no longer a constant parameter, it is dynamically computed for both children and depends on the parents. Every time a couple of individuals is chosen for mating, the mutation rate is computed and will be applied to their children after crossover occurs. If the parents are quite close (i.e. their mating is likely to be considered as incest), that would lead to a high mutation rate for their children, whereas mutation rate will be smaller if they are distant.

Parallel implementation

Parallel genetic algorithm for solution of the above described problem on the MIMD computers was created. Time of objective function calculations are very different one by another for different parameters values. By this reason this algorithm is asynchrone, i.e. calculation on the different processors are occurred independently one by another.

After creation of new subgeneration on the current processor two steps should be done

1. All *available* data from other processors are received
2. All *new* data (new subpopulation members and their fitness function values) are put to the *list* for the following using on the other processors

On the base of above described asynchrone real-coded GA the parallel solver for the networking parallel computers was created.

Conclusion

All numerical results are obtained on the 18-nodes cluster in the Tomsk State University. As a whole the numerical calculations showed, that the suggested method for solving the variational problem is stable, has high level of the arithmetical cost efficiency and enables one to compute variants for wide governing parameters range. Calculations are shown, that its parallel version has high efficiency and fast convergency rate.

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References

1. *Sefioui M., Periaux J., Ganascia J.-G.* Fast convergence thanks to diversity. Evolutionary Programming V. Proc. of the 5th Annual Conference on Evolutionary Programming. L.J.Fogel, P.J.Angeline and T.Back editors. MIT Press. 1996.
2. *Peigin S.V.,Tirskii G.A. et al.* Super- and hypersonic aerodynamics and heat transfer. New-York. CRC Press. 1993.