

Comparison the Capability of Shuffled Frog Leaping Algorithm with Other Metaheuristic Algorithms in Design of Urban Sewage Network

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ABSTRACT

The optimal design and construction of sewage networks have always been considered by researchers and experts due to the very high costs of implementing this infrastructure. Being consisted of various variables and subjected to complex constraints, conventional mathematical optimization procedures are unlikely to be able to solve sewage network optimization problems. Thus, utilizing meta-heuristic optimization algorithms is a must to tackle these problems. The shuffled frog leaping algorithm (SFLA) is one of the new meta-heuristic algorithms which has shown its ability to solve a large number of optimization problems. In this research, the capability of the SFLA in solving the problem of optimal design of sewage networks has been investigated. The diameter of the pipes as discrete decision variables and the depth of pipe placement as continuous decision variables were simultaneously considered in this study as the unknowns. To this end, three sewage networks with 13, 41, and 65 decision variables have been selected as case studies. Various technical, operational, and hydraulic constraints are controlled by defining appropriate penalty functions. The results showed that for case studies 1 and 3, the SFLA decreased the minimum construction costs derived by GA, PSO, and SCE algorithms by 0.43 and 3.2 percent respectively, and for the second case study, with the less number of function evaluations, SFLA has reached the equal objective function compared to other algorithms.

KEYWORDS

Metaheuristic algorithm, Optimization, Cost minimization, Urban Sewage Networks, Shuffled frog leaping algorithm.

1. Introduction

Sustainability is now an inseparable part of the goals in urban planning and management and water resources infrastructures play a crucial role in this regard. One of the main components of these infrastructures is the sanitary sewer network. These networks are costly to construct and maintain. Thus, the optimum design of these networks is essential to cut expenses. These costs are mainly due to piping and excavation and thus the optimization problem is developed around these variables. Literature consists of various methods and modeling of optimum design of sanitary sewer networks and these methods range from classic optimization methods such as dynamic programming and nonlinear programming to novel metaheuristic optimization algorithms. These optimization problems have proven to be hard to solve since it has highly nonlinear equations inherited both in the cost function and in the constraints. The complexity escalates quickly when the network grows in size. The other matter that hinders the solution of these problems is that the decision space consists of both discrete and continuous variables. Novel metaheuristic algorithms that have proven useful in recent years usually operate in continuous decision space and can experience difficulties in converging to the global optimum. To alleviate this problem, in this research, the Shuffled Frog Leaping Algorithm (SFLA) is utilized to solve the optimum design of sanitary sewer networks. This algorithm has proven useful in various fields and since its capabilities were yet to be assessed in handling sanitary sewer networks design problems, it was chosen to solve three different optimization problems (presented in [1]-[3]) and to conduct a comparison the results were compared to well-known optimization algorithms such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and Shuffled Complex Evolution (SCE).

2. Methodology

Optimization problem

The main cost function is defined as Equation (1):

$$\text{Minimize: } f = \sum_{i=1}^N L_i K_p(d_i, \bar{E}_i) + \sum_{j=1}^M K_j(h_j) \quad (1)$$

Where f = the cost function; N = number of the pipes; M = number of the manholes L_i = the length of the pipe i , K_p = unit cost of piping (including provision and installation) as a function of diameter, d_i , and \bar{E}_i the average cover depth, of pipe i and K_m = unit cost of manhole construction as a function of h_j manhole depth of the joint j .

The piping and excavation costs are computed using equations (2) till (5)

$$K_{p_{1,2}} = \begin{cases} 1098d_i + 0.8\bar{E}_i - 5.98 \text{ cdn}_1 \\ 5.84d_i + 1.66\bar{E}_i + 0.504d_i\bar{E}_i - 9.64 \text{ cdn}_2 \\ 30d_i + 4.9\bar{E}_i - 105.9 \text{ cdn}_3 \end{cases} \quad (2)$$

$$\text{cdn}_1: d_i \leq 3 \quad \& \quad \bar{E}_i \leq 10$$

$$\text{cdn}_2: d_i \leq 3 \quad \& \quad 10 \leq \bar{E}_i$$

$$\text{cdn}_3: 3 < d_i$$

$$K_{j_{1,2}} = 250 + h_m^2 \quad (3)$$

$$K_{p_3} = 10.93 \exp(3.43d_i) + 0.012\bar{E}_i^{1.53} + 0.437\bar{E}_i^{1.47} d_i \quad (4)$$

$$K_{j_3} = 41.46h_m \quad (5)$$

In equation (2) till equation (5) Unit cost of piping for different case studies is denoted with a subscript of 1,2, and 3.

This optimization problem consists of various kinds of constraints. These constraints are presented in equations (6) till (12)

$$\sum_{j=1}^{N_i} \pm Q_j = -q_i \quad \forall i = 1, 2, \dots, K \quad (6)$$

$$V_{\min} \leq V_i \leq V_{\max} \quad \forall l = 1, 2, \dots, N \quad (7)$$

$$S_i \geq S_{\min} \quad \forall l = 1, 2, \dots, N \quad (8)$$

$$E_{\min} \leq \bar{E}_i \leq E_{\max} \quad \forall l = 1, 2, \dots, N \quad (9)$$

$$\beta_{\min} \leq \beta_i \leq \beta_{\max} \quad \forall l = 1, 2, \dots, N \quad (10)$$

$$\beta_i = \left(\frac{y}{d} \right)_i \quad \forall l = 1, 2, \dots, N \quad (11)$$

$$d_i \in \bar{D} \quad \forall l = 1, 2, \dots, N \quad (12)$$

Q_i = the discharge in node i where the inflow and outflow discharges are considered positive and negative respectively; N_i = number of pipes joined in node i ; M = number of nodes of the network; V_i = velocity in pipe i ; V_{\min} and V_{\max} = the minimum and maximum permitted velocities, respectively; E_{\min} and E_{\max} = the minimum and maximum required cover depths, respectively; β_i = relative flow depth in pipe i ; β_{\min} and β_{\max} = the minimum and maximum required relative flow depths respectively; y = flow depth; S_i = slope of pipe i ; S_{\min} = the minimum allowed slope and \bar{D} = list of commercially available pipes.

As the flow in the pipes is a uniform steady flow type, Manning's Equation governs the flow as equation (13)

$$Q_l = \frac{1}{n} \alpha_l r_l^{\frac{2}{3}} s_l^{\frac{1}{2}} \quad \forall l = 1, 2, \dots, N \quad (13)$$

Where Q_l = the design discharge of pipe l ; n = Manning's coefficient, α_l = cross-section of pipe l ; r_l = hydraulic radius of pipe l ; s_l = slope of pipe l .

SFLA

Eusuff et al. proposed the shuffled frog leaping algorithm (SFLA) inspired by the social behavior of the frogs' search for food [4]. This algorithm is an improved version of the Shuffled Complex Evolution (SCE) algorithm. The SFLA inherits two famous GA and PSO algorithms such that each frog is a representation of each chromosome in the GA. These frogs are divided into smaller complexes to create smaller swarms. The optimization occurs in two levels. At the first level, the frogs are influenced by their group members. At the second level, the frogs are inspired by other groups to find the best location for their food. The frogs update their position until at least one of the convergence criteria is satisfied.

3. Results and Discussion

In this study, three different sanitary sewer networks are modeled and designed using the SFLA algorithm. These problems are of different layout and sizes and thus provide a good example to assess the SFLA's performance regarding the optimum design of these networks. Like other algorithms (GA, PSO, and SCE), the SFLA is run 20 times for each problem. Figure 1 presents the convergence curves of the SFLA for the best, worst and average results obtained during these 20 runs. This figure shows that in problems 1 and 2 with the relatively smaller size the best, worst and average result is close to each other and the algorithm shows acceptable reliability. Although there is a difference in worst and best answers in the third problem, according to Table 1, the SFLA has shown a much superior performance both concerning the best result and the lower standard deviation compared to the other three algorithms.

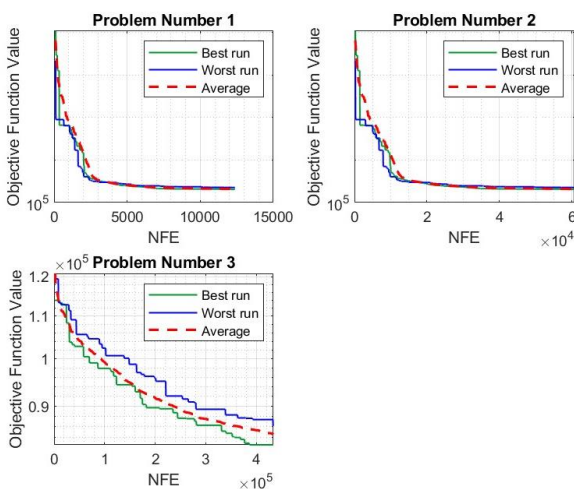


Figure 1 Convergence curves of the SFLA for 3 case studies

Table 1 Optimization results of 3 problems using GA, PSO, SCE, and SFLA algorithms

Problem No	Algorithm	Minimum	Maximum	Average	Standard Deviation	Average NFE
1	SCE	225480	318839	254460	27415.8	64000
	SFLA	203249	325532	208321	5466.48	37774
	GA	209116	272169	228381	17717.7	57063
	PSO	204138	240889	208862	8018.6	60000
2	SCE	140454	185242	157931	12138.1	64000
	SFLA	129588	164989	150636	11402.3	37774
	GA	129588	153716	141388	9606.8	57063
	PSO	129588	168341	142880	9346.3	60000
3	SCE	97751	146010	115942	1496	68088
	SFLA	79079	84663	81054	1011.5	60680
	GA	81692	86685	83532	1568.1	123137
	PSO	82606	86133	84538	1456.3	132132

4. References

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