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Efficient and Intelligent Decision Support System for Smart Irrigation

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Abstract

The main aim of present analysis is to develop a novel efficient and intelligent irrigation system (EIIS). The proposed irrigation system configured using five components arranged in a series configuration along with the internal cold standby redundancy on sensor unit. The failure and repair rates are exponentially distributed. By using the Markovian birth-death process differential difference equations of the model are developed to derive the availability expressions and estimation of parameters. The availability of the system is optimized by employing Grey-Wolf optimization (GWO) and Dragon Fly algorithm (DA) for efficiency and performance evaluation. The derived results are helpful for the system designers.

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1. Introduction

Agriculture is one of the oldest occupations done by human being. It is one of the strong pillars that contribute to the development of the economic development of any country. A big portion of the population of any country depends on the agriculture for survival. In most of the countries traditional methods of irrigation are adopted for farming but these methods suffer due to several drawbacks. The wasteful use of water and inappropriate irrigation are the major drawbacks while smart irrigation technology ensures the efficient use of water in irrigation. The traditional method of irrigation is very challenging due to several factors like soil nature, crop requirement, etc. while in smart irrigation system based on soli and environmental measurements irrigation decision can be made. Several researchers like Morais et al. [1], Vellidis et al. [2], Kehui et al. [3], Giusti and Marsili-Libelli [4], Navarro-hellín et al. [5], and Sinwar et al. [6] proposed model for smart irrigation systems in various aspects. Nasikou et al. [7] proposed a model for smart energy utilization in smart irrigation systems. Gu et al. [8] developed a software for irrigation scheduling that work on the crop water stress. Shekhar et al. [9] developed an automated irrigation system using intelligent IoT. Goap et al. [10] used machine learning and open source technologies in development of a internet based irrigation management systems. Nawandar and Satpute [11] devloped a smart irrigation system based on IoT . A lost cost intelligent module has beem utilized in the development of the system. Wang et al. [12] proposed a decision support system to manage the canal irrigation. It is observed

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that the performance aspects of these smart system has not been extensively explored so far. Reliability and availability are the major concern with the perofrmance of these systems. Many researchers worked in the direction of reliability evaluation and optimization of performance of systems. Maihulla and Yusuf [13] examined the reliability, availability, maintainability and dependability to check the sensitivity effect in a grid-connected photovoltaic systems. This sensitivity analysis shows that close attention and close monitoring are needed to ensure the distribution board's reliability of the system. Venkatakrishnan et al. [14] compare the effect of modified differential evolution algorithm (MDE) on wind turbine system along with GA and PSO techniques. It concludes that in addition to meet energy demand, the modified DE algorithm assists in finding the system's most cost-effective solution. Kumar et al. [15] proposed an efficient model for availability optimization of cooling tower using metaheuristic algorithms. Saini et al. [16] optimized the performance of a biological and chemical processing unit using genetic algorithm and particle swarm optimization. Saini et al. [17] proposed a stochastic model for availability optimization of condenser used in steam turbine power plants using GA and PSO. Though area of reliability optimization of smart irrigation systems is still untouched. But efficient and intelligent irrigation-based systems are necessary nowadays for optimum utilization of fresh water. So, the work is proposed develop such an efficient and intelligent irrigation system which ensures the availability of the system as and when required for irrigation.

The rest of the work is arranged in six sections: Section 2 devoted to the novelty claims by the investigators, section 3 explained the notations and section 4 briefed the system description. Mathematical model proposed in section 5 and in section 6 numerical discussion and graphical representation is made followed by concluding section 7.

A very less efforts have been made so far for development of efficient and intelligent irrigation systems. So, here an effort is made to develop and efficient and intelligent irrigation system. The efficiency of the system is evaluated in terms of availability of the system for use. By probabilistic arguments and Markov methodology, a mathematical model is developed and optimized using Grey-Wolf optimization (GWO) and Dragon Fly algorithm (DA). The state transition diagram of proposed system is shown in Figure 2. The blow mentions points are claimed as the novelty by the inventors.

1. **Design:** A novel design of the proposed system is developed for efficiency improvement. The cold standby redundancy is used at sensor level, and it is verified that it performed better.

2. **Efficient:** The availability of the proposed irrigation system is optimized using various algorithms like Grey-Wolf optimization (GWO) and Dragon Fly algorithm (DA). In literature so far these algorithms are not employed on availability optimization of irrigation systems. The system is proved efficient when it is operated with the parameters estimated by GWO parameters.

3. **Intelligent:** The proposed system is capable of taking intelligent decisions for irrigation based on the data captured by sensors in real time.

2. Notations

The nomenclatures used in the development of the model are as follows:
S_i: i^{th}state of smart irrigation system
$P_i(t)$: Probability that smart irrigation system is in state i at time t
$P_i^{'}(t)$: Derivative of first order of $P_i(t)$
A, B_1, B_2, C, D, E: Description of the operative states of smart irrigation system
a, b_1, b_2, c, d, e: Description of the failed states of smart irrigation system
$\alpha_i/\beta_i i = 1, 2, 3, 4, 5$: Failure/repair rates of A, B_1, B_2, C, D, E respectively.

3. System Description

In this section, the configuration of the efficient and intelligent irrigation system is presented. A smart irrigation system is presented in Figure 1 that depicts five main components viz. power unit, active and cold standby sensor unit, Raspberry pi, water pump, and irrigation unit. As the name suggest, power unit is needed to provide the power supply to the smart irrigation systems. The power may come directly or through solar power supply. On the other hand, sensor unit indicates a collection of sensors (i.e., moisture, temperature, water, humidity, etc.) needed for decision making by the control unit. The heart of this smart irrigation system is Raspberry pi that is responsible for taking efficient irrigation decisions based on data captured by sensor unit. In addition, Raspberry pi is utilized to trigger the water pump whenever required. Once the water pump is turned on, the irrigation unit (i.e., sprinklers) start working towards irrigation of the field. Upon reaching the threshold values by sensor units, Raspberry pi initiates actions to turn off the water pump. It is evident that sensor unit is more prone to failures, that's why the redundancy has been utilized in sensor unit of the system. If primary sensor failed in fetching information any one or more of these than standby sensor starts immediately and failed sensor undergoes for repair. The concept of cold standby redundancy and exponential distributed random variable have been utilized in development of the stochastic model. The repair and switch devices are perfect and sufficient repair facility is available with system. The architecture and state transition diagram of smart irrigation system is depicted in Figure 1 and Figure 2 respectively.

4. Mathematical Modelling and Analysis

Here, mathematical model for the smart irrigation system is developed using Markov birth-death process. The Chapman-Kolmogorov differential difference equations derived based on Figure 2.

$$P_0(t+\Delta t) = (1-\alpha_1\Delta t-\alpha_2\Delta t-\alpha_3\Delta t-\alpha_4\Delta t-\alpha_5\Delta t)\, P_0(t)$$

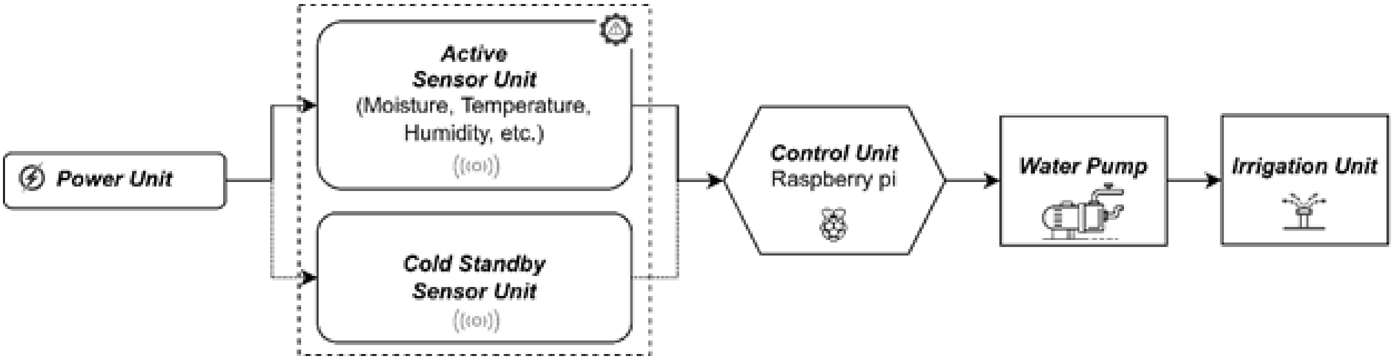

Figure 1. Framework of intelligent decision support system for smart irrigation

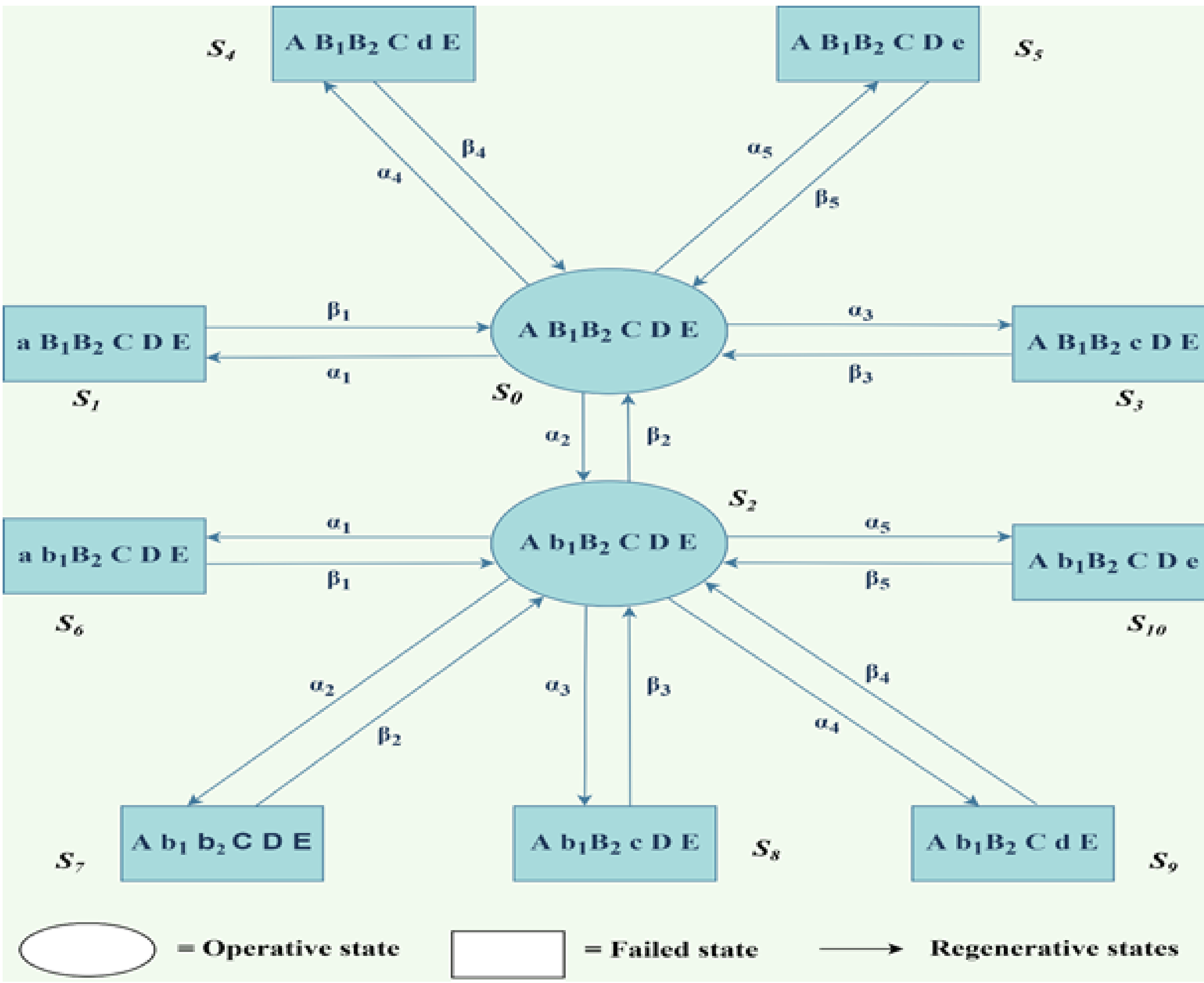

Figure 2. State Transition Diagram

$$+\beta_1 P_1(t)\Delta t+\beta_2 P_2(t)\Delta t+\beta_3 P_3(t)\Delta t+\beta_4 P_4(t)\Delta t+\beta_5 P_5(t)\Delta t$$

$$\lim_{\Delta t\to 0}\frac{P_0(t+\Delta t)-P_0(t)}{\Delta t}=-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5)P_0+\beta_1 P_1(t)$$

$$+\beta_2 P_2(t)+\beta_3 P_3(t)+\beta_4 P_4(t)+\beta_5 P_5(t)$$

$$P_0^{'}(t)=-(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5)P_0+\beta_1 P_1(t)+\beta_2 P_2(t)$$

$$+\beta_3 P_3(t)+\beta_4 P_4(t)+\beta_5 P_5(t)$$

$$\lim_{t\to\infty} P_0'(t) = -(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5)P_0+\beta_1 P_1+\beta_2 P_2 +\beta_3 P_3+\beta_4 P_4+\beta_5 P_5 - (\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5)P_0+\beta_1 P_1+\beta_2 P_2 +\beta_3 P_3+\beta_4 P_4+\beta_5 P_5 = 0 \quad (1)$$

$$P_1 = \frac{\alpha_1 P_0}{\beta_1} \quad (2)$$

$$P_2 = \frac{\beta_1 P_6+\beta_2 P_7+\beta_3 P_8+\beta_4 P_9+\beta_5 P_{10} + \alpha_2 P_0}{(\alpha_1+\alpha_2+\alpha_3+\alpha_4+\alpha_5 + \beta_2)} \quad (3)$$

$$P_3 = \frac{\alpha_3 P_0}{\beta_3} \quad (4)$$

$$P_4 = \frac{\alpha_4 P_0}{\beta_4} \quad (5)$$

$$P_5 = \frac{\alpha_5 P_0}{\beta_5} \quad (6)$$

$$P_6 = \frac{\alpha_1 P_2}{\beta_1} \quad (7)$$

$$P_7 = \frac{\alpha_2 P_2}{\beta_2} \quad (8)$$

$$P_8 = \frac{\alpha_3 P_2}{\beta_3} \quad (9)$$

$$P_9 = \frac{\alpha_4 P_2}{\beta_4} \quad (10)$$

$$P_{10} = \frac{\alpha_5 P_2}{\beta_5} \quad (11)$$

The initial conditions are as follows:

$$P_0(0) = 1$$

$$P_i(0) = 0 \text{ where i = } 1 \text{ to } 10 \quad (12)$$

The set of linear equations [1]-[11] along with initial conditions [12] constitute the mathematical model for smart irrigation system. After simplification the probabilities at respective states are derived as follows:

$$P_0 = P_0, P_1 = \frac{\alpha_1}{\beta_1}P_0, P_2 = \frac{\alpha_2}{\beta_2}P_0, P_3 = \frac{\alpha_3}{\beta_3}P_0, P_4 = \frac{\alpha_4}{\beta_4}P_0, P_5 = \frac{\alpha_5}{\beta_5}P_0, P_6 = \frac{\alpha_1}{\beta_1}\frac{\alpha_2}{\beta_2}P_0, P_7 = \frac{\alpha_2}{\beta_2}\frac{\alpha_2}{\beta_2}P_0, P_8 = \frac{\alpha_3}{\beta_3}\frac{\alpha_2}{\beta_2}P_0, P_9 = \frac{\alpha_4}{\beta_4}\frac{\alpha_2}{\beta_2}P_0, P_{10} = \frac{\alpha_5}{\beta_5}\frac{\alpha_2}{\beta_2}P_0 \quad (13)$$

By normalizing criteria that sum of all are transition probabilities is equal to 1

$$\sum_{i=0}^{10} P_i = 1 \quad (14)$$

we get

$$P_0 = \left[1 + \left(1 + \frac{\alpha_2}{\beta_2}\right)\left(\frac{\alpha_1}{\beta_1} + \frac{\alpha_2}{\beta_2} + \frac{\alpha_3}{\beta_3} + \frac{\alpha_4}{\beta_4} + \frac{\alpha_5}{\beta_5}\right)\right]^{-1} \quad (15)$$

The system availability function is defined as:

$$A_0 = P_0 + P_2 = \left(1 + \frac{\alpha_2}{\beta_2}\right)\left[1 + \left(1 + \frac{\alpha_2}{\beta_2}\right)\left(\frac{\alpha_1}{\beta_1} + \frac{\alpha_2}{\beta_2} + \frac{\alpha_3}{\beta_3} + \frac{\alpha_4}{\beta_4} + \frac{\alpha_5}{\beta_5}\right)\right]^{-1} \quad (16)$$

5. Numerical Results and Discussion

In this section, parameter estimation of the failure and repair rates of the smart irrigation system is done using swarm-intelligence based algorithms namely Gray Wolf Optimization (GWO) and Dragon Fly algorithm (DA). The possible search space of the decision variables is appended in Table 1. The estimated values of the parameters with respect to 30 iteration levels at several population sizes is derived and appended in Table 2. The availability of smart irrigation system derived at various population sizes are appended in Figure 3-6. The execution time of the program taken by algorithms are appended in Table 6. The simulation study is performed using R software on Windows 10 64-bit operating system having 8 GB of RAM and Intel Core i5 8^{th} generation CPU. The range of these decision variables is provided in Table 1 as follows:

Here parameters of failure and repair rates for GWO are constant for different population sizes and system attains its maximum availability in early stage of simulation process. Parameters values change rapidly when using DA algorithm. It is seen that failure rate of Controller Arduino uno increase rapidly for population size 600 and water pump failure increase with population size 400 and 1000.

Table 3 appended the various parameters values after 50 iterations corresponding to various population sizes. It also shows that by using GWO, parameters for failure rates and repair rates have its minimum and maximum value simultaneously and system attains its maximum availability. for DA, range of parameters of failure rates increase for sub-system sensor/standby sensor unit, Controller Arduino uno and water pump for population size 800 and 1000.

Table 4 highlights the estimated values after 70 iterations on different population sizes. For GWO, system attains its maximum availability. While using DA, range of parameters of failure rates increase rapidly for sub-system sensor/standby sensor unit for population size 800.

Table 5 reported the estimated parametric values of failure and repair rates after 90 iterations at various population sizes. For GWO, system attains its maximum availability. While using DA, range of parameters of failure rates increase rapidly for sub-system Controller Arduino uno for population size 600 and 1000. The best parameter values of failure and repair rates, derived by simulation process done in R studio for GWO and DA optimizations. Parameters obtained for different population sizes and various iterations. These are the best parameters

Table 1. Range of the decision variables

Sub-system	Range of failure-rate (α)	Range of repair-rate (β)
Power unit	α_1 = [0.000003, 1.99]	β_1 = [0.000009, 2.11]
Sensor unit &Stand by Sensor unit	α_2= [0.000005, 1.89]	β_2 = [0.000006, 2.30]
Controller Arduino uno	α_3 = [0.000001, 1.53]	β_3 = [0.000008, 2.57]
Water pump	α_4 = [0.000004, 1.24]	β_4 = [0.000007, 2.08]
Smart valve	α_5 = [0.000002, 1.32]	β_5 = [0.000019, 2.34]

Table 2. Parameter estimation of various failure and repair rates after 30 iterations and different population sizes by using GWO and DA

Iter\NP		400	600	800	1000
GWO	α_1	0.0000030	0.0000030	0.0000030	0.0000030
	α_2	0.0000050	0.0000050	0.0000050	0.0000050
	α_3	0.0000010	0.0000010	0.0000010	0.0000010
	α_4	0.0000040	0.0000040	0.0000040	0.0000040
	α_5	0.0000020	0.0000020	0.0000020	0.0000020
	β_1	1.86464	2.11	2.11	2.11
	β_2	2.3	2.3	2.3	2.3
	β_3	2.57	2.57	2.57	2.57
	β_4	2.08	2.08	2.08	2.08
	β_5	2.34	2.34	2.34	2.34
DA	α_1	0.0000030	0.0000030	0.0000030	0.0000030
	α_2	0.0000050	0.0000050	0.243093	0.0000050
	α_3	0.0000010	1.53	0.0000010	0.0000010
	α_4	1.24	0.0000040	0.0000040	1.24
	α_5	0.0000020	0.0000020	0.0000020	0.0000020
	β_1	2.11	2.11	2.11	2.11
	β_2	0.6341965	2.118504	2.3	2.3
	β_3	2.57	2.57	1.130091	2.57
	β_4	2.08	2.08	2.08	2.08
	β_5	2.34	2.34	1.496042	2.34

Table 3. Parameter estimation of various failure and repair rates after 50 iterations and different population sizes by using GWO and DA

Iter\NP		400	600	800	1000
GWO	α_1	0.0000030	0.0000030	0.0000030	0.0000030
	α_2	0.0000050	0.0000050	0.0000050	0.0000050
	α_3	0.0000010	0.0000010	0.0000010	0.0000010
	α_4	0.0000040	0.0000040	0.0000040	0.0000040
	α_5	0.0000020	0.0000020	0.0000020	0.0000020
	β_1	2.11	2.11	2.11	2.11
	β_2	2.3	2.3	2.3	2.3
	β_3	2.57	2.57	2.57	2.57
	β_4	2.08	2.08	2.08	2.08
	β_5	2.34	2.34	2.34	2.34
DA	α_1	0.0000030	0.0000030	0.0000030	0.0000030
	α_2	0.0000050	0.0000050	1.047884	1.414718
	α_3	0.0000010	0.8860956	1.190195	0.02381295
	α_4	0.0000040	0.0000040	0.0000040	1.24
	α_5	0.0000020	0.0000020	0.2853557	0.0355639
	β_1	0.239885	2.11	0.7081718	2.11
	β_2	2.3	2.3	2.3	2.3
	β_3	0.6369218	1.704359	2.57	2.57
	β_4	2.08	0.1690187	2.08	2.08
	β_5	2.34	1.701183	2.34	2.34

Table 4. Parameter estimation of various failure and repair rates after 70 iterations and different population by using GWO, DA

Iter\NP		400	600	800	1000
GWO	α_1	0.0000030	0.0000030	0.0000030	0.0000030
	α_2	0.0000050	0.0000050	0.0000050	0.0000050
	α_3	0.0000010	0.0000010	0.0000010	0.0000010
	α_4	0.0000040	0.0000040	0.0000040	0.0000040
	α_5	0.0000020	0.0000020	0.0000020	0.0000020
	β_1	2.11	2.11	2.11	2.11
	β_2	2.3	2.3	2.3	2.3
	β_3	2.57	2.57	2.57	2.57
	β_4	2.08	2.08	2.08	2.08
	β_5	2.34	2.34	2.34	2.34
DA	α_1	0.0000030	0.0000030	0.0000030	0.0000030
	α_2	0.0000050	0.05620236	1.89	0.0000050
	α_3	0.0000010	0.0000010	0.0000010	0.0000010
	α_4	0.4775554	0.1183404	0.0000040	0.1965477
	α_5	0.0000020	0.8200995	0.0000020	0.0000020
	β_1	2.11	0.00640018	2.11	2.11
	β_2	0.1106202	2.3	2.3	2.3
	β_3	2.57	0.7383446	1.424582	2.267976
	β_4	1.718693	1.26267	2.08	0.8067474
	β_5	1.063321	2.34	2.34	2.34

Table 5. Parameter estimation of various failure and repair rates after 90 iterations and different population sizes by using GWO and DA

Iter\NP		400	600	800	1000
GWO	α_1	0.0000030	0.0000030	0.0000030	0.0000030
	α_2	0.0000050	0.0000050	0.0000050	0.0000050
	α_3	0.0000010	0.0000010	0.0000010	0.0000010
	α_4	0.0000040	0.0000040	0.0000040	0.0000040
	α_5	0.0000020	0.0000020	0.0000020	0.0000020
	β_1	2.11	2.11	2.11	2.11
	β_2	2.3	2.3	2.3	2.3
	β_3	2.57	2.57	2.57	2.57
	β_4	2.08	2.08	2.08	2.08
	β_5	2.34	2.34	2.34	2.34
DA	α_1	1.059087	0.0000030	0.5533655	0.0000030
	α_2	0.0000050	0.4501209	0.0000050	0.0000050
	α_3	0.6671488	1.53	0.0000010	1.53
	α_4	0.0000040	0.4808177	0.0000040	0.1965477
	α_5	0.0000020	0.1602266	0.0000020	0.0000020
	β_1	2.11	1.725929	2.11	2.11
	β_2	0.5978837	1.181086	2.3	2.3
	β_3	1.702016	2.57	2.57	2.57
	β_4	1.457232	1.438981	0.2638387	2.08
	β_5	2.34	2.34	2.34	2.34

Table 6. Elapsed time (in seconds) of the GWO and DA algorithms used in finding the optimum availability with respect to iterations at various population size

Iteration	Population size							
	400		600		800		1000	
	GWO	DA	GWO	DA	GWO	DA	GWO	DA
30	3.96	9.37	3.72	7.01	4.5	8.52	4.32	7.89
50	4.18	7.75	4.61	7.82	7.98	7.69	4.2	12.61
70	3.81	9.8	3.55	7.1	3.79	7.05	3.58	7.39
90	3.37	7.17	3.92	7.75	3.63	7.2	4.35	7.84

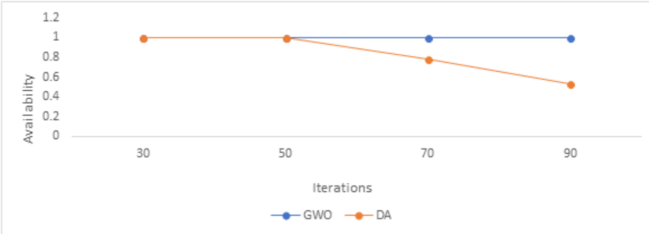

Figure 3. Availability of Smart Irrigation System at various iterations at Pop. Size =400

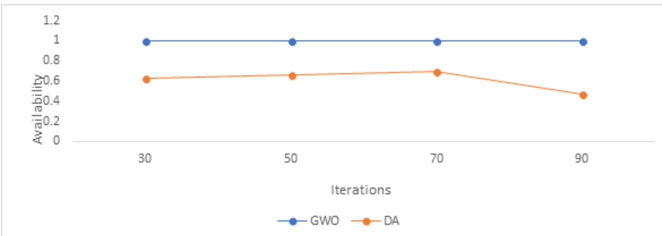

Figure 4. Availability of Smart Irrigation System at various iterations at Pop. Size =600

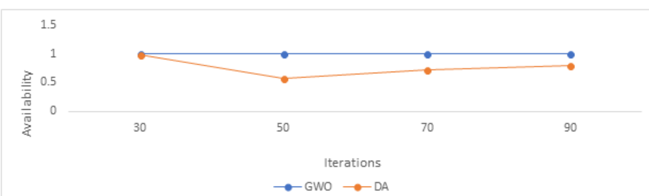

Figure 5. Availability of Smart Irrigation System at various iterations at Pop. Size =800

for which system attains its maximum availability. For GWO, parameters for failure rates and repair rates have its minimum and maximum value simultaneously and system attains its maximum availability at early stage of simulation. For DA the values of parameters are fluctuating rapidly, and sub-systems need adequate maintenance at time.

In Figure 3, graphical representation of the optimum availability of system using GWO and DA with respect to various iterations with population size 400 is shown. It is seen that at iteration 30 and 50 both techniques attain the same and maximum availability after that availability for DA is decreasing with increasing the iteration size and for GWO it remains same at 0.9999954.

In Figure 4, graphical representation of the optimum availability of system using GWO and DA with respect to various iterations with population size 600 is shown. Here availability for GWO remains constant at 0.9999954 for each iteration. Availability for DA slightly increase from 0.6268276 to 0.6919241 for iteration 30 and 70 respectively but iteration 90 availability decreases rapidly to 0.4754869.

Figure 5 shows the graphical representation of the optimum availability of system using GWO and DA with respect to various iterations with population size 800 is shown. Availability for GWO remains constant at 0.9999954 for each iteration.

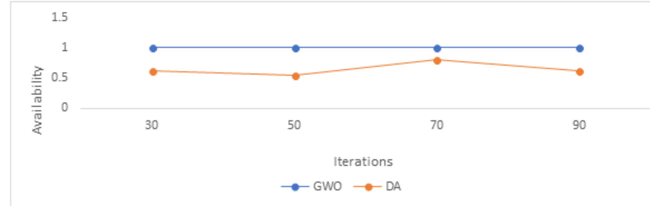

Figure 6. Availability of Smart Irrigation System at various iterations at Pop. Size =1000

Availability for DA decreases rapidly from 0.9899925 to 0.5788153 in-between iteration 30 to 50. Then after it increases to 0.7922205 for iteration 90.

Figure 6 is the representation of the optimum availability of system using GWO and DA with respect to various iterations with population size 1000. System attains its maximum availability 0.9999954 in early stage of population size and iteration by using GWO and then remain constant for higher population size and iterations. For DA availability varies between 0.804096 at iteration 70 to 0.5391205 at iteration 50.

Table 6 show elapsed time taken by optimization techniques which includes time taken by system and optimization technique and provide the total execution time. The variation in time taken to complete the task by using GWO and DA can be easily seen. Time taken by GWO is almost half of the time taken by DA. It is also seen that GWO attains the maximum availability at early stage with respect to DA.

6. Conclusion

In present work, a novel efficient and intelligent irrigation system is developed using the concept of cold standby redundancy. The availability expression for the model is derived and optimized using the Grey-Wolf optimization (GWO) and Dragon Fly (DA) algorithms. The parameters of all failure and repair rates are estimated by both algorithms. The maximum availability derived is 0.9999954 in the search space by both the algorithms. It is observed that Dragon fly algorithm is not given sustain results with the increase of number of iterations. Though the elapse time taken by Grey-Wolf optimization (GWO) is sufficiently less in comparison to Dragon Fly (DA) algorithm. So, it is recommended that the system when operated according to the parameters estimated by grey wolf optimization perform more efficiently. The present work may be further extended to the component level investigation by using some other nature inspired algorithms. The concept of simultaneous failure and redundancy can be involved in further study. The proposed methodology may be opted in other process industries.

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