Hybrid genetic and particle swarm algorithm: redundancy allocation problem

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Abstract Redundancy allocation problem (RAP) is a non-linear programming problem which is very difficult to solve through existing heuristic and non-heuristic methods. In this research paper, three algorithms namely heuristic algorithm (HA), constraint optimization genetic algorithm (COGA) and hybrid genetic algorithm combined with particle swarm optimization (HGAPSO) are applied to solve RAP. Results obtained from individual use of genetic algorithm (GA) and particle swarm optimization (PSO) encompass some shortcomings. To overcome the short-comings with their individual use, HGAPSO is introduced which combines fascinating properties of GA and PSO. Iterative process of GA is used by this hybrid approach after fixing initial best population from PSO. The results obtained from HA, COGA and HGAPSO with respect to increase in reliability are 50.76, 47.30 and 62.31 respectively and results with respect to CPU time obtained are 0.15, 0.209 and 3.07 respectively as shown in Table 3 of this paper. COGA and HGAPSO are programmed by Matlab.

Keywords Reliability · Optimization · RAP · COGA · HGAPSO

1 Introduction

Due to innovation of new technology and complex systems there arise a need of more reliable components or machines which are used in manufacturing and mechanical frame-work for the good quality of products. The increased need of reliability optimization is due to market pressure, safety issues, development risks and management emphasis etc. RAP is a well-known reliability optimization problem. In RAP the resolution of components among discrete choices with suitable stages of redundancy to maximize the reliability of the device under some predefined restrictions. RAP is a non-linear mixed integer programming problem. Because of discrete search space it is quite difficult to solve these problems by direct or indirect methods. Billionnet (2008) applied integer linear programming for solving RAP and consider the number of units of each subsystem and choice of units as decision variables. Garg and kumar (2009) tries to analyses the reliability of a pharmaceutical plant using matlab tool. Devi et al. (2017) also analyses the reliability of the system by heuristic algorithms.

Several researchers have already used GA with so many creative approaches to this problem. Holland (1975a, b) introduced GA on the basis of Darwinian evolution theory "survival of the fittest". It works with coding variables and converts the design space into genetic space. GA is the heuristic search algorithm for finding RAP resolution. David and Alice (1996) have utilized a consolidated neural system and GA to solve RAP. Busacca et al. (2001) applied informative GA for solving optimization problem where each goal have given a separate importance to be optimized. Gupta and Agarwal (2006) applied GA for solving RAP. Penalty strategy has been used dealing with infeasible solution and a graphical representation has been

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presented for effective results of using penalty function. Puzzi and Carpinteri (2008) also applied GA with penalty strategy for handling the constraint optimization in a easy and efficient way. Garg and Kumar (2010) also applied GA for finding optimal solution of the availability of the screw plant. After that Zhao et al. (2012) introduced a hybrid GA with a flexible allowance technique to tackle restricted design optimization problems. Ghodrati and Lofti (2012) and Kanagaraj et al. (2013) and introduced a half and half cuckoo seek (CS)/GA calculation to take care of RAP and global enhancement issues, separately. Ghorabaeea et al. (2015) has contemplated a bi-target RAP, which is expounded to independent K-out-n subsystem in series.

Habib et al. (2016) proposed GA and present a comparison between GA and LINGO software tool. They showed how GA is superior to LINGO in respect of speed of getting results. Further, Saleem et al. (2018) developed a hybrid GA to solve RAP and compared the results with previous approaches. A combination of GA with other heuristic algorithm was also a great notion for enhancing

the efficiency of GA. While comparing between GA and PSO, it is going to be found that both are executed on the basis of operation of population.

Mechanism of PSO is motivated by social behavior of birds and ants in a swarm. The population and the individuals are considered as swarm and particles respectively in PSO. Each particles in the swarm have a velocity and these particles moves in the search space trying to find the best velocity or solution. To solve optimization problem, Kennedy and Eberhart (1998) presented an effective approach named as PSO algorithm. It is a kind of search algorithm which is grounded on artificial intelligence of school of fish, a group of birds or swarm of bees. PSO is to get a solution of unconstrained optimization problem. Then PSO become a very interesting topic for researchers and been carried out in a diffusion of fields. Coello et al. (2004), Zhang et al. (2008), Chang (2009) and Zielinski et al. (2009) have applied PSO because of its smooth implementation, simplicity and efficiency. For enhancing the efficiency of PSO, Banks et al. (2008) developed a

Table 1 Reliability and cost of each sub-unit

Subunits	k1	k2	k3	k4	k5	k6	k7
Reliability of subunit Rj(kj)	0.97	0.9542	0.9018	0.8432	0.8555	0.9107	0.955
Cost of subunit D1(kj)	1,170,000	940,000	2,600,000	1,030,000	10,400,500	960,000	260,000

Table 2 Steps/results of HA

S. no.	\multicolumn{7}{c}{Number of components in each subsystem}	Exhaust/spend resources	\multicolumn{7}{c}{Subsystem selection factor}
	k_1	k_2	k_3	k_4	k_5	k_6	k_7	$\sum_{i=1}^{7} h^1(y_i) * n_i$	$R_1(k_1)$	$R_2(k_2)$	$R_3(k_3)$	$R_4(k_4)$	$R_5(k_5)$	$R_6(k_6)$	$R_7(k_7)$
1	1	1	1	1	1	1	1	17,360,500	0.97	0.9542	0.9018	0.8432	0.8555	0.9107	0.9550
2	1	1	1	2	1	1	1	18,390,500	0.97	0.9542	0.9018	0.9755	0.8555	0.9107	0.9550
3	1	1	1	2	2	1	1	28,791,000	0.97	0.9542	0.9018	0.9755	0.9792	0.9107	0.9550
4	1	1	2	2	2	1	1	31,391,000?	0.97	0.9542	!!!!!	0.9755	0.9792	0.9107	0.9550
5	1	1	1	2	2	2	1	29,751,000	0.97	0.9542	!!!!!	0.9755	0.9792	0.9921	0.9550
6	1	2	1	2	2	2	1	30,691,000?	0.97	!!!!!	!!!!!	0.9755	0.9792	0.9921	0.9550
7	1	1	1	2	2	2	2	30,011,000	0.97	!!!!!	!!!!!	0.9755	0.9792	0.9921	0.998
8	2	1	1	2	2	2	2	31,181,000?	!!!!!	!!!!!	!!!!!	0.9755	0.9792	0.9921	0.998
9	1	1	1	2	2	2	2	30,011,000	!!!!!	!!!!!	!!!!!	0.9755	0.9792	0.9921	0.998

Table 3 Result of COGA

Subunits	k_1	k_2	k_3	k_4	k_5	k_6	k_7
No. of components used by each subunits	3	4	1	5	1	4	4

Fig. 1 Flow chart of HGAPSO
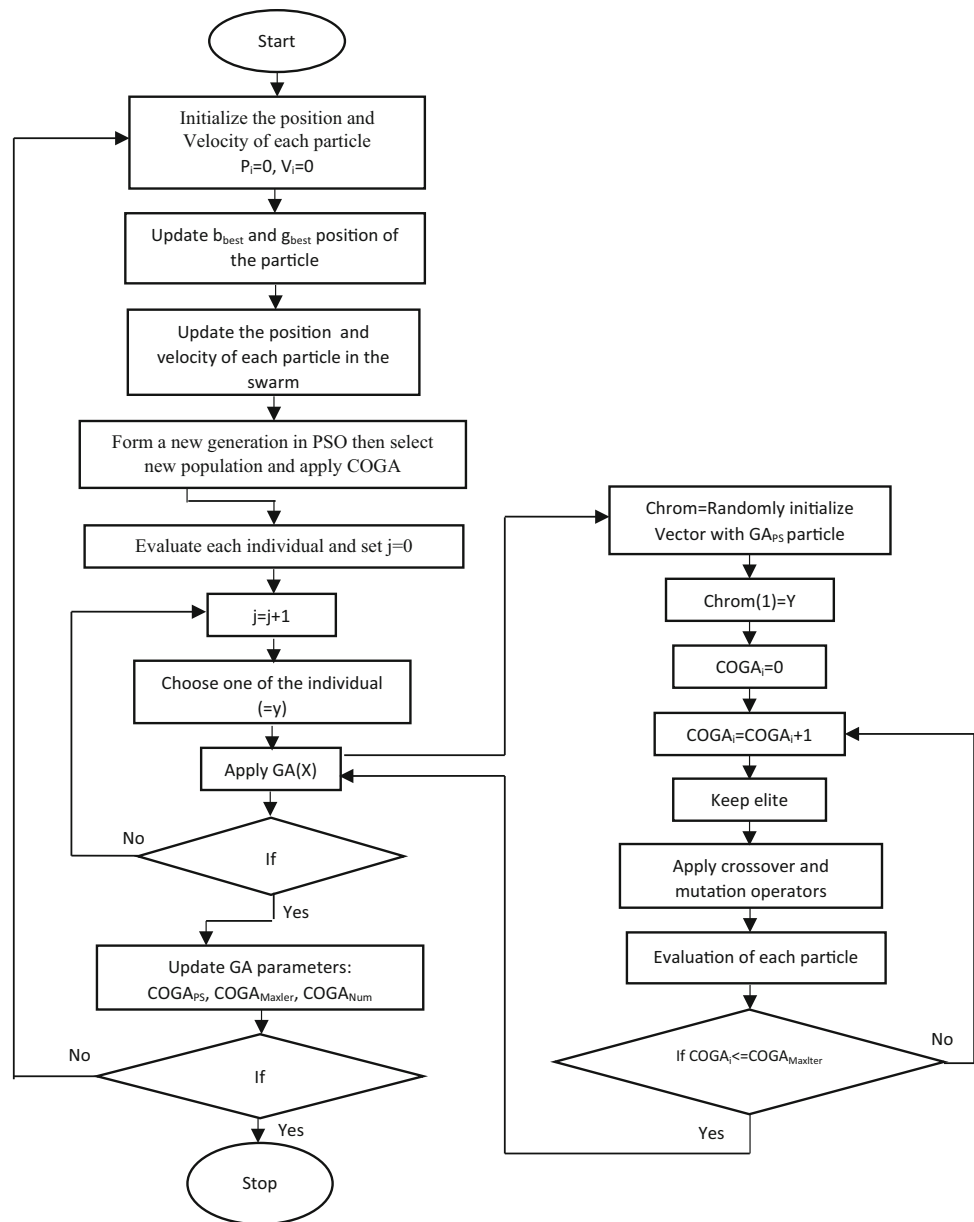
Table 4 Result of HGAPSO

| Subunits	k_1	k_2	k_3	k_4	k_5	k_6	k_7
No. of components used by each subunits	2	3	3	3	1	3	4

variety of PSO algorithms. Zou et al. (2010) proposed a modified and improved particle swarm optimization technique in which they modifies the velocity updating and introduced a new interia weight into the velocity updating. Kong et al. (2014) focused on specific redundancy allocation problem with multiple strategy choices (RAP-MSE) and applied a simplified particle swarm optimization (SPSO) with new position updating system with stochastic

perturbation. A comparative analysis have been done with well-known PSO modifications in literature. Arif et al. (2016) presented the research and advancement calculation of PSO particularly for Distributed Generation (DG) position and estimating. A discussion has been made regarding combination of PSO with other algorithms and attained better results. Ouyang et al. (2019) applied PSO with stochastic disturbance type for solving reliability
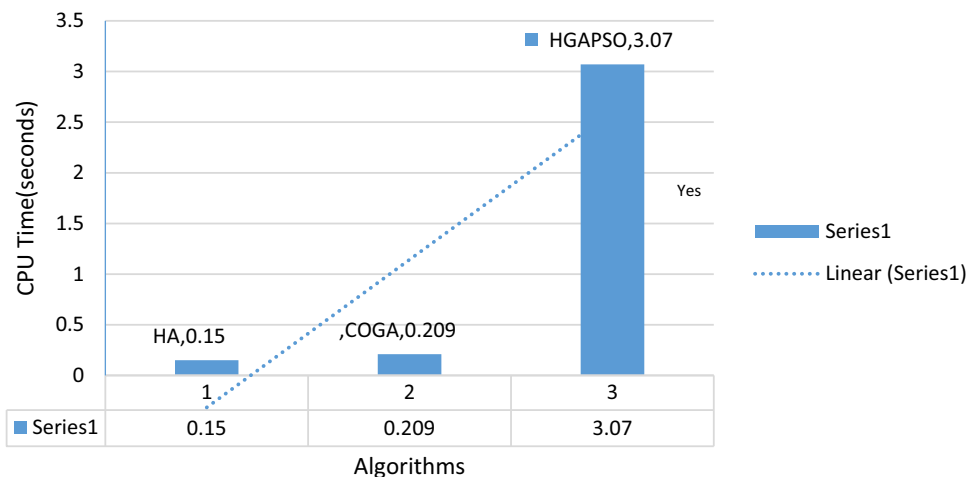
Table 5 Comparison of optimal solution of three algorithms

Algorithm	Results of RAP							Increase in reliability (%)	CPU time (in s)
	k1	k2	k3	k4	k5	k6	k7		
HA	1	1	1	2	2	2	2	50.76	0.15
COGA	3	4	1	5	1	4	4	47.30	0.209
HGAPSO	2	3	3	3	1	3	4	62.31	3.07

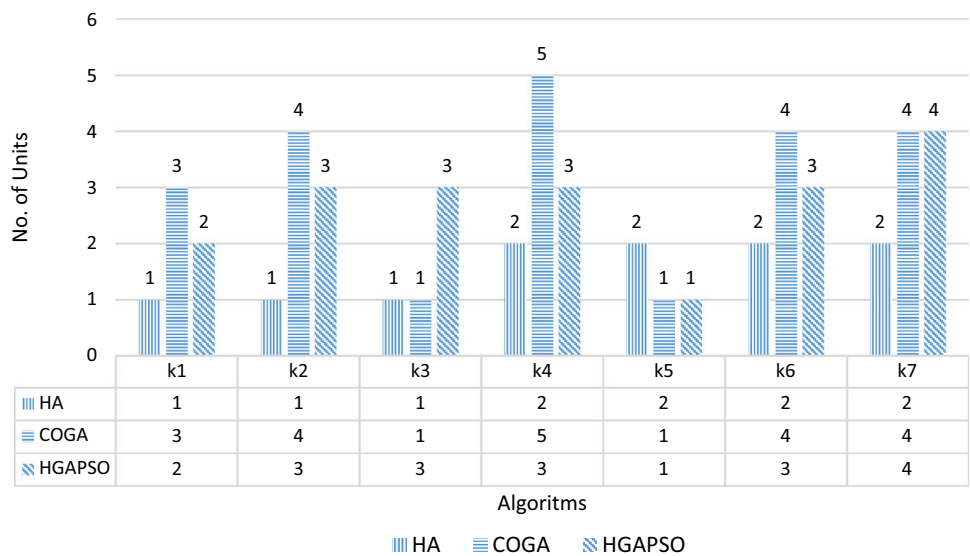**Fig. 2** Comparison of optimal solution (increase in reliability) of three algorithms
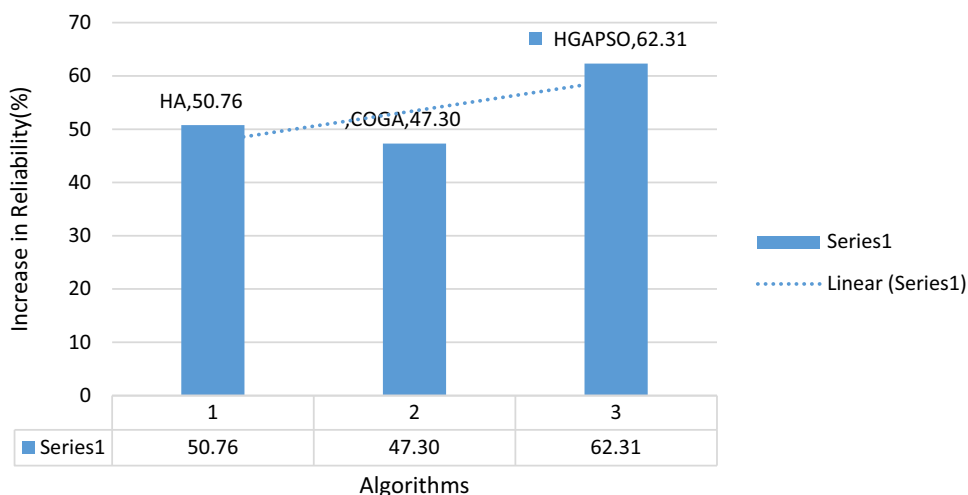
Fig. 3 Comparison of optimal solution (CPU time) of three algorithms

redundancy allocation problem (RRAP) and considered mixed redundancy strategy. Heterogeneous components are introduced in RRAP that is the strong base of this contribution. Robinson et al. (2002) used two methods hybrid PSO and GA for finding the best solutions of complicated electromagnetic appliance designs. After that Krink and Lvbjerg (2002) applied hybridized PSO with GA and Hill climbing approach for finding the solution of optimization problems without any constraint. Grimaldi et al. (2004) projected a hybrid technique named as Genetically Swarm Optimization (GSO) which is a combination of GA and PSO for solving electromagnetic optimization problems. Gandelli et al. (2006) and Grimaccia et al. (2007) created the application of few other hybridization procedures of GSO technique and verified with a few multimodal standard problems. Garg and Sharma (2013) have applied an efficient penalty based PSO algorithm to solve reliability redundancy allocation problem. They used the algorithm to determine and resolve the problem under cost, weight and volume constraints. After

Fig. 4 Results of RAP

	k1	k2	k3	k4	k5	k6	k7
HA	1	1	1	2	2	2	2
COGA	3	4	1	5	1	4	4
HGAPSO	2	3	3	3	1	3	4

Algoritms

▥ HA   ≡ COGA   ▧ HGAPSO

this technique Garg (2014) introduced another hybrid algorithm to solve nonlinear optimization problems with mixed variables under some constraints. Some studies have been conducted to analyze the reliability of the system and results are compared with previous results. Devi et al. (2017) applied a technique named as hybridization of constraint optimization genetic algorithm with particle swarm optimization (H-COGAPSO) and compare results with other heuristic algorithms.

The other contents of this paper are classified as per following: Introduction is followed by methodology which contains description of the system, entire notation used in the paper and formulation of the CRAP and methods. Next section highlights the proposed algorithm HGAPSO and its procedure by flowchart. Next section attends to the results of three techniques and comparison of the results. Last section caters to the drawn conclusion.

2 Methodology

2.1 System description

Seven units named as crane, rolling, blanking, stacking, pressing, molding and packaging of a manufacturing plant is connected in series Devi and Garg (2017). They work in a sequence in which they are connected.

2.2 Notations

k_j	jth component
$R_j(k_j)$	Reliability
$Q_j(k_j)$	Unreliability of component-t_j

$R_s(k)$	Overall system reliability
N_j	Subunit level
$h_i(k_j)$	ith resource exhausted by jth component
$n = 7$	Total units
L	Maximum cost
$U(.)$	A function which calculate value of reliability of whole system
$COGA_{num}$	Number of individuals in running iteration of COGA
$COGA_{PS}$	Population size of the particles in COGA
$COGA_{maxlter}$	Maximum limit of iteration in PSO
PSO_j	Running PSO iteration

2.3 Problem description

As any Unit management want to minimize cost L and maximize reliability/productivity in a manufacturing plant. So the given problem which defined by a function U and demonstrated in Table 1.

Problem is to maximize:

$$R_s(k) = U(R_1(t_1), \ldots, R_n(k_n)) = \prod_{j=0}^{7} R_j(k_j)$$

$$R_j(k_j) = \prod_{j=0}^{7} \left[1 - \left[Q_j(k_j)\right]^{n_j}\right]$$

$$\sum_{j=1}^{7} D^1(k_j) * n_j \leq 30410000$$

Devi et al. (2017) solved RAP by using HA and COGA. Alike algorithms are adopted in this paper and results are shown in Tables 2 and 3.

The main attention of the paper revolves around the proposed algorithm HGAPSO. The procedure of HGAPSO is shown by flowchart in Fig. 1.

3 Results

The result of RAP obtained by HA, COGA and HGAPSO is demonstrated by Tables 2, 3 and 4 respectively. Table 5 specifies the comparison of results of three algorithms w.r.t. increase in reliability and CPU time. Result demonstrate that percentage increase in reliability in HGAPSO comparatively much higher than HA and COGA results (Figs. 2, 3, 4).

4 Conclusion

This paper comprised three algorithms HA, COGA and HGAPSO to solve optimization problem with cost constraint. The intent of this paper is to increase the reliability is fulfilled by HGAPSO which is depicted in Table 5. The performance of three algorithms are compared and observed that the performance of proposed HGAPSO is better than other two algorithms with respect to reliability but the CPU time 3.07 s which is more than other two algorithms. It depends on different techniques; if combination of two algorithms is applied then it takes more CPU time than a single algorithm applied. But reliability is improved by 62.31% when combination of algorithms applied together like HGAPSO as shown in Table 5.

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