Geospatial Network Analysis Using Particle Swarm Optimization

Varun Singh, Mainak Bandyopadhyay, Maharana Pratap Singh

***Abstract*—**The shortest path (SP) problem concerns with finding the shortest path from a specific origin to a specified destination in a given network while minimizing the total cost associated with the path. This problem has widespread applications. Important applications of the SP problem include vehicle routing in transportation systems particularly in the field of in-vehicle Route Guidance System (RGS) and traffic assignment problem (in transportation planning). Well known applications of evolutionary methods like Genetic Algorithms (GA), Ant Colony Optimization, Particle Swarm Optimization (PSO) have come up to solve complex optimization problems to overcome the shortcomings of existing shortest path analysis methods. It has been reported by various researchers that PSO performs better than other evolutionary optimization algorithms in terms of success rate and solution quality. Further Geographic Information Systems (GIS) have emerged as key information systems for geospatial data analysis and visualization. This research paper is focused towards the application of PSO for solving the shortest path problem between multiple points of interest (POI) based on spatial data of Allahabad City and traffic speed data collected using GPS. Geovisualization of results of analysis is carried out in GIS.

***Keywords*—**GIS, Outliers, PSO, Traffic Data.

I. Introduction

SHORTEST-PATH analysis is one of the most fundamental problems. The huge interest in the problem is mainly due to the wide range of its applications like in communication networks, route guidance, scheduling etc. Furthermore, the shortest-path problem also has numerous variations such as the minimum weight problem, the quickest path problem. Several heuristic algorithms have been developed to solve network analysis problems. The shortest path problem has been investigated extensively. Researchers have studied a large number of algorithms for network analysis along with their classification [1]. The well-known algorithms for solving SP problem are the Bellman's dynamic programming algorithm for directed networks, the Dijkstra labeling algorithm and Bellman–Ford successive approximation algorithm for networks with non-negative costs. These algorithms are widely applied to generate the shortest path between a pair of nodes. Evolutionary algorithms like GA, Ant Colony Optimization and Particle Swarm Optimization (PSO) have emerged as effective method to solve shortest path problem between multiple points of interests. This paper is focused towards the development and implementation of integrated solution for solving shortest path problem between multiple point of interests (POIs) on real word road network based on integration of Dijkstra Algorithm and Particle Swarm Optimization (PSO). Solution is validated through problem solution obtained through solver module of network analyst extension of ArcGIS Software. It is apparent that application of PSO is helpful the solving the shortest path problem efficiently for dense network and large number of nodes.

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II. Literature Review

Extensive researches in the area of shortest path algorithm have been carried out since there is always a requirement for more efficient optimization algorithms for solving shortest path problem. Considering evolutionary algorithms for path finding optimization problems in networks, use of Genetic Algorithms (GA) [2]-[5], Tabu Search (TS) [6], [7], Ant Colony Optimization (ACO) [8], [9], Particle Swarm Optimization (PSO) [10] have been reported. Further solution of generalized variant of shortest path algorithm namely Travelling Salesman Problem has been reported by researchers using GA [11]-[13], Ant Colony Optimization [14]-[16], PSO [17], [18].

Further comparative studies of efficacy of PSO for solving shortest path problem have been carried out. Comparative performances analysis of GA and PSO has also been carried out by different researchers [19]-[23]. All these studies established effectiveness of PSO compared over GA.

III. Particle Swarm Optimization

Particle swarm optimization technique in computing corresponds to the social behaviour of birds, animal, insects, etc., for performing their day to day activities. PSO algorithms were first introduced by Kennedy and Eberhart [24] for optimizing continuous nonlinear functions. The iterative process of PSO starts with a population of particles whose position and velocity is randomly assigned in the search space. In every iteration, with the goal of finding optimal position of particle according to some defined fitness function, the velocity of the particle is updated by keeping track of two "best" positions i.e. the best position travelled by the particle so far with a value pBest and the best position travelled by its neighbour so far nBest. When a particle takes the whole population as its neighbourhood, the nBest becomes the global best and is accordingly called gBest.

IV. Solution Framework

Solution of shortest path analysis is a incremental solution based on combination of PSO and Dijkstra algorithm. Fig. 1 shows the flowchart for implementation of solution. Dijkstra algorithm is used to calculate node to node cost along the real world road network. For PSO implementation, particles are encoded sequence of nodes that needs to be visited.

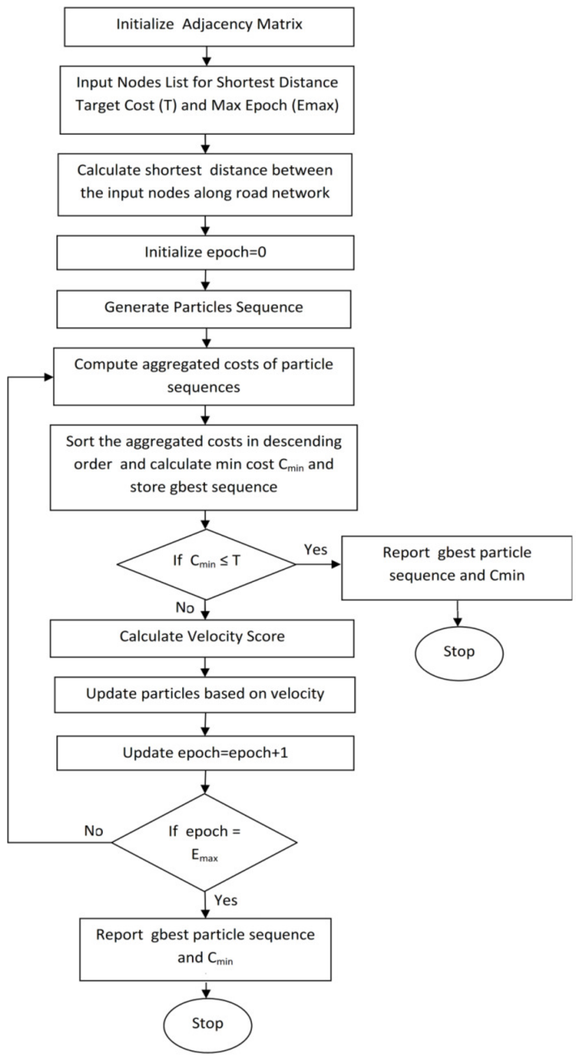

Fig. 1 Flowchart for solution Framework

Table I shows the particle encoding for five numbers of nodes. The velocity score of particle is calculated using the global worst, defining velocity as the measure of how bad each particle is performing in terms of total cost. Generalized velocity score of the particle is calculated as:

$$Vs(i) = V_{max} \times \frac{p_{besti}}{p_{bestw}} \quad (1)$$

where $pbest_i$ = total cost of travel for a sequence of nodes of particle i, $pbest_w$ is total cost of travel for a sequence of nodes of worst performing particle. V_{max} is the maximum velocity score. Modification of particles is carried out by swapping digits within each particles own data set. Further particles are moved towards the global best by copying pieces of the next best particle's data. Higher the velocity score larger the number of swapping operations is required for a particle. Swapping and copying operations are carried out to all particles except the global best.

Optimization process is continued till the target distance or number of iteration become equal to maximum allowed iteration (epoch).

TABLE I
Particle Encoding

Particle 1	1	2	3	4	5
Particle 2	1	3	4	5	2

V. Spatial Database

Spatial database is developed for sample road network of Allahabad City as shown in Fig. 3 with red colour lines. Real time speed on each link is calculated using low cost GPS logger HOLUX M1000C and GIS functionality. An important aspect of obtaining GPS trajectory is to set the sampling interval between consecutive GPS observations. Shorter sampling interval is recommended for accuracy in segment speed calculation [25]. In the present work the GPS data is captured with sampling interval of 1second. For link speed calculation, GPS observations are matched to correct links in the Road Network. GIS proximity analysis function Near is used to match GPS observations to Road Links. Subsequently link speed is used to calculate travel time in minutes on each link.

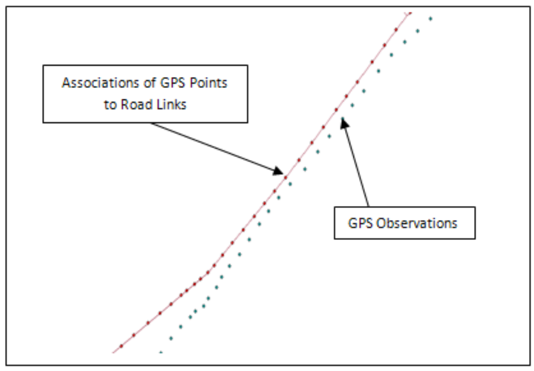

Fig. 2 GPS Trajectory and Associated GPS Points on Road Links

Generally GPS observations are within 30 meter of actual position 95% of time [26]. Considering this, the search radius for NEAR proximity analysis tool is set to 30 meter. The Link speed is calculated by taking average of speed values of Individual GPS observations as given in (2):

$$AvgSpeed_i = \frac{1}{n}\sum_{j=1}^{n} GPS_j Speed \quad (2)$$

where GPS point j belongs to link i. Average travel time on

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the link can be calculated by dividing length of the link with average speed. Link length is calculated using calculate geometry tool in ArcGIS.

VI. Implementation of Algorithm

A Java program has been developed to implement the algorithm. Algorithm has been tested for a sample road network data and same data is used to compare the results of the algorithm with the results of Network Analyst extension of ArcGIS software. Algorithm is tested for origin point taken at MNNIT Campus (Node No. 3) and Fire Station (Node No. 15) in Allahabad City. Result obtained by algorithm is matching with result obtained by Network Analyst. For maximum number of iterations of 1000, maximum velocity score of 4 and particle count of 2, the total cost of travel as obtained by Algorithm is 20.13 minutes which is obtained from program. This result is matching with travel cost obtained from Network Analyst Extension as shown in Fig. 4.

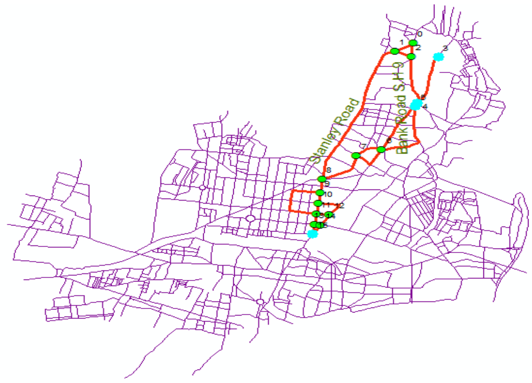

Fig. 3 Sample Road Network

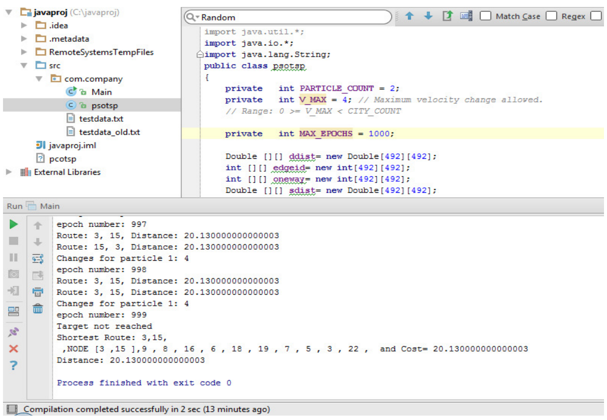

Fig. 4 Result obtained from JAVA Programme

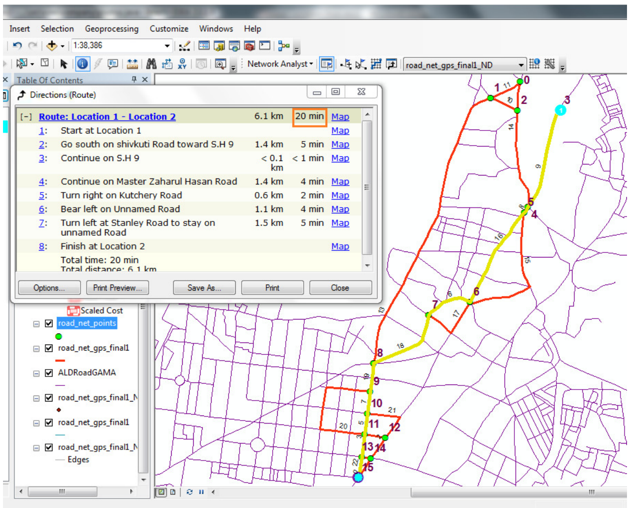

Fig. 5 Result obtained for Network Analyst Extension

VII. Conclusions

This paper presented the research work to develop PSO algorithms for the shortest path analysis. Paper presented an methodology to design effective PSO application for the shortest path analysis that can be extended to other discrete optimization problems. Further methodology to use the real time GPS data for network analysis is presented in the paper Computational verification with given sample was presented. The results of analysis show that the proposed method produces satisfactory solution. Further algorithm can be integrated in GIS Environment using ArcObjects based customization.

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