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Convex Optimization of Reliability and Cost for Reduction Oxygen Supply System of a Spacecraft via Dragonfly Algorithm

Fouad Hamza Abd Alsharify

Dep. of Physics, College of Science, University of Babylon, Iraq.

sci.fouad.hamzah@uobabylon.edu.iq

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Abstract

To optimize the reliability of the Reduction Oxygen Supply System of a Spacecraft, Dragonfly algorithm was used which simulates the swarming behavior of dragonflies. To find out the best reliability with the lowest cost, we used two different cost functions: logarithm and exponential functions with this algorithm. A comparison was made between the results of cost functions.

Keywords: - reliability; optimization; Dragonfly Algorithm.

Introduction

Nowadays, reliability has become an additional problem for the development of advanced technology. One of the contemporary problems has become the problem of improving the reliability of complex networks, which began to develop with updating methodologies for solutions after the development of modern engineering technology. The task of improving reliability requires the conceptualization of choice variables, constraints, and one or more individual abilities describing the overall performance of an engineering design problem for any product, and experimentation and discovery of the total values of choice variables that lead to the preference of goals. Whether expressed in mathematical terms or not, every product design problem has schematic objectives that need to be changed to meet some appropriate requirements [1-4].

Researchers in the field of mathematical programming are interested in creating and developing new algorithms to solve larger and more difficult problems, more efficiently than before. Mirjalili is one of those researchers who managed 2016 to simulate the behavior of the Dragonfly Algorithm (DA). Dragonflies form small groups and tend to catch flying prey. These groups form a swarm that moves in one direction and over long distances. Dragonfly swarming behavior is the main source of the DA algorithm. Their continuous swarming behavior enables them to form small swarms and to investigate the optimal in many areas. Dragonflies migrate in huge swarms towards most locations for global optimization, and this is a description of the condensation phase of the optimization algorithm [4,5].

We used this algorithm with two cost functions (logarithm and exponential) to optimization the reliability of Reduction Oxygen Supply System (ROSS) for the spacecraft at the lowest possible cost and we got the best reliability and the lowest cost.

Reliability of Reduction Oxygen Supply System Network

The reliability polynomial of ROSS network for the spacecraft shown in Fig. (1) was calculated by a probability theory approach [6,7].

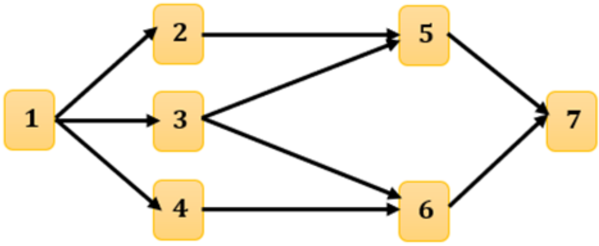

Figure 1. Reduction Oxygen Supply System Network

$$R_N = R_1R_2R_5R_7 + R_1R_3R_5R_7 + R_1R_3R_6R_7 + R_1R_4R_6R_7 - R_1R_2R_3R_5R_7 - R_1R_3R_4R_6R_7 - R_1R_3R_5R_6R_7 - R_1R_2R_4R_5R_6R_7 + R_1R_2R_3R_4R_5R_6R_7$$

From Fig. 2, it is clear that R_N is a concave function, and therefore, $-R_N$ is a convex function.

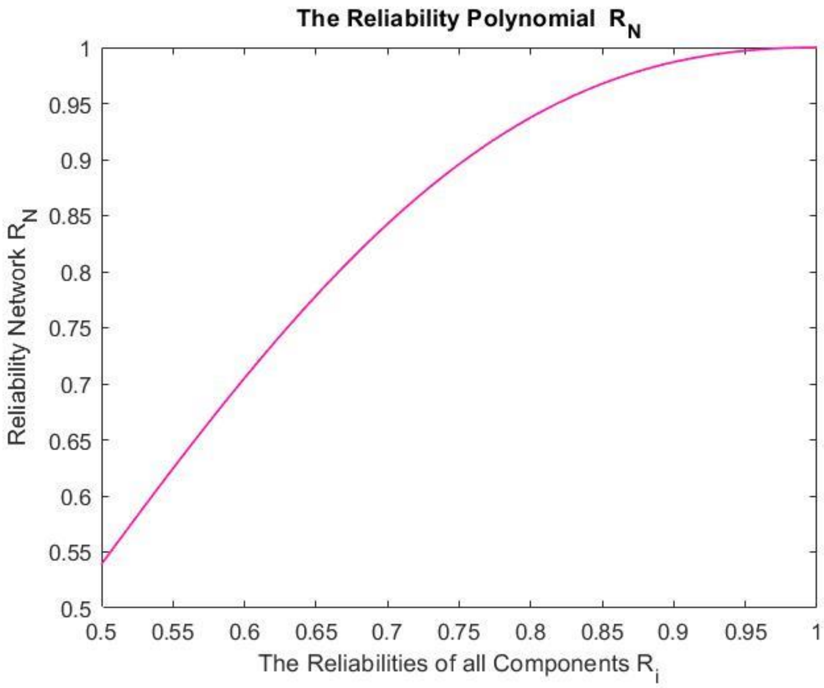

Figure 2. The Reliability Polynomial

Convex Optimization

Convex optimization is a mathematical optimization concerned with studying problems of reducing convex functions on convex sets. Many optimization problems can be paraphrased equivalently in convex optimization. For example, the problem of maximizing a concave function f can be equivalently reformulated as the problem of minimizing the $-f$ convex function [8].

The main goal is to allocate reliability to all units of the network in order to obtain the best network reliability at the lowest possible cost.

Assume that C_i and R_i are the cost function and the reliability of $i-$th unit, C_N is the value of total cost and R_N is the reliability network. Then the problem will be formulated as a multi-objective optimization problem as follows:

Minimize $\left(C_N(R_i), -R_N(R_i)\right)$
Subject to: $0.50 \le R_i \le 0.95$
$R_N \ge R_G$
$0 < C_i \le 1$
$C_N \le C_G$

We choose the objective of network reliability $R_G = 0.95$ and the objective of total cost $C_G = 7$.

We use the following two models of cost functions:

1. Logarithmic function: $C_i(R_i) = a_i \log(1/1 - R_i)$
2. Exponential function: $C_i(R_i) = a_i \exp(b_i/(1 - R_i))$.

Here a_i and b_i are constants such that $a_i, b_i \in (0,1)$.

Dragonfly Algorithm (DA)

There are three primary principles followed by flocks of dragonflies: The first one is the principle of separation: avoid collision of the dragonfly individuals. The separation motion for the $i-$th dragonfly individual in the $t-$th iteration $S_{(i,t)}$ can be written in the following form:

$$S_{(i,t)} = -\sum_{j=1}^{n}\left(X_{(i,t)} - X_{(j,t)}\right)$$

where $X_{(i,t)}$ and $X_{(j,t)}$ represent to the position of $i-$th dragonfly individual and $j-$th neighboring dragonfly individua in the $t-$th iteration while N is the number of neighboring dragonfly individuals [5].

The second principle is the alignment: matching the speed of the dragonfly individuals in the neighborhood. The alignment movement for the $i-$th dragonfly individual in the $t-$th iteration $A_{(i,t)}$ is calculated by:

$$A_{(i,t)} = \left(\sum_{j=1}^{n} V_{(j,t)}\right) \Big/ n$$

where $V_{(j,t)}$ represents to the speed of $j-$th neighboring dragonfly individual in the $t-$th iteration.

The third principle is cohesion: all the dragonflies move toward the neighborhood at the center of the mass. The cohesion motion for the $i-$th dragonfly individual in the $t-$th iteration $C_{(i,t)}$

is given by[5,9]:

$$C_{(i,t)} = \left(\left(\sum_{j=1}^{n} X_{(j,t)}\right) \Big/ n\right) - X_{(i,t)}$$

The prey attraction motion for the i −th dragonfly individual in the t −th iteration $F_{(i,t)}$ is calculated by:

$$F_{(i,t)} = X_{(p,t)} - X_{(i,t)}$$

where $X_{(p,t)}$ represents to position of the prey source in the t −th iteration.

Distraction of prey for the i −th dragonfly individual in the t −th iteration $E_{(i,t)}$ is quantified by:

$$E_{(i,t)} = X_{(p,t)} + X_{(i,t)}$$

In each iteration, the corrective pattern of the dragonfly individuals can be predicted by observing the above-mentioned movements. Individuals are updated using the current position of the dragonfly $X_{(i,t)}$ and the step vector $\Delta X_{(i,t)}$, which shows the direction of movement for each individual dragonfly, and is defined as follows:

$$\Delta X_{(i,t+1)} = sS_{(i,t)} + aA_{(i,t)} + cC_{(i,t)} + fF_{(i,t)} + eE_{(i,t)} + w\Delta X_{(i,t)}$$

where s, a, c, f, e and w represent to separation weight, alignment weight, cohesion weight, prey attraction weight, predator distraction weight and inertia weight, respectively.

Updated site vectors can be calculated by:

$$\Delta X_{(i,t+1)} = X_{(i,t)} + \Delta X_{(i,t)}$$

When no nearby solutions are discovered, the dragonfly members fly around the search space randomly with a view to improving random behavior and explore the dragonfly individuals. In this case, the poses of the dragonfly are updated by [9]:

$$X_{(i,t+1)} = X_{(i,t)} + 0.13\ r_1 r_2^{-2/3} X_{(i,t)}$$

here $r_1, r_2 \in [0,1]$ are random constants.

Fig.3 shows the flowchart of the DA.

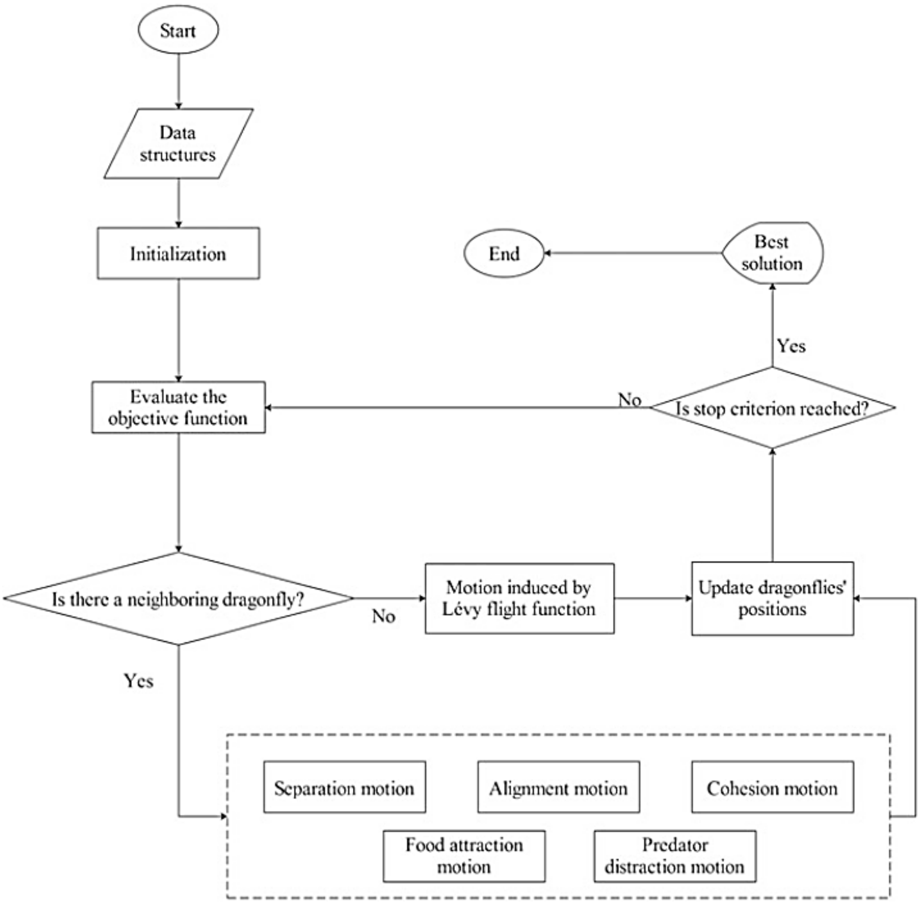

Figure 3. The flowchart of dragonfly algorithm

Use the dragonfly algorithm to reach the best solution

The results of the DA were calculated using MATLAB R2020a in COM. with a device (Intel(R) Core (TM) i7-7500U CPU @ 2.70GHz 2.90 GHz RAM 12 GB VGA 920M 4GB).

The results of DA with cost functions listed in Table 1.

Table 1: Values of R_i, C_i, R_N and C_N by DA

i	Logarithmic function		Exponential function	
	R_i	C_i	R_i	C_i
1	0.945	0.290	0.931	0.383
2	0.847	0.207	0.654	0.133
3	0.671	0.133	0.861	0.215
4	0.939	0.252	0.933	0. 465
5	0.945	0.276	0.925	0.365
6	0.922	0.281	0.904	0.276
7	0.927	0.314	0.925	0.331
N	0.991	1.753	0.987	2.168

From table (1) we have the following notes:

(1) Best network reliability R_N was greater than 0.98 by using DA with two cost functions which is a very acceptable value.

(2) The difference between largest and lowest value is 0.004 which has two indications, first one is that the value of R_N is not much affected by the cost function, and the second is that we are on the right path to convergence values.

(3) The best cost is $C_N = 1.753$, this value was done by using logarithm cost function, while the highest cost is $C_N = 2.168$ when use an exponential cost function. The difference between higher and lower total costs is due to two reasons, the first is the difference in formulas of cost functions, and the second is random selection of values for constants a_i and b_i.

Conclusions

The results of dragonfly algorithm with two cost functions despite their differences has been shown that, they can be relied upon to optimization the reliability of complex networks at a low cost. The best reliability value at the lowest cost is by using the dragonfly algorithm with logarithmic function.

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