Pure Sciences International Journal of Kerbala

Year:2024 Volume : 1 Issue : 2 ISSN: 6188-2789 Print 3005 -2394 Online

Fouad Hamza Abd Alsharify, Cuckoo Search Algorithm for Optimize Reliability of Reduction Oxygen Supply System, Pure Sciences International Journal of Kerbala, Vol. 1, No. 2, (2024) 75-79

2024 ,Volume 1 , Issues 2 PSIJK 75-79

Pure Sciences International Journal of Kerbala

Journal Homepage:https://journals.uokerbala.edu.iq/index.php/psijk

Cuckoo Search Algorithm for Optimize Reliability of Reduction Oxygen Supply System

Fouad Hamza Abd Alsharify [1*]

[1] *Department of Physics, College of Science, University of Babylon, Iraq.*

P A P E R I N F O

Received 11 June 2024
Accepted 23 June 2024
Published 30 June 2024

Keywords:
Cuckoo Search Algorithm, Optimization approach, Reliability system, Reduction Oxygen Supply System

A B S T R A C T

The goal of this paper is to maximize reliability of the spacecraft's oxygen reduction system at the lowest possible cost. The cuckoo algorithm was used with cost constraints based on two cost functions (sine and cosine). There was a comparison between the results of these two cost functions, where the best reliability of the system was obtained using the cosine function, and at a slightly higher cost when using the sine function.

NOMENCLATURE			
ROSS	Reduction Oxygen Supply System	p_e	parameter switching
R_S	Reliability System	**Greek Symbols**	
$R_i, i = 1, \cdots, 7$	Reliability of i −th component	δ	Scaling factor
R_t	Reliability target	ε	Random value from uniform distribution
C_S	Cost System	μ	Scaling factor $1 < \mu \leq 3$
$C_i, i = 1, \cdots, 7$	Cost of i −th component	**Subscripts**	
C_t	Cost target	$\otimes$	Entry-wise multiplication
CSA	Cuckoo Search Algorithm		
x_i^t	Position of of i −th cuckoo		
x_i^{t+1}	Next position		
h	Step size		
H	Heavy-side function		
$L(h, \mu)$	Lévy distribution		
S	System		

1. INTRODUCTION

System reliability for a specific product is a measure of its ability to achieve the goals for which it is made. It is expressed in terms of the reliability of its components or in terms of the reliability of its sub-systems. One of the goals of technological development is optimization reliability system for manufactured devices, as the marketing of the product depends on its reliability in addition to its cost. Optimization reliability system of any product is very important to make use of available natural resources and to evolve the design of that system according to market demand. To optimization reliability system for a particular product, its components, limitations, and capabilities of those components must be visualized to shape the engineering design of that product, and discover specifications that

*Corresponding Author Institutional Email: *fn1551988@gmail.com* (Fouad Hamza Abd Alsharify)

lead to product preference [1,2]. Many researchers have conducted various techniques to solve the problem of optimization reliability for many systems using deferent meta-algorithms inspired by nature. Wei-Chang Yeh et al [3] proposed particle swarm algorithm to solve the reliability optimization problems of complex system. Abdullah and Hassan discussed and compared the results of the two algorithms genetic and particle swarm to optimization reliability of a complex system [4]. Yun Chia and Smith introduced the ant colony algorithm to solve the redundancy allocation problem of a parallel system [5]. Bat, and gray wolf algorithms were studied by Alsharify and Hassan to optimize a complex network [6]. Alsharify et al [7] used firefly algorithm to optimize the reliability of a mixed system. Abed et al [8] focused on optimization the reduction oxygen supply system in spacecraft by genetic algorithm. Sulaiman et al [9] studied the reduction oxygen supply system in spacecraft by genetic and particle swarm algorithms. These researchers were interested in the cost of these systems, as they included multiple cost functions in their algorithms, such as logarithmic, exponential, power, tangent, and other functions. In this study, cuckoo search algorithm was used by including sine and cosine as cost functions to optimize reduction oxygen supply system in spacecraft. The optimization problem was studied under specific constraints and the results were acceptable within those constraints.

2. PROBLEM STATEMENT

It is very necessary to provide oxygen to the spacecraft crew. Accordingly, space agencies are seeking advanced technologies to increase oxygen on spacecraft, and it is very important to optimize the reliability of these systems. The (ROSS) network shown in Figure 1 is a complex system with seven components.

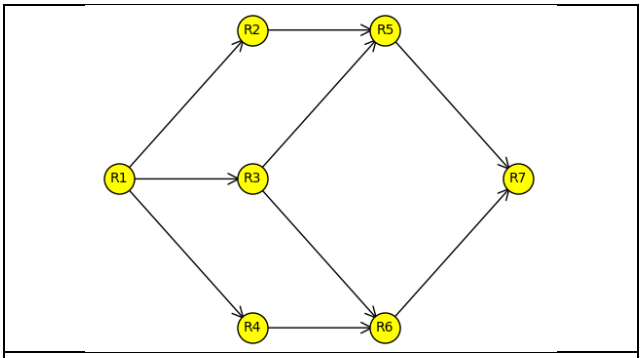

Figure 1. ROSS network

The reliability polynomial of ROSS in Equation 1 was calculated using one of the approved methods to find reliability polynomial [8,9].

$$\begin{aligned} R_S = {} & R_1R_2R_5R_7 + R_1R_3R_5R_7 + R_1R_3R_6R_7 \\ & + R_1R_4R_6R_7 - R_1R_2R_3R_5R_7 - R_1R_3R_4R_6R_7 \\ & - R_1R_3R_5R_6R_7 - R_1R_2R_4R_5R_6R_7 \\ & + R_1R_2R_3R_4R_5R_6R_7 \end{aligned} \quad (1)$$

The goal of this study is to maximize R_S.

Bi -objective optimization problem is minimizing or maximizing of two objective functions subject to a set of constraints [10-13]. Bi -objective optimization problem in this study involves maximizing reliability and minimizing the cost at the same time. Therefore, a negative sign will be placed before the total cost C_S to match the maximization.

The optimization problem is formelted as follows:

$$\begin{aligned} &\text{Maximize} \quad \left(R_S(R_i), -C_S(R_i)\right) \\ &\text{Subject to:} \quad 0.66 \le R_i \le 0.96 \\ &\qquad R_S \ge R_t \\ &\qquad 0.1 < C_i \le 1 \\ &\qquad C_S = \sum_{i=1}^{n} C_i \le C_t \end{aligned} \quad (2)$$

To obtain acceptable system reliability R_S, value target reliability was chosen $R_t = 0.85$**.** In order to make the total cost be low, the target total cost was chosen $C_t = 6.9$.

There are many cost functions, but the sine and cosine functions were chosen to suit the topic of the paper.

1.Sine function:

$$C_i(R_i) = R_i \sin(R_i) \quad (3)$$

2.Cosine function

$$C_i(R_i) = R_i \cos(1 - R_i) \quad (4)$$

3. METODOLOGY

The cuckoo search algorithm (CSA) is an optimization algorithm using random paths devised by Yang and Deb. It is based on the behavior of a cuckoo that lays eggs in the nests of different birds. When this bird finds eggs other than its own, it will leave its nest to the cuckoo. This behavior can be considered an ideal behavior as it is applied to the cuckoo algorithm, which outperforms many other algorithms.

Yang and Deb established three rules in which he summarized the main ideas:

(1) A random nest is chosen by every cuckoo to lay one egg, which represents one of the solutions.

(2) The nest containing the best eggs will be passed on to a new generation.

(3) The number of nests is fixed, and if the host detects a foreign egg with a probability p_e, it either discards it

or the nest, leading to the building of another nest in a new location [14-18].
CSA alternates between a local random walk and a global random walk with parameter switching $p_e \in [0,1]$.

Local random walk defined by:

$$x_i^{t+1} = x_i^t + \delta h \otimes H(p_e - \varepsilon) \otimes (x_n^t - x_m^t) \quad (5)$$

Where

$$H(p_e - \varepsilon) = \begin{cases} 1 & \text{when } p_e \geq \varepsilon \\ 0 & \text{when } p_e < \varepsilon \end{cases} \quad (6)$$

The global random walk defined by

$$x_i^{t+1} = x_i^t + \delta \otimes L(h, \gamma) \quad (7)$$

Where

$$L(h, \mu) = \frac{\Gamma(\mu + 1)\sin(\pi\mu/2)}{\pi} \frac{1}{h^{1+\mu}} \quad (8)$$

When generating new solution x_i^{t+1} for i −th cuckoo, Lévy flight is performed [11,12].

4. RESULTS AND DISCUSSION

Result values for CSA with sine and cosine functions are shown in Table 1.

TABLE 1. Results of R_i, C_i, R_S and C_s by CSA

i	Sine function		Cosine function	
	R_i	C_i	R_i	C_i
1	0.9598	0.7861	0.9582	0.9574
2	0.8999	0.7049	0.9470	0.9457
3	0.7985	0.5720	0.8015	0.7858
4	0.9539	0.7781	0.9433	0.9418
5	0.9558	0.7807	0.9358	0.9339
6	0.9378	0.7561	0.9240	0.9213
7	0.9399	0.7590	0.9542	0.9532
S	0.8975	5.1368	0.9081	6.4390

If we consider the values of Table 1, the following observations can be established:
(1) The value of reliability system $0.89 \leq R_S \leq 0.91$ by CSA with the sine and cosine functions which are logical values. It is larger than target reliability**.**
(2) Best reliability system is $R_S = 0.9081$, with cosine function.
(3) Best cost is $C_S = 5.1368$, it is obtained by CSA with sine function, the value is the most cost $C_S = 6.439$ with cosine function. It is lower than target cost**.**

5. CONCLUION

Results of cuckoo search algorithm with sine and cosine functions show that the difference is very small in the final value of the system reliability. This means that this algorithm can be adopted to optimize the reliability of the CSA with any cost function, as the cost is reasonable in both cases. The best reliability value is using CSA with the cosine function, while the least cost is by CSA with sine function.

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Arabic Abstract

الهدف من هذه الورقة هو زيادة موثوقية نظام امداد الأوكسجين في المركبة الفضائية بأقل تكلفة ممكنة. تم استخدام خوارزمية الوقواق مع قيود التكلفة بناءً على دالتين للتكلفة (الجيب والجيب تمام). وتمت المقارنة بين نتائج هاتين الدالتين، حيث تم الحصول على أفضل موثوقية للنظام باستخدام دالة الجيب تمام، وبتكلفة أعلى قليلاً عند استخدام دالة الجيب.