MINOR-1 PROJECT

SYNOPSIS

Swarm Intelligent Approach for Vehicle Routing Problem

Submitted by:

NAME	ROLL NO	BATCH
SAI ANKITA KASIBATLA	R2142210910	B4
GURLEEN KAUR	R2142211092	B4
AARUSHI KHURANA	R2142210969	B4
ARYAN SHRIVASTAV	R2142210181	B1

School Of Computer Science

UNIVERSITY OF PETROLEUM & ENERGY STUDIES,

DEHRADUN- 248007. Uttarakhand

Dr. G. Hanumat Sastry

Project Guide **Cluster Head**

School of Computer Science
University of Petroleum & Energy Studies, Dehradun

SYNOPSIS REPORT

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Abstract:

The Vehicle Routing Problem (VRP) is a complex logistical task involving optimal route planning for a fleet of vehicles to deliver goods to customers while minimizing costs and following constraints. Due to its complexity, the VRP belongs to the NP-hard problems category, which means finding the best solution becomes tougher as the problem grows, leading to significant computational and time requirements. As a result, many researchers are working on this problem using different approaches to create inventive solutions. These vary from precise algorithms, great for small cases but struggling with larger ones, to heuristic and metaheuristic methods that offer nearly optimal solutions promptly.

Among different approaches, Swarm Intelligence is one of the promising approaches to solving complex problems. This project focuses on developing a hybrid swarm intelligence algorithm to solve vehicle routing problems. This hybrid strategy aims to leverage swarm intelligence's potential to tackle the challenges posed by VRP complexity, delivering efficient solutions for real-world logistics scenarios.

Introduction:

To deliver goods or provide services in specific places while minimising costs like travel duration, distance, or vehicle utilization, the Vehicle Routing issue (VRP), a crucial optimization issue in logistics and transportation, must be solved [1]. Scientists and researchers from the past few years have shown significant interest in this topic due to its characteristics like cost reduction and sustainability prospects [2,3].

Swarm intelligence (SI) is a hypothesis that is based on how social animals like ants, bees, and birds work together to find solutions to complex problems [4,5]. A variety of optimization issues have been successfully solved by the well-known algorithms Particle Swarm Optimisation (PSO) and Grey Wolf Optimisation (GWO) [6,7]. Due to its capacity to effectively explore the solution space, adapt to changing circumstances, and choose ideal or nearner to ideal solutions, PSO is especially alluring for VRP [1, Para. 25], [2].[8]

Grey Wolf Optimization (GWO) is another innovative way to solve VRP [9]. GWO exploits the hierarchal structure of wolf packs to optimize the routes of vehicles, replicating the hunting process in the wilderness to rapidly identify optimum or near-optimal solutions. By synergizing the qualities of PSO and GWO, the authors hope to propose an innovative and resilient solution strategy for complicated routing issues that transcend the individual capabilities of each algorithm [10].

Particle Swarm Optimisation (PSO) is a nature-inspired optimisation approach developed in 1995[11] by Dr. James Kennedy and Dr. Russell Eberhart, who were inspired by the social behavior of birds swarming and fish schooling. Its main ideas are simple yet highly effective: particles, velocity and location, fitness evaluation, local and global bests, and update rules. PSO has found wide-ranging applications in various areas, including function optimization, neural network training, feature selection, image and signal processing, engineering design, financial modeling, and vehicle routing and scheduling [12].

Seyedali Mirjalili, Shima Seyedali, and Andrew Lewis created the Grey Wolf Optimisation (GWO) algorithm in 2014 [13], drawing inspiration from nature and the social structure and hunting habits of grey wolves in the wild. GWO is based on the idea of duplicating grey wolf hunting and social behaviour by depicting the wolf pack as a hierarchy with alpha, beta, and delta wolves. Wolves explore the search area for potential prey, with the alpha wolf leading the pack, followed by beta and delta wolves. Each wolf's location is updated using a formula that takes into account their current position, alpha, beta, and delta locations, as well as a random exploration component.

Numerous optimisation issues, including as function optimisation, feature selection, image segmentation, load balancing, neural network training, and vehicle routing and scheduling, have been solved with GWO [14,15]. GWO may be used to enhance routes in the context of vehicle routing issues, guaranteeing effective exploration and exploitation of the solution space by modelling the hierarchical and cooperative behaviour of wolves. Both PSO and GWO offer unique benefits and may be customised for certain optimisation issues. Based on the details of the issue, the accessibility of computer resources, and prior exposure to several approaches, researchers and practitioners often choose one of them [16].

A well-known combinatorial optimisation issue that has garnered a lot of interest from academics and business experts over the years is the "Vehicle Routing Problem" (VRP). As a consequence of developments in optimisation methods, processing power, and useful applications, the VRP has grown significantly over time.. Early formulations (1950s–1960s), heuristic approaches (1970s–1980s), exact algorithms (1990s–2000s), hybrid algorithms (2000s–present), metaheuristics (2000s–present), and real-world applications (2000s–present) are all included in the history of VRP solutions [17].

Advanced computing technologies have allowed for the creation of more advanced algorithms and the solution of bigger VRP instances, considering dynamic changes in client needs and traffic situations. Sustainability considerations (2010s-present) have led to the creation of eco-friendly routing systems and multi-objective VRP variations and solution strategies to handle complex trade-offs [18].

To stimulate fresh approaches on solving the VRP, consider data-driven approaches, hybrid algorithms, sustainability focus, cooperative and cooperative approaches, multi-objective and uncertainty management, and quantum computing. The progress of VRP solutions reflects the continuous problems and possibilities in optimization, and future advances will likely be determined by breakthroughs in technology, computational methodologies, and the changing environment of logistics and transportation [19], [2].

Problem Statement:

The vehicle routing problem shows how things are delivered from one/more depots that have a given set of vehicles that can move on a given road network to a set of customers.
Mathematically, it can be defined using graph theory, where a directed graph represents the locations (nodes) and the paths (edges) between them.

Let **G = (V, E)**

Where, **V = {0,1,2,3,. . . .,n }**, in which **0** is the depot(starting and ending point of each vehicle), and **1,2,3,. . . ., n** are the customer locations.

Let E be the set of edges **{ (i, j) : i, j V , i j }**, each associated with a weight C i,j is the cost of travelling from vertex i to vertex j.
Constraints:
Capacity Constraint: Each vehicle has a limited carrying capacity, and the total demand of the customers assigned to a vehicle must not exceed this capacity.
Time Constraint: Each customer has a specified time window during which it can be serviced. Vehicles must follow the time window to ensure deliver goods.
Starting and Ending Point Constraint: The routes for each vehicle should start and terminate at a common depot or initial point.
This provides a clear and concise roadmap for the research problem, and helps to ensure that this project is well-designed and addresses a significant and relevant issues.

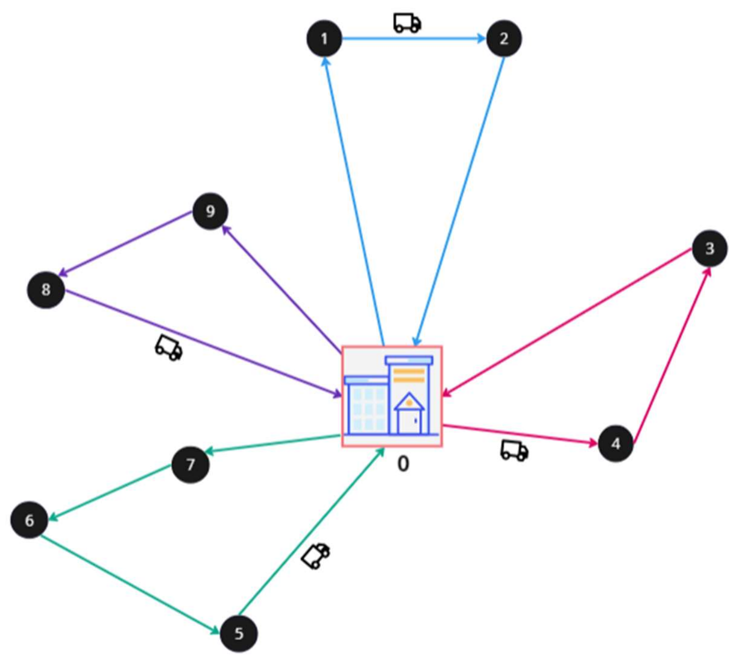


Figure 1:A high-level graphical representation of the Vehicle Routing Problem

Literature Review:

Reference	Findings	Applications
[3]The Vehicle Routing Problem: State of the Art Classification and Review	States how 'Vehicle Routing Problems' have evolved over time and also about the advancements of solutions and applications over the decades. It includes the general notations that are used for popular VRP variants and the classification of the academic literature on the VRP.	The results show that there is a wide variety of VRP problems, therefore real-life characteristics are essential to include so that the model becomes more realistic and the proposed solutions are more applicable.

[4]Particle Swarm Optimization	This paper introduces the relationship between Particle Swarm Optimization and artificial life. The main purpose of this paper is to optimize the continuous nonlinear functions. It reviews its stages from being a social simulation to optimization. It also describes the ease of implementing it which requires simple code and a few operators along with its inexpensiveness.	The main objective of this paper is to optimize the nonlinear continuous functions of real-world problems. This paper shows how PSO can be used to enhance wind speed forecast keeping in mind factors such as wind speed, wind direction, relative humidity, precipitation and air pressure.
[5]Grey wolf optimizer: a review of recent variants and applications	The paper describes how GWO is better than other swarm intelligent algorithms being simple, scalable, flexible and easy to use. It consists of a detailed introduction to GWO along with procedural details of its main operations. The categorization of recent versions of GWO is studied further in a detailed manner.	This paper discussed the real-world applications of GWO, including the machine learning applications, engineering applications, medical and bioinformatics applications, and wireless sensor network applications and image processing applications.
[6]Grey Wolf Optimizer paper by Seyedali Mirjalili, Seyed Mohammad Mirjalili, Andrew Lewis	Proposed meta-heuristic method inspired by grey wolves which mimics their social hierarchy and hunting behavior and demonstrated GWO provide better results than other well-known meta-heuristic approaches.	This article demonstrates how GWO can be used to enhance constrained problems in classical engineering. A real world application is also discussed in this article, which is to optimise the structure of Photonic Crystal Waveguide(PCW) which is an important component of optical CPUs.

[7]Solving the CVRP Problem using a hybrid PSO approach	The paper aims to develop a hybrid algorithm model combining two different algorithms (Particle Swarm Optimization and Simulated Annealing) to solve Vehicle Routing Problems in a better way.	The algorithm proposed in the paper can solve CVRPs in a reasonable time for real-world scenarios.

Objectives:

- **To develop** and **implement** a hybrid optimization algorithm that combines Particle Swarm Optimization (PSO) and Grey Wolf Optimization (GWO) techniques for addressing the Vehicle Routing Problem.
- **To minimize** the number of vehicles needed to serve all the customers.
- **To find** the optimal solution of the VRP nearer to the global optima.

Methodology:

Vehicle routing problem can be described as follows: a fleet of vehicles has to visit a number of customers with some demands located in various cities. It involves finding the most efficient way to deliver goods or services. The primary objective is to minimise transportation costs and, in some cases, minimise the number of vehicles used while satisfying various constraints.

The proposed work aims to achieve improved results, by hybridising the Swarm Intelligent Approaches, Particle Swarm Optimisation (PSO) with Grey Wolf Optimizer (GWO). The proposed algorithm has mainly two phases.

1. The exploration phase
2. The exploitation phase

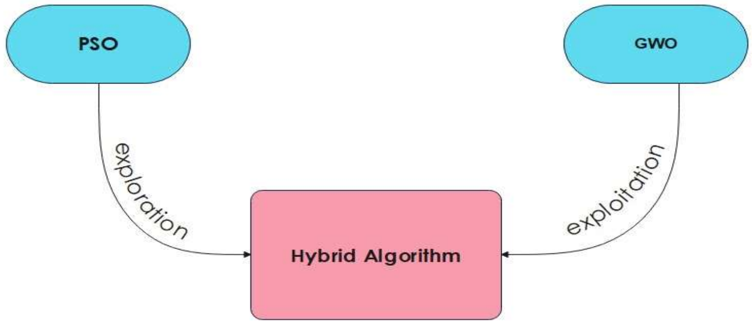


Figure 2: Representation of the hybrid algorithm

Particle Swarm Optimisation (PSO) will be employed in the exploration phase.

The function f(X) produces a real value from a vector parameter X (such as coordinate (x, y) in a plane). The PSO algorithm will return the parameter X that produces the minimum of f(X). The position of a particle i at iteration t is denoted by X^i(t). The position of each particle is updated as

$$X^i(t+1) = X^i(t) + V^i(t+1) \tag{1}$$

equivalently,

$$x^i(t+1) = x^i(t) + v_x^i(t+1) \tag{2}$$

$$y^i(t+1) = y^i(t) + v_y^i(t+1) \tag{3}$$

and at the same time, the velocities are also updated by the rule

$$V^i(t+1) = wV^i(t) + c_1r_1(P^i - X^i(t)) + c_2r_2(\ G - X^i(t)) \tag{4}$$

where r1 and r2 are random numbers between 0 and 1, P is the personal best solution and G is the global best solution, and the constants w, c1, and c2 are the parameters of the PSO algorithm.

Grey Wolf Optimizer (GWO) will be employed in the exploitation phase. The mathematical equations are as follows

$$\underline{D} = \left|\underline{C}.\underline{X_P}(t) - \underline{X}(t)\right| \tag{5}$$

$$\underline{X}(t+1) = \underline{X_P}(t) - \underline{A}.\underline{D} \tag{6}$$

where t indicates the current iteration,

A and C are coefficient vectors,

Xp = the position vector of the prey,

X = the position vector of a grey wolf.

The vectors A and C are calculated as follows:

$$\underline{A} = 2\underline{a}.\underline{r_1} - \underline{a}$$

$$\underline{C} = 2.\underline{r_2}$$

where components of a are linearly decreased from 2 to 0 over the iterations r1, and r2 are random vectors in [0, 1].

Therefore, we save the first three best solutions (alpha, beta, and delta) so far and improve the other search agents to update their positions according to the best search agent. The formulas are as follows:

$$\underline{D_\alpha} = \left|\underline{C_1}.\underline{X_\alpha} - \underline{X}\right|, \underline{D_\beta} = \left|\underline{C_2}.\underline{X_\beta} - \underline{X}\right|, \underline{D_\delta} = \left|\underline{C_3}.\underline{X_\delta} - \underline{X}\right| \tag{7}$$

$$\underline{X_1} = \underline{X_\alpha} - \underline{A_1}.(\underline{D_\alpha}), \underline{X_2} = \underline{X_\beta} - \underline{A_2}.(\underline{D_\beta}), \underline{X_3} = \underline{X_\delta} - \underline{A_3}.(\underline{D_\delta}) \tag{8}$$

$$\underline{X}(t+1) = \frac{\underline{X_1}+\underline{X_2}+\underline{X_3}}{3} \tag{9}$$

The exploitation stage (GWO phase) will be used for fine-tuning the hybridized algorithm to get an optimal solution.

Therefore, our approach is designed to find optimal or near-optimal solutions efficiently, thus significantly enhancing the quality of solutions compared to single-algorithm approaches.

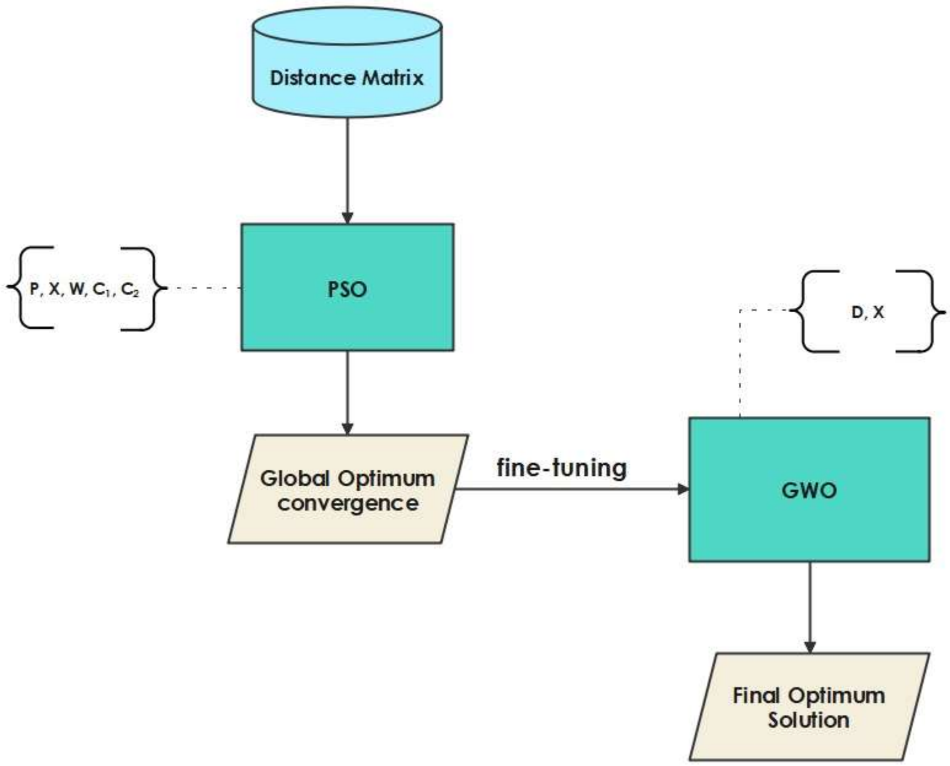
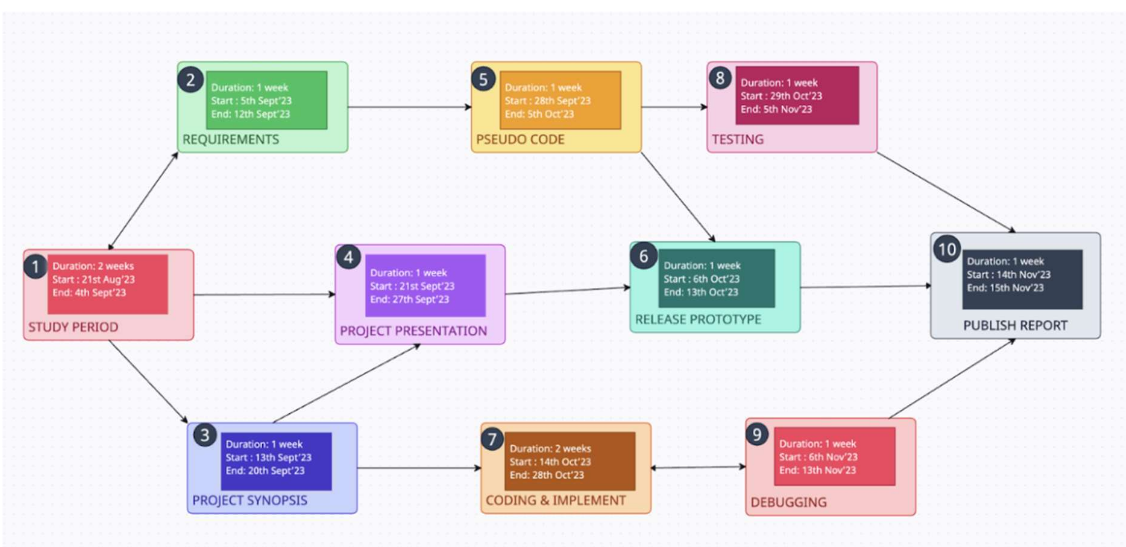


Figure 3: Flowchart

Pert Chart:



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