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Particle Swarm Optimization Modeling for Solid Waste Collection Problem with Constraints

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Abstract— **Solid waste management is a prime concern in any country. Among all the steps of its management, collecting it efficiently is the biggest challenge. Waste collection can be treated as a Vehicle routing problem (VRP) as it involves waste collection vehicles to collect waste from different waste bins. This paper deals with the solid waste collection efficiency improvement by solving optimized route using Travelling Salesman Problem (TSP) and Particle Swarm Optimization (PSO) algorithm. Vehicle routing problem (VRP) for solid waste collection using Particle Swarm Optimization (PSO) is a new concept. Route optimization is modeled considering different scenarios and constraints such as time window, vehicles maximum capacity, percentage of waste level, etc. to find the most efficient route to collect the solid waste. Waste level of the bin can be found using smart bin technology of ZigBee and GSM/GPRS. This study shows overall improved, optimized route. It shows a very impressive result while only bins filled with threshold amount of waste are considered. Algorithm application for finding the optimized route for improving collection efficiencies are the main objective of this study.**

Keywords— ***particle swarm optimization; travelling salesman problem; sweep algorithm; solid waste collection optimization; smart bin***

I. INTRODUCTION

Solid waste management (SWM) is one of the important challenges that cities all around the world are facing now. There have been a huge number of studies for finding the efficient solid waste management techniques. Solid waste collection is a part of solid waste management and it takes up around 60%-80% of the total budget for SWM. Therefore, it is very crucial to find the most efficient waste collection route to minimize the expense.

Vehicle routing problem (VRP) is a common problem of optimization. VRP can be solved by a wide range of approaches. It generalizes the well-known Travelling Salesman Problem (TSP). It is an NP-hard problem in combinatorial optimization. There has been a wide range of different algorithms application to solve this problem.

PSO has been widely used to optimize several continuous nonlinear functions as well as combinatorial problems. Vehicle routing problem (VRP) has been solved by set based PSO in [1], whereas a hybrid of PSO and noising meta-heuristic has been applied in [2] for computing the shortest path. But to best knowledge of the authors, there is no such report published on the use of PSO for the solid waste collection problem. Route optimization for collecting solid waste has been done applying different heuristic, meta-heuristics e.g. Genetic Algorithm (GA), Ant Colony optimization (ACO) etc. The most common application to find waste collection route is ArcGIS. So application of PSO for finding optimized route for waste collection is a new concept. PSO will be applied to find the most effective route for collecting waste. But solid waste collection can be made more efficient by considering the waste bin level[3]-[4]. Again, in modern time, different technologies are trying to be used to make the solid waste management more efficient. Use of different information and communication technologies and their applications are briefly discussed in [5].

In this paper, a procedure of applying Particle Swarm Optimization (PSO) will be proposed to solve TSP by visiting all the waste bins for waste collection. Then model will be discussed if waste is collected based on the waste bin level only. In both the cases a set of constraints will be considered to make it more realistic.

II. PARTICLE SWARM OPTIMIZATION

The word swarm intelligence came from artificial intelligence, where we analyze the behavior of ants, insects or birds etc. to use this behavior to solve different optimization problem. Particle Swarm Optimization (PSO) is an evolutionary optimization algorithm is a population-based optimization method simulating social behavior of flocks of birds in searching for foods. In 1995, Kennedy and Eberhart originally proposed the method to optimize solutions for difficult problems in case of both continuous and discrete optimization [6]. Now-a-days it is one of the popular algorithms that is applied in the area of combinatorial optimization for its simplicity in coding and consistency in performance.

A. Basic steps of PSO algorithm

In PSO a particle is treated as a point in an M-dimension space, where its status is characterized by its position and velocity [7]. PSO algorithm deals with a population of particles (solutions) and their velocities that drag the particles towards the best solution. At the beginning, it starts with a number of randomly initialized positions of the particles and velocities in the search space. The optimized position (solution) is found by updating the particle velocities, hence positions, in each iteration/generation in a specific manner as follows. Fitness is the measurement of how optimized the solution is. In every

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iteration, the fitness of each particle is determined by some fitness measure and the velocity of each particle is updated by keeping track of the two "best" positions, that is, the first one is the best position (XBEST) of a particle in which it has achieved the best fitness (FBEST) by traveling so far, called PBEST, and the other "best" value is the best position that any neighbor of a particle has traversed so far, called neighborhood best (nBest). When a particle takes the whole population as its neighborhood, the neighborhood best becomes the global best and is accordingly called GBEST [2]. Till the maximum number of iteration is met, a particles velocity and position is updated to reach the best solution. The formulae of velocity and position update are given below:

$$V_{id}=V_{id}+c_1r_1\,(P_{BEST}-X_{id})+c_2r_2\,(G_{BEST}-X_{id});$$

$$i=1,2\ldots,n;\ d=1,2\ldots,D \tag{1}$$

$$X_{id}=X_{id}+V_{id} \tag{2}$$

where c_1 and c_2 are positive constants, called as acceleration coefficients, n is the total number of particles in the swarm, D is the dimension of problem search space, that is, number of parameters of the function being optimized, $r1$ and $r2$ are independent random numbers in the range [0, 1].

Velocity of each particle is updated based on its previous velocity and present position as well as global best position. Sometimes when a particle is far away from the optimal solution, it attains a large velocity leaving boundary of the search space. To avoid that situation, a fixed limit of ±Vmax is applied so that it does not exceed the boundary. After updating velocity, new position of the particle is updated by adding the previous position with the updated velocity. The Pseudo code of the simple particle swarm optimization algorithm is given as follows

```
FBEST ← ∞ ,  XBEST ←NIL
initialize Xid randomly
initialize Vid randomly
evaluate fitness F(Xid)
PBEST ← Xid
GBEST ←Xj    // j is the index of the best neighbor
particle
iteration count ←0;
while (iteration count < max_iteration)
for each particle i,
if F(GBEST) < F(Xj),  ∀j ε {neighbors of i}
F(GBEST) ← F(Xj)
GBEST ← Xj
if F(Xid) < F(PBEST)
F(PBEST) ← F(Xid)
PBEST ← Xid
update Vid according to (1)
update Xid according to (2)
evaluate F(Xid)
iteration count ← iteration count + 1;
end while
return XBEST
```

III. Travelling Salesman Problem

Travelling Salesman Problem is a well-known NP-hard combinatorial optimization problem. In a directed complete graph G= (V, E), where V= (v_1, $v_2 \ldots v_n$) is the set of vertexes/nodes and E= {(v_i, v_j): v_i, v_j € V, $v_i \neq v_j$} is the edge set. Corresponding to each edge, there is a nonnegative number C_{ij} representing the cost (distance, transit times etc.) of the edge from node v_i to node v_j. The objective of TSP is to find a route with minimum cost starting from the initial node and coming back to the same node after visiting all the vertexes exactly once. TSP is an intensively studied benchmark in combinatorial optimization.

IV. Proposed PSO for TSP Model

Proposed method finds out the best path for solid waste collection using PSO algorithm applying the concept of TSP. the goal of the routing problem is to find the effective way to collect waste with vehicles travelling least distance. The mathematical expression of optimization can be shown as below:

$$Z_1=\min \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=1}^{v} C_{ij} * x_{ij}{}^{k}. \tag{3}$$

Where, C_{ij} is the cost (distance) of the edge between bins i and j. v is the number of vehicles. Therefore (3) is the objective function of optimized distance.

In this section proposed procedure will be described. There are a number of constraints that we will consider. Constraints are:

- Vehicle capacity
- Each bin will be visited once only
- All the routes will start and end on depot
- Time window
- Drivers lunch break
- Percentage of waste level in bin

A. Sweep algorithm

The optimization model will be developed by applying sweep algorithm with PSO. Sweep algorithm will be applied to find the polar angle of each bin from the depot. The route to collect waste will be constructed by adding the bins with ascending polar angle till the last bin. This route will be considered as the initial solution. Therefore in this model the initial particle (solution) is found by sweep algorithm.

B. Velocity update

Initial velocity of the route will be found randomly. Then using this initial velocity and particle, velocity is updated. In PSO velocity update is done according to (1). A minimum and maximum range of velocity is fixed so that updated velocity does not exceed the limit of the search space. If the velocity is less than the minimum or more than the maximum value, then the velocity is taken as the minimum and maximum value, respectively. The Pseudo code for the velocity update in the particle swarm optimization algorithm is given as follows.

iteration count $\leftarrow 0$
initialize V_{id} *randomly*
V_{id} *update according to (1)*
if $V_{id} < V_{min}$
$V_{id} \leftarrow V_{min}$
else if $V_{id} > V_{max}$
$V_{id} \leftarrow V_{max}$
else $V_{id} \leftarrow V_{id}$

C. Particle update

Particle update is done according to (2). It generally occurs on real number. But for waste collection path optimization it will be better to use natural number system. So inspired from [8], in the proposed model, updated particle will be represented using Shortest positioning index. In shortest position indexing the values are sorted from minimum value to maximum value and position is given accordingly. In this manner the candidate solutions will be randomly generated. Among the candidate solutions those satisfying all the constraints will be taken as feasible solution.

D. Fitness

PSO is an iterative algorithm. In the proposed method the best path is considered to be the path with least fitness. Fitness is the distance of the total route starting from and ending on the depot after visiting all the bins for collecting waste. It is found according to (4).

Fitness value, $f = C(depot, i) + C(i, j) + C(j, depot)$ (4)

Using fitness value best particles are found. Those will be used to update velocity in next iteration.

E. Route construction

1) Considering all the bins

Without considering constraints, the optimized updated particle could be considered as the desired route for collection. But to make the model more realistic, routes has been constructed by considering constraints. After updating particles each time, it is verified whether the collection vehicle will go to the next bin or not. If constraints does not exceed, then it will proceed to the next bin. Otherwise it will come to depot. Following is a decision variable explaining this situation.

Where,

$$x_{ij}^{k} = \begin{cases} 1, if\ vehicle\ k\ travels\ directly\ from\ i\ to\ j \\ 0, otherwise \end{cases}$$

2) Considering bin level

Waste level of the bin is taken in consideration by using smart bin. Smart bin transmits the information about the waste level of the bin in the server. The information will be updated after a fixed duration of time. Smart bin system uses ZigBee and GSM/GPRS communication technologies and a set of carefully chosen sensors to monitor the status of solid waste bins in real time[9].

V. Results and Discussion

Result shows a good optimized route for collecting waste by applying PSO. The experiment has been done for 25 waste bins. It shows that the distance obtained by applying PSO is reasonable. Here only one depot has been considered which is located at the middle of the bins. Bins acceding 70% of its capacity are taken as a cluster for collecting. These bins are shown in *Fig. 1*.

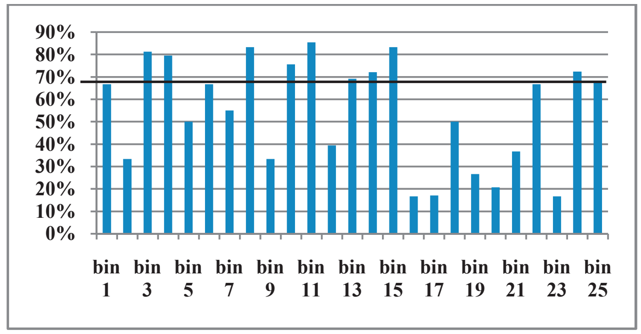

Fig. 1. Bins acceding 70% of its capacity

Route optimization has been done using MATLAB. After the optimization process, it has been seen routes considered by travelling all the bins give good reasonable routes. But considering only 70% filling level of bins, number of routes is decreased. Most of the time, even though number of bins are reduced much compared to the former case, number of routes is not decreased that much. This is mainly because the vehicle reaches its capasity very soon as the bins with highest amount are collected only. Optimized routes of waste collection in both the cases are shown in *Fig. 2.*

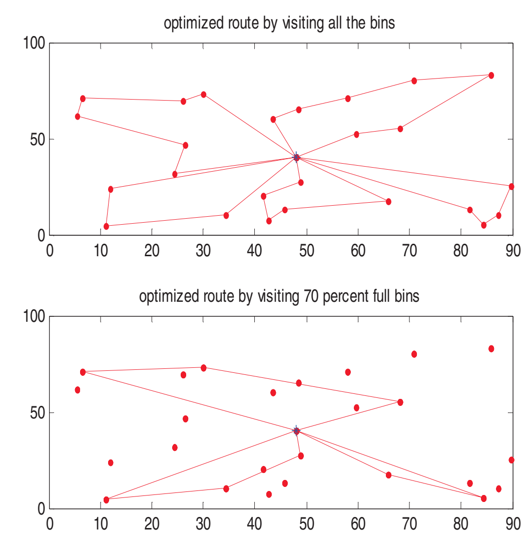

Fig. 2. Optimized route for waste collection vehicles in both the cases

The application shows after considering all the constraints and if all the bins are visited, 3 waste collection vehicles needed to be assigned. The total distance travelled by these vehicles is 314.88 km., whereas, by applying smart bin technique, we can get informed which bins are needed to be emptied or not. As we have taken 70% as our threshold value, there are only 8 bins those are needed to be emptied. For this we need highest 3 vehicles. The total distance in this case travelled by vehicles is 125.35 km. Therefore, by applying this, almost 60% of the distance can be saved, that eventually will save all other costings. Again, due to the bin reduction and reduction in time, even a single vehicle can travel to all paths for waste collection. In this paper, costing for fuel has been considered only. All the optimized results are given in the tabulated form in table 1.

TABLE I. OPTIMIZATION RESULTS

Parameters	**Cost/Distance**	
	All bins	***Bins ≥ 70% full***
Bins collected	25	8
Bins uncollected	0	17
No. of routes	5	3
No. of vehicles needed	3	1
Distance for vehicle 1(km)	118.46	125.35
Distance for vehicle 2(km)	102.72	0
Distance for vehicle 3(km)	93.70	0
Total distance (km)	314.88	125.35
Distance saved (%)	0.00	60
Cost of fuel/km (RM/km)	0.60	
Cost for fuel (RM)	188.92	75.21

VI. CONCLUSION

In this paper, travelling salesman combinatorial optimization problem is solved using particle swarm optimization. Several constraints are considered to develop the PSO algorithm for optimizing solid waste bin route. It is found that the PSO optimized model provides good optimized routes for waste collection in both the cases- collecting waste from all the bins and bins filled more than a threshold percentage. It has been seen that by using smart bin technology for identifying 70% full bins for collection, gives tremendous improvement in distance and cost. In terms of distance, only 40% of the total distance of the former route needs to be travelled by saving cost RM. 113.71in terms of fuel expense only. PSO already reduces the number of vehicles also. Routing according to percentage lessens it even more. Thus, the application of PSO algorithm optimized the solid waste route based on bin level efficiently. Therefore, implementation of the proposed system is quite efficient in solid waste collection and optimization. It concludes that the solid waste collection optimization model could be implemented using the developed optimization for real time applications.

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