A Brief Review of the Intelligent Algorithm for Traveling Salesman Problem in UAV Route Planning

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***Abstract*—In the future, unmanned aerial vehicles(UAVs) will be used in a wide range of applications in areas such as wireless communications, logistics, inspections, search and rescue. Path planning in these areas often involves Traveling Salesman Problem (TSP). It is extremely difficult to select the optimal path from a large number of nodes, but it is easy to solve the complex problem after converting it to TSP. The optimization methods for solving TSP include meta heuristic algorithm and fuzzy neural network. With the rapid growth of demand, there is an urgent need for faster and more accurate methods to make UAVs more intelligent. This article reviews the application of UAV route planning in the field of wireless communications and express delivery, and selects a variety of classic and up-to-date algorithms for solving TSP and its variants to promote future researches.**

Keywords-unmanned aerial vehicles; meta heuristic algorithm; traveling salesman problem; wireless communication; neural network; fuzzy neural network

I. INTRODUCTION

Human beings promote the development of society through exchanges of information and goods. People are also constantly promoting the transmission of information and goods to be faster and more reliable. With the continuous development of 5G networks, intelligent transportation, Internet of Things and smart city research, many scenes that people have never thought of have already been integrated into our lives. Due to the fact that UAV has fewer obstacles, higher efficiency and lower cost when navigating in the air, it is an ideal choice for communication, logistics, inspection, search and rescue, surveying and photography. The UAV group with sensors forms a mobile communication network, which can also connect with other Internet of Things such as the Internet of Vehicles to create more refreshing applications, such as sharing images of roads in various regions between vehicles to ensure traffic safety. However, due to the limitation of load and battery capacity, UAV can only fly for a short time. Therefore, UAV and vehicles can be combined for logistics and other fields, and complex applications can be converted into multi-traveling salesman problem (MTSP). Then it can be conveniently solved with multiple UAVs at the same time, which expands the scope of service and improves efficiency [1]. In the future, UAV wireless charging stations such as UAV charging towers will be built in urban areas to increase the flight distance of UAVs. By then, UAVs will be applied to a wider field [2], the pollution will be greatly reduced and the environment will be better.

It is always essential to solve TSP in path planning in the fields of wireless communication and logistics. Such problems are combination-optimized scheduling problems, using existing resources to accomplish the task in the best way. A typical TSP gives the distance between nodes and each pair of nodes, finding the minimum total path length from one point through each node and back to the starting point. We can find the best path by solving the TSP according to the constraints in the field, thereby improving efficiency, saving energy, protecting the environment and providing better service to customers. However, TSP is a difficult problem in the non-deterministic polynomial (NP) of operations research. When the number of waypoints exceeds 50, the calculation time of the precise algorithm such as linear programming will be astronomical. To this end, scholars have invented many meta-heuristic algorithms, such as: Gravitational Search Algorithm (GSA), Genetic Algorithm (GA), Ant Colony Optimization (ACO), and Neural Network (NN), etc. They are used to obtain an approximate optimal solution or an optimal solution of TSP. However, with the rapid increase of vehicles in the sea, land and air, and the complication of wireless communication between vehicles, people are faced with various TSP variants that are more difficult to solve, such as multi-traveling salesman problem (MTSP) and vehicle route problems (VRP). Therefore, it is necessary to continuously improve and innovate algorithms to improve the level of vehicle intelligence. At the same time, TSP is also a classic problem to verify various new algorithms. People can easily and quickly improve and create new algorithms by solving TSP. Various methods such as meta heuristic and fuzzy logic can accurately verify the accuracy and speed of this type of problem.

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Techniques such as meta-heuristic algorithms, fuzzy logic and their combined algorithms have been successfully applied in many fields. Neural networks have made striking progress in the fields of image recognition and natural language processing. Therefore, fuzzy neural networks (FNN) can be formed by combining fuzzy logic. Further research can be carried out through TSP. Some meta-heuristic algorithms can be further integrated to speed up the convergence of the results by adjusting the parameters in the FNN.

In this work, we briefly reviewed TSP, metaheuristics, and fuzzy neural networks by searching the publications of IEEE Xplore, Springer, and Google Scholar index journals in recent years. The purpose of this paper is to compare and summarize the main points and application effects of different meta heuristic algorithms and hybrid meta heuristic algorithms through TSP, and study the characteristics and applicable fields of each algorithm in order to improve them. For more complex system applications, it can be combined with fuzzy inference system or FNN to achieve better optimization effects and functions, and promote the intelligentization of UAVs, so that it can realize newer and better applications in the field of wireless communication.

II. INTRODUCTION TO TSP RELATED ISSUES

A. Traveling Salesman Problem (TSP)

With the support of 5G technology, more UAVs, automobiles and home appliances will be connected to the Internet of Things in the future to realize information interconnection. In the fields of communication, logistics, remote sensing and disaster relief, it is involved in the problem of traversing multiple locations. People often abstract this problem into TSP or TSP variants. In the face of growing demand, there is a need for better ways to solve such problems. For example, UAV can detect changes in the environment such as farmlands, and transmit data to the information center through the Internet of Things in real time to achieve precision agriculture, which will increase efficiency and reduce the waste of resources. Many computer and operations research problems can be solved with TSP, and some optimization methods can also use TSP as a test benchmark.

1) Classic traveling salesman problem

There are many extensions to the application of TSP in different fields, such as Dynamic Traveling Salesman Problem (DTSP), Multiple Traveling Salesman Problem (MTSP) and Traveling Salesman Problem for Unmanned Aerial Vehicle (TSP-DS) [3]. In the graph theory, TSP finds a Hamilton loop with the smallest weight in the weighted completely undirected graph. The TSP that solves the Euclidean metric (ETSP) is usually selected, which is the straight line distance between the connected waypoints. According to the "no free lunch" theorem [4], no metaheuristic algorithm can solve problems in various fields. Therefore, many experiments have good results under certain constraints, but the effect of replacing the application scene may not be maintained. In response to these TSPs and their extension problems, researchers often use improved algorithms, multi-algorithm fusion or phased solution to improve computational accuracy and speed.

2) Multiple Traveling Salesman Problem (MTSP)

MTSP is an extension of TSP, that is, M passengers return to the starting point after traveling N cities from the same point, and request to visit all cities. Each city can be only visited once. But in order to make the path the shortest, passengers can pass through the same city multiple times.

TSP is for a single visitor to tour all the cities. But MTSP will divide all cities into M groups, and each group will use TSP to obtain the shortest travel route. The difficulty of this problem is how to group urban agglomerations. There are some commonly used methods such as clustering .

MTSP is also a multi-objective optimization problem (MOOP), which is also a hot topic of research. MOOP is ubiquitous in various fields, that is, each target cannot be optimal at the same time, and there are different weights. Therefore, it is necessary to study how to assign each weight.

3) Vehicle Routing Problem (VRP)

VRP refers to the fact that some vehicles transport goods from warehouses to multiple customers, each of which requires a different quantity of goods. The result is a transport path that requires minimum cost or shortest path conditions. We can say that TSP is a special case of VRP.

In the future, there will be many UAVs combined with vehicles to transport parcels. To control the heterogeneous multi-robot systems such as UAVs and unmanned ground vehicles (UGVs), the corresponding algorithms need to be developed to exploit the advantages of each vehicle. Heterogeneous Transfer Problem (HDP) belongs to the static Vehicle Routing Problem (VRP), which is also known as the Cooperative Carrier - Vehicle Traveling Salesman Problem (CV-TSP). There are coordination constraints between vehicles. These problems can be solved using metaheuristics algorithm or exact solver to calculate. HDP uses the tight coupling characteristics of team motion on the chart to convert the problem into a single vehicle generalized traveling salesman problem (GTSP), and then simplifies the GTSP with the Noon-Bean method to TSP, which can be used to solve the TSP metaheuristic with high optimization algorithm to calculate[1].

B. TSP related expansion problem research

1) Dubins path planning problem

The TSP that returns to the place of departure can be called "tour-TSP", while the "path-TSP" does not return to the place of departure. If the adjacent waypoints are directly connected, the TSP of the Euclidean metric (ETSP) is formed. If the dynamics of the actual vehicle is taken into consideration, the limit of the turning radius must be added, which is the Dubins vehicle. The Dubins Shortest Path Problem (DSPP) is the problem of solving the continuous waypoint. The Dubins path is widely used in the field of track planning to solve the problem of the shortest path. The Dubins path can be connected to the turning point to form a smooth trajectory according to the turning angle requirement. In order to reduce transportation costs and improve service quality, UAVs are used in the "last mile delivery" of new logistics, which cooperate with vehicles to transport goods for customers. This method is called the TSP-Drones (TSP-D). Considering the minimum operating cost, the TSP patrol is segmented into a TSP-D solution using the Greedy Random Adaptive Search Program (GRASP) [5].

2) Path planning problem (PP)

The pp problem is also called "route planning problem" in applications such as network optimization. It is a feasible path for finding a sequence of waypoints, and generally does not consider vehicle dynamics. Trajectory optimization (TO) considers only feasible trajectories regardless of the waypoint order. Because the vehicle turns with a circular arc-shaped transition path, it is necessary to change the route after the PP to the actual navigable route through TO. UAV routing and trajectory optimization problems (UAVRTOP) is introduced by combining PP and TO [6].

3) Orienteering problem (OP)

To find the best path or loop, the total weight of the arc with capacity constraints is taken into consideration. [7] studied the Orienteering Problem with Random Weights (OPSW) and developed a two-stage stochastic model to solve large instances. The heuristics are also used to handle uncertainty based on the OPSW structure, which dynamically adds additional nodes online.

III. Solving TSP with metaheuristic algorithm

The Mongols learned the tactics from the wolves. Researchers were inspired by bats to create radars, and learned how to find the shortest path through the behavior of ants. The meta-heuristic algorithm is inspired by nature and animal behaviors to create new ways to optimize problems.

The meta-heuristic optimization algorithm combined with the random search algorithm and the local search algorithm can quickly find the approximate optimal solution for the NP-hard problem. It is easy to use, has a good effect, and solves problems in many industries. In the application, a variety of algorithms are often used in combination, or a step-by-step process is used to exploit the advantages of each algorithm. The algorithm should balance exploration and development to find global optimal solutions as quickly as possible. Hybrid algorithms generally improve in terms of convergence speed and stability. The main points, features, and application examples of commonly used algorithms are discussed below.

A. Genetic Algorithm (GA)

GA is easy to understand and easy to use, has parallelism and robustness, and has a good global search capability. It is divided into three parts: coding, evaluation of individual fitness and genetic operation. Many researchers use genetic algorithms to solve TSP, which is an evolutionary algorithm. Evolutionary computation consists of genetic algorithm (GA), evolutionary strategy (ES), evolutionary programming (EP), and genetic programming (GP). Evolutionary operators use selection, crossover, and mutation. In order to ensure the continuity of the population, the operator is chosen to retain the best individual of the next generation. In order to make the group diverse, the crossover and mutation operators are used to perturb the individual.

The genetic algorithm is designed according to the theory of biological evolution. It can combine the multi-objective optimization problem (MOOP) and play the ability of GA to excel in global search, thus avoiding the traditional multi-objective optimization (MOO) method in the optimization process falling into the local optimal solution, which maintains the diversity of the individual. Multi-objective optimization strategies based on genetic algorithms are used in many fields.

1) Based on the genetic algorithm, the problem of imbalance between diversity preservation and convergence is encountered when solving the multi-objective traveling salesman problem (MOTSP). Therefore [8] proposed a hemorrhagic heuristic calculation model (PCM). Based on prior knowledge of PCM, in order to enhance the distribution of the solution, the group initialization process is first optimized, and then the hill climbing method (HC) is used to avoid falling into local optimum. The improved pNSGA-II algorithm solves the dual-objective symmetric TSP (BTSP) over other algorithms.

2) PSO's local search ability is strong, and it complements the advantages of GA. The GA selection operator allows the PSO to continuously allocate resources to better individuals, using PSO to classify and find the most useful features.

3) [9] proposed a HGAPSO method using a new feature selection method, combining genetic algorithm and particle swarm optimization. The method also integrates support vector machine (SVM). The feature selection method is to combine the update rules and standard speed of particle swarm optimization (PSO) with the selection, crossover and variation of GA to achieve hybridization. The overall accuracy of the support vector machine classifier on the verification sample is taken as the fitness

value. This method can also be used for applications such as road detection.

B. Ant Colony Optimization Algorithm (ACO)

ACO is essentially a parallelized positive feedback algorithm that is similar to a distributed multi-agent system in its entirety. It has the advantages of robustness, low parameters and self-organization.

1) The fast exploration random tree (RRT) algorithm is suitable for high-dimensional space. In order to solve the non-convex problem, the filling tree is constructed step by step from the search space to the random extraction sample for the detection region. [10] uses the RRT method to avoid collisions, which saves the continuously generated feasible traces into the tree. The "planner" can change the track according to changes in the state of the environment to avoid collisions.

2) The cooperative algorithm is used to solve the TSP through the distributed algorithm ant colony system (ACS) [11]. Ants use pheromone communication, so a group of ants is used to represent the cooperative agent, and the pheromone stored at the edge of the TSP map constitutes a solution. The results show that ACS is superior to evolutionary computation and simulated annealing algorithms.

3) The ant system (AS) is used as a new stochastic combinatorial optimization method to solve the TSP [12]. The main features of the model are positive feedback, distributed computing, and the use of constructive greedy heuristics. There are some advantages. Positive feedback can quickly find good solutions. Distributed computing can avoid premature convergence. Greedy heuristics help find better solutions in the early stages of the search process.

4) The improved ACO (IBSO-ACO) [13] is proposed. In order to solve the vehicle path problem with time window, the solution obtained by the ant colony algorithm is updated based on the brainstorm optimization algorithm. Compared with the ant colony algorithm and the simulated annealing ant colony algorithm, the routing cost is saved, and the local and global convergence speed is improved.

C. Particle Swarm Optimization (PSO)

PSO is a probabilistic class algorithm that can optimize the path. It has advantages of concise concept, easy implementation, strong robustness, ability to store past iterations, simulation evolution, and easy implementation with parallel distributed algorithms. However, the PSO population tends to converge too early. PSO and other evolutionary algorithms are firstly started with a random set of solutions, and then searched for approximate optimal values through iterative updates.

1) The PSO local optimization effect is good, and it can be tried in combination with a genetic algorithm that is good at global optimization, such as GA. For the first time, a particle swarm optimization algorithm (PSO) was proposed [14], which is a population-based stochastic continuous optimization algorithm. The algorithm is inspired by the bird's foraging behavior. Each "bird" is used as a "particle" to find the best solution, and iteratively updates the current position and flight speed based on its own and other particle flight experience. At present, PSO has become the main optimization algorithm for solving continuous space optimization problems.

2) The research on discrete combination optimization problem (COP) in discrete space is gradually increasing. [15] proposed a new set-based PSO (S-PSO) method, which uses the concept of set and probability to define position and velocity. The candidate solutions and velocities of the method are defined as clear sets and possible sets respectively. Based on the proposed S-PSO method, most PSO variants can be extended to discrete versions, such as Integrated Learning PSO (CLPSO).

3) The fitness-dependent optimizer (FDO), inspired by the colony breeding process, is a new group intelligence algorithm [16]. FDO updates the search agent location by adding speed, and FDO uses the fitness function values

to generate weights that guide the search agent during the exploration and development phases to push the search agent to optimal.

D. Wolf Pack Optimization Algorithm

There are several variants of optimization algorithm inspired by Wolf herd behavior. Wolf Pack Algorithm (WPA) has been rapidly growing in recent years and has played a very good role in many fields. WPA is a promising algorithm. It can achieve better application effects through perfection, and can fully exert its advantages of robustness, high efficiency and accuracy. Some researchers have improved the search mechanism, population initialization and parameters of WPA, and expanded the application of wolf group algorithm in complex function optimization, combinatorial optimization and parameter optimization.

1) Combining the behavioral characteristics of bee optimization (MBO) and wolves, [17] proposed wolves pack search (WPS). In the bee optimization algorithm, WPS is used to enter the local search process, and a new bee optimization algorithm (WPS-MBO) is proposed. The TSP simulation shows that the algorithm has good convergence performance.

2) [18] proposed a gray wolf optimizer (GWO), which uses the wolf group simulation to lead the hierarchical structure. The three steps of hunting, hunting prey, group prey and attacking prey are used to obtain an approximate optimal solution. It has good effects in the fields of route planning and industrial design.

3) [19] proposed the wolf group algorithm (WPA) and proved the convergence of the algorithm. The simulation results show that the proposed algorithm has better robustness and global convergence performance for high-dimensional complex functions, which can effectively avoid the premature convergence problem. There are many improvements to the wolf group algorithm, which can further improve the optimization performance.

E. Simulated Annealing Algorithm (SA)

1) SA is suitable for global optimization, which adds a random state. The solution speed is fast, and the optimal state is approximated by probability selection. [20] proposed a matrix-based UAV data collection trajectory (OUDCT) scheme, using UAVs to collect regional information. The matrix can recover the information in the monitored area by selecting a matrix of the backbone sample points and the following sample points. Finally, the simulated annealing algorithm is used to plan the optimal path of the UAV according to the selected sampling points.

2) The UAV is equipped with a radar life detector to search for and rescue people in distress such as earthquakes. [21] proposed a coupling method between the SA algorithm and the Dijkstra algorithm for optimizing the search path. Abstracting the problem as TSP, they extracted digital elevation model (DEM) data from Google Earth and simulated the three-dimensional path of the UAV with MATLAB.

F. Other algorithms

1) [22] studied multi-warehouse and multi-charging station scenarios, in order to ensure that the delivery of parcels within a certain time requires the addition of a time window. Multiple UAVs can be centrally deployed by the control center through cloud services to achieve rational use of resources. The authors propose a vehicle-assisted multi-UAV detection (VAMU) joint routing scheduling algorithm that can use the dispatch list to assign paths to UAVs and optimize the route using multiple layers to increase flight distance, improve efficiency, and save costs.

2) [23] studied UAV wireless communication in which a dispatching rotor drone communicates with multiple ground nodes (GN). The goal is to minimize the total energy consumption of the drone, including propulsion energy and communication-related energy, while meeting the communication throughput requirements of each GN. A new path discretization method is proposed to transform the original problem into discretized equivalents with a finite number of optimization variables. For this reason, the continuous convex approximation technique is used to obtain the suboptimal solution of TSP quality. The proposed algorithm optimizes the hover position and duration, as well as the flight trajectory connecting these hover positions.

3) [24] proposed a joint path scheduling algorithm called Vehicle Assisted Multi-UAV Detection (VAMU), and the vehicle path uses the Dijkstra algorithm to establish the shortest path. The UAV route first uses the Floyd algorithm to cluster and then uses the greedy method to construct the route. A car can be used to assist multiple drones in area detection.

Other algorithms can refer to relevant review articles. For example, [25] discusses several meta-heuristic methods for solving the path planning problem of UAVs . Focused on new algorithms and potential problems. The characteristics of various algorithms are compared graphically, and a smoothing strategy is used for the generated paths.

IV. Solving TSP with Neural Network (NN) and Fuzzy Neural Network (FNN)

A. Introduction to Neural Network and Fuzzy Neural Network

1) Neural Network

NN can be combined with methods such as fuzzy systems and GA to improve the effect. NN can be used for adaptive control problems in communication networks, aviation scheduling and TSP. NN has nonlinear adaptive processing capability, and can inherit domain knowledge for missing data. It can flexibly process data of multiple decision systems and resources. At the front end of the expert system, the feature is automatically selected by the preprocessor to generate useful representation data. The optimization process can be performed quickly on distributed devices. NN has been successfully applied in areas such as intelligent control, pattern recognition, prediction, combinatorial optimization and expert systems. NN-based intelligent simulation can be used for a variety of controls and is an important form of intelligent control [26].

2) Fuzzy Neural Network

FNN is well suited to solve optimization problems such as constraint satisfaction and scheduling. It can calculate and react according to inaccurate or incomplete data; it can reach stable state in a short time; its design and development cost is low and easy to implement; fewer parameters, rules and decisions are needed. However, it is difficult to automatically generate and adjust membership functions, it is difficult to create models from fuzzy logic, and more fine-tuning is required.

Combining the fuzzy system with the neural network, we can construct a FNN with adaptive learning ability. FNN can store information, learn knowledge and express ideas in a distributed manner, and can model and control complex systems. FNN uses fuzzy logic, where parameters and nodes in the network have meanings, so the learning algorithm can quickly converge to the desired input or output relationship.

And it is easier to learn and adjust parameters than a simple fuzzy logic system. For real-time control systems, in order to avoid falling into local extremum, making an initial solution based on prior knowledge can greatly increase the speed of convergence. With the self-learning function of neural network, the adaptive neural network is generated by modeling and analyzing the model features. This network is a very useful tool for building fuzzy rule bases [26].

B. Application of Neural Network and Fuzzy Neural Network

1) [27] proposed a fuzzy-based compact genetic algorithm (FCGA) method to solve TSP, which can optimize fuzzy rules online. In the changing real-time situation, the optimal fuzzy rule configuration of the offline system may lead to the performance degradation of the algorithm. Therefore, it is necessary to extract and refine the fuzzy rules online. FCGA uses FNN to handle the population size of compact genetic algorithm (CGA) simulations. FCGA can directly derive fuzzy output without complex fuzzy inference operations, and the fuzzy rules obtained under offline conditions can be improved online .

2) Classification and clustering are important methods for processing large amounts of data. Fuzzy neural networks are useful for classification and clustering, and are suitable for online training data [28]. The evolutionary algorithm (EA) and the Markov decision process (MDP) were compared using mathematical formulas [29]. Thus a special form of EA is the adaptive comment design (ACD) method of MDP.

3) People can extract relevant knowledge by training NN. An effective method to acquire knowledge is FNN modeling nonlinear system. However, FNN requires a long training time, so [30] proposed a hierarchical fuzzy system using genetic algorithm (GA) and FNN. By obtaining the fuzzy model that can identify the nonlinear object through the fine tuning of the FNN, the appropriate structure can be roughly searched in the fuzzy model. This modeling method can very effectively identify accurate fuzzy models with strong nonlinear systems.

4) A dynamic constrained multi-objective GFS is proposed, which can dynamically learn and adjust fuzzy function (MF) and learn fuzzy rules. Initialization combines the advantages of Wang-Mendel (WM) and decision tree algorithms, reducing the number of rules, search space and input variables and improving optimization efficiency. This method is suitable for high-dimensional classification problems [31].

V. SUMMARY

It is expected that the global drone market will form a market of RMB 100 billion per year in a few years, which will definitely promote the research of corresponding optimization algorithms, and relevant research work is very important. In this paper, we introduce a variety of algorithms, such as meta heuristic algorithm and FNN, which can solve TSP and its variants better. As the actual requirements increase the intelligence requirements, it is still necessary to continuously enhance the real-time and calculation accuracy.

Many of the above algorithms need to be further improved in theory, and there is still much room for development. Suitable algorithms can be innovated or combined depending on the field. You can also try to combine different meta heuristics with FNN. The meta heuristic algorithm is suitable for preliminary feature selection, and NN has higher approximation accuracy. After adding fuzzy logic, qualitative knowledge has increased. We can better converge to the ideal input and output relationships, and it is easier to learn and adjust parameters. The combination of swarm intelligence algorithm and FNN neural network can improve the predictive quality of membership function and reduce the influence of unrelated features, and can select better feature subsets in decision making.

To make drones and vehicles transport parcels like couriers or to carry out more advanced intelligent communications, it is necessary to achieve "general intelligence", which is still difficult to achieve. This needs to be realized with the development of related fields such as brain science, computational intelligence and hardware. We envision that reasoning ability can fully reflect intelligence, so adding fuzzy theory to the system is more intelligent. Moreover, it is necessary to join the "common sense library", use common sense knowledge maps for common sense reasoning, and even add a variety of intelligent methods such as Bayesian theory. It is possible to develop artificial intelligence with understanding human ability. At present, artificial intelligence has achieved success under the conditions of complete information game such as Go, because the following points are met: limited field, deterministic information, complete information, single task and static rule. However, for large space, uncertainty information, incomplete information, multi-task and dynamic issues, it is difficult to solve it at present. [32] wants to establish a unified theoretical framework: transforming symbols into vectors by "embedding" and "lifting", projecting feature space and symbol space into the same "semantic vector space", and solving "understanding" problem in this space.

In addition, because the factors considered in the general planning route are not comprehensive enough, it is necessary to evaluate the planned route and make corresponding adjustments. Air route assessment is a multi-criteria decision-making problem, and a reasonable route evaluation index system needs to be established [33].

The Fuzzy Minimum-Maximum (FMM) neural network combines the operation of artificial neural networks and fuzzy set theory into a common framework. FMM is considered to be one of the most useful neural networks for pattern classification. FMM plays a key role in providing solutions to pattern classification problems [34]. In the next step, we will combine the above methods for further research.

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