GENETIC ALGORITHM: TRAJECTORY OPTIMIZATION FOR STRATOSHERIC BALLOONS

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ABSTRACT

Genetic algorithms are versatile methods for the optimization problems. Varying the fitness function the solutions will solve different problems, or the same problem in different ways.

They could be applied to stratospheric balloon flight, to analyze how valves and ballast can make altitude transfers and trajectory variation. The ascending phase can be optimized for high-populated areas avoidance. Floating phase can be adjusted for rendezvous opportunities or for altitude maintenance whit minimum cost.

Forecast atmospheric models and radiosoundings give the wind direction and speed. The trajectory prediction uncertainty should be taken into account.

Real time applications are also possible. A workstation could find the optimal maneuvers' sequence during the flight, starting from actual balloon position. Parallel architecture could reduce the computational time.

1. INTRODUCTION AND SCOPE

Genetic algorithms are based on a biological metaphor [1]. A constant-size population of individuals, each one represented by a finite string of symbols, known as the genome (or DNA), encode possible solutions of a given problem. An initial population of individuals is random generated. Every evolutionary step, known as a generation, the individuals in the current population (or family) are decoded and evaluated. A fitness function analyses each solution to decide whether it will contribute to the next generation of solutions. High-fitness individuals have a better chance of reproducing, while low-fitness ones will disappear [2]. Then, through operations analogous to gene transfer in sexual reproduction, the algorithm creates a new population of solutions.

This method could be applied for stratospheric balloon flight. Valves and ballast are commonly used for altitude transfers and consequent trajectory variation. The ascending phase can be optimized for high-populated areas avoidance, using vertical velocity variations. Floating phase can be adjusted for overpassing target areas or for altitude maintenance whit minimum cost.

The paper shows a preliminary analysis of a possible method and its applications. The authors will describe the following points:

- ✓ Algorithm
- ✓ Fitness function
- ✓ Applications
- ✓ System architecture

2. ALGORITHM

The maneuvers are quantized and represented by an N elements vector. The ith component is the maneuver to be performed at time T+i Dt from launch. Technical and operational constrains impose T and Dt values. In fact maneuvers should be made after a time delay from launch and with a minimum interval between them. Both T and Dt are considered around 30 minutes. The DNA elements can have different values for different actions; e.g.: 0=coast (no maneuver), 1=50kg ballast release, 2=75kg, 3=100kg, -1=3minutes valve opening, -2=10minutes, -3=30minutes. The Nth element represents the starting free lift that can be between 8 and 12%.

Fig. 1 shows the algorithm flow chart. The first population (initialization) is composed of M+L genomes representing: a nominal solution, or a supposed good solution, plus M+L-1 random generated sequence of maneuvers. The nominal case drives algorithm interactions along a given direction. In this way, if the optimum can be obtained by adjusting that solution, as sometimes happens, the process will converge faster. Then genomes are decoded and propagated in order to evaluate their fitness. The best M solutions are selected (first selection) and reproduction starts within them. We impose M and L around N+50% and M/3 respectively. The reproduction routines are explained in Fig. 2. The first two methods are true reproductions, called block swap and single point cross over. The last example represents the so-called standard mutation. The vector positions where routines apply (larger black lines in Fig. 2) are random generated.

High fitness genomes have more probabilities to be chosen for these processes then lower ones. The new generation (M dna) is obtained as follow: 70% by reproductions (standard mutations and block swaps), 20% by mutations and, the remaining part, by conservation of the best 0.1 M old solutions.

During our tests few iterative cycles were sufficient. After 8-20 steps the algorithm found a good solution covering mission goals and constrains. The computational time could vary from 15 minutes to 2 hours in a common Windows desktop, depending on constrains' complexity and simulated flight duration.

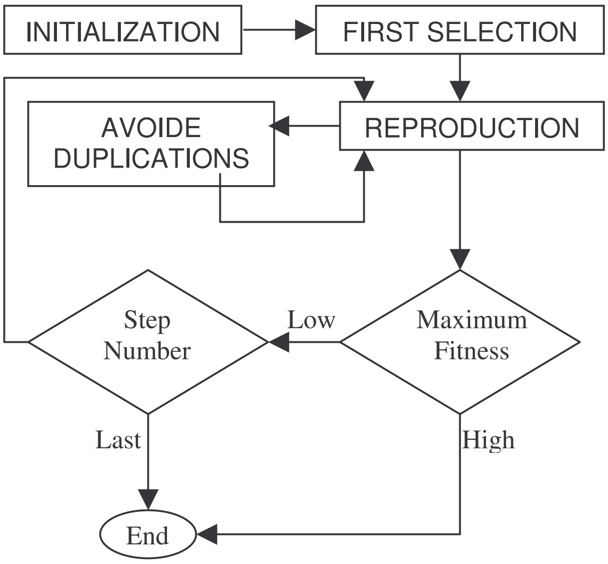

Fig. 1. Algorithm Flow Chart

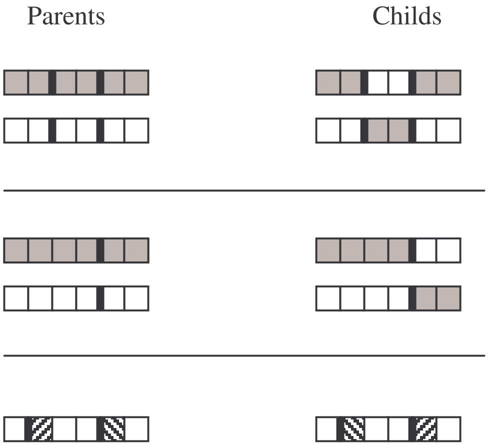

Fig. 2. Reproductions and mutation.

2. FITNESS FUNCTION

The fitness function is the core of the genetic algorithm: it decides whether a solution is valid or not.

Following a simple multi-objectives approach the fitness function can be made as sum of some objectives operators.

The proposed function (Eq. 1) must be minimized. ρ is the population density, h balloon altitude, L represents the balloon trajectory while D(lat,lon,h) is a routine that calculates the minimum distance between balloon trajectory and target point (lat,lon and h coordinates). A_i, b_i and c_i are weight factors.

$$f = a_1\left[\frac{dh}{dt}_{\substack{\max \\ h>25km \\ t<4h}} - 6\frac{m}{s}\right]^{a_2} + b_1\left[30km - h_{\substack{\min \\ t>2h \\ t<4h}}\right]^{b_2} +$$

$$c_1\left[\left(m_0 - m_{fin}\right)\right]^{c_2} + d_1\left[\sum_i D(lat_i, lon_i, h_i)\right]^{d_2} +$$

$$e_1\left[\int_L \rho(lat, lon)\cdot dl\right]^{e_2} \qquad (1)$$

The first two objectives (first two square brackets of the f formula) take care of realistic solutions: floating altitude above 30km after no more than 4 hours and vertical velocity, near gas discharge, below the allowable maximum. The mission objectives are: maximum payload mass (maximum final mass after maneuvers), overpassing target areas and minimum risk assessment (by computing density population of the trajectory's ground track). The weight factors can be functions of balloon's altitude or time from launch, this depends on the desired trajectory's type.

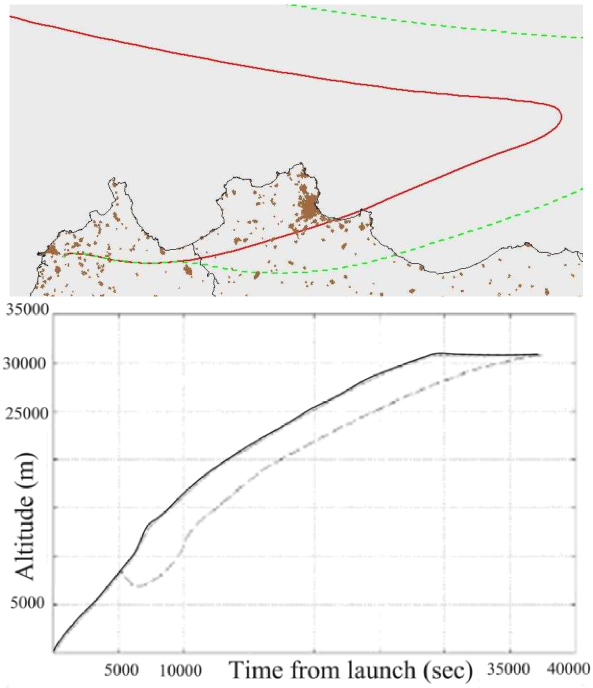

Fig. 3. Ascending nominal and optimized (dashed) trajectories and their altitude profiles

3. APPLICATIONS

Changing weight factors, the solutions will solve different problems, or will solve the same problem in different ways.

The first possible application is the optimization of a safe ascending trajectory. The last term of the fitness function allows avoiding high-populated areas, so trajectory reduces the risk assessment. At same time the final altitude constrains (second square bracket of fitness function) imposes floating altitudes after 2-4 hours from launch. A particular example is reported in Fig. 3: the nominal trajectory overpasses a city, painted in red, which was avoided maintaining the balloon altitude around 8 km for 20 minutes (in fact a possible but risky gas discharge of 10-12 minutes, 80 minutes after launch).

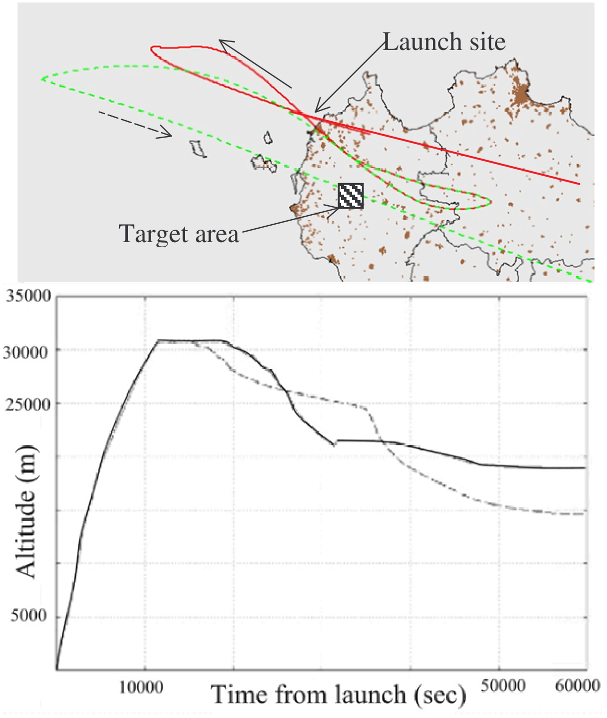

Fig. 4: Area overpassing optimization, nominal and adjusted (dashed) trajectories and altitude profiles

The Fig. 4 case allows an area overpassing using wind variation versus altitude [3]. After the floating height (imposed by final altitude constrains of the fitness function) the predicted trajectory overpasses the target point if optimized altitude transfers are used.

Another example is a longitude overpassing from a predefined altitude. Valve and ballast maneuvers can be optimized to maintain the balloon at that altitude above target longitudes [4].

4. SYSTEM ARCHITECTURE

Two important aspects must be analysed: how to connect the trajectory optimizer with the Flight Prediction Monitoring and Control System and how make it faster.

4.1 Connections

Fig. 5 explains the general system architecture. Available data sources, for trajectories predictions, are: radiosoundings, forecast atmospheric models and meteorological satellites images [5, 7]. Trajectory predictor calculates the balloon's ground track and its uncertainty, starting from the defined sequence of maneuvers. The balloon monitoring software, connected with both predictor and telemetry, can display the actual and forecast trajectories. It superimposes high-resolution maps, made using Gis (Geographic Information Systems) techniques, satellite images and balloon ground track [6]. The optimizer is located between predictor and monitoring software. In off-line mode (before flight) it will give the optimal trajectory, obtained by computing the optimal maneuvers' sequence; in other words the maneuvers that have the maximum probability to accomplish mission goals. Then users, using monitoring software, will check the resulting trajectory and they decide how to realize it.

In real-time mode (during flight) actual and predicted trajectories will be compared. The optimizer could start simulations from the actual balloon position, in order to have a new updated sequence of maneuvers, or, in case of failure, compute a safe recovery trajectory. During flight Gps telemetry data reduces the prediction's uncertainty.

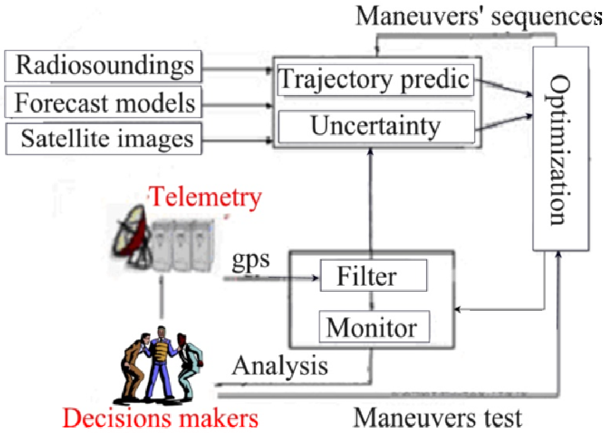

Fig. 5: Connections between telemetry, predictor and trajectory optimizer

4.2 Parallelization

At each step of the optimization procedure, a family of trajectories is analyzed by ordering the values of their fitness functions, from lowest to highest. Reproduction and mutation will pass the genes of best elements to the next generation.

While ordering and reproduction work on the results of all trajectories predictions, namely the whole generation, the predictor needs, to be initialized, only the maneuvers' sequence (genome). So each prediction can be performed independently of each other.

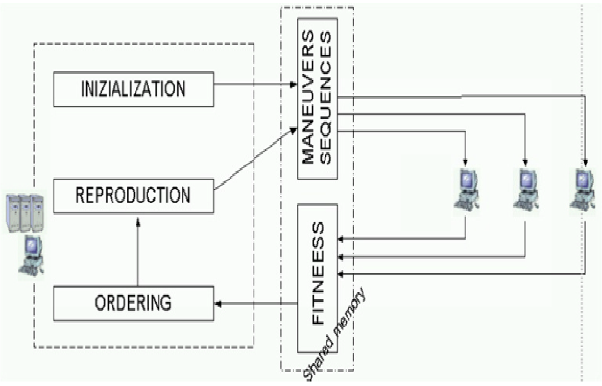

Fig 6: A parallelization of the trajectories' propagations

A simple parallelization is proposed. A central workstation defines the genomes first by initialization, then by ordering, reproduction and mutation of the previous step's results. On the other side there is a network of computers, connected with the first by memory sharing. Each of them predicts some trajectories, taking the first genome of the list not yet calculated, and it gives the related fitness functions. When all the trajectories are predicted the central workstation orders the fitness values, it processes the reproduction and mutation routines and it defines new maneuvers' sequences to be propagated. At this point the next optimization step starts.

5. CONCLUSIONS

The authors have made a preliminary application of genetic algorithm to stratospheric balloons. The results show that a trajectory can be adjusted reaching particular goals or optimum in short time. With a simple but stable configuration, the software could help managing balloons' missions, when integrated inside the Flight Prediction Monitoring and Control System.

6. REFERENCES

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