A review: On Intelligent Mobile Robot Path Planning Techniques

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***Abstract*—Path planning is one of the vital and defining features of autonomous robots. Robot navigation is a process designed to avoid any hitch or obstacles to aim at a particular position. This paper presents a brief review of the intelligent robot navigation methods. A brief discussion on the approaches is made to understand the path planning techniques to identify their research gap. The artificial intelligence methods such as genetic algorithm (GA), fuzzy logic (FL), ant colony optimization (ACO), neural network (NN), firefly algorithm (FA), particle swarm optimization (PSO), bacterial foraging optimization (BFO), artificial bee colony (ABC), and other miscellaneous algorithms are reviewed. This paper further concludes with a discussion of the analysis of the reviewed articles and the challenges faced.**

Keywords— Path Planning, A-Star, Artificial Intelligent, Mobile Robots, Neural network.

I. INTRODUCTION

At first, the manufacturing sectors were the major areas utilizing the application of autonomous mobile robots. However, recently, it is frequently used in other sectors: Medical, Military, mining, agriculture, etc. For the mobile robot to model its environment, localize its position, detect and avoid using a specific path planning technique, it is required to be provided with intelligent information. Choosing the proper path planning method is necessary for the robot to navigate a clustered environment from a given initial position to the target without colliding with obstacles. Robot navigation can be classified into global and local navigation. In global navigation, the positions of the elements are defined based on a reference axis while moving towards the target. In the latter, the dynamic constraints of the environment have identified the relations among elements positions established. The basic steps in mobile robot navigation are described in figure 1 [1].

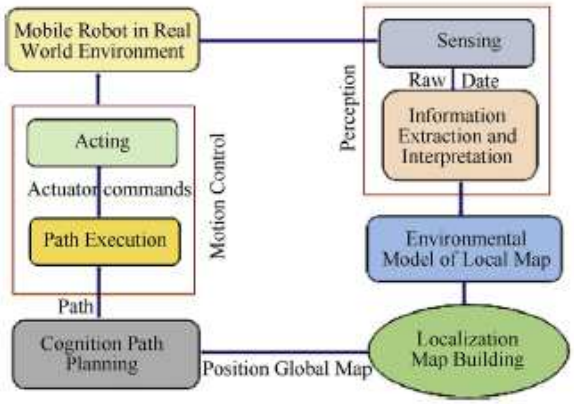

Figure 1: Robot navigation chart [1]

This paper provides a survey on the intelligent mobile robot navigation techniques with an in-depth of the algorithms and reported studies aiming to find the research gaps. Section 2 provides the literature survey and discussion, and then the conclusion in section 4.

II. MOBILE ROBOT NAVIGATION TECHNIQUES

The nature-inspired approaches are metaheuristic algorithms that imitate the principle of nature which natural science provides [2]. Numerous researchers have attempted to solve robot path planning problems (path search and obstacle avoidance) using approaches that mimic the natural behaviors of animals (birds, ants, bees, fly cats) [3]. These stochastic techniques used in solving research problems are called nature-inspired methods [4].

These methods adopt the behavior used by nature in solving complex problems to achieve a robust solution within a short period. Some of the popular nature-inspired approaches include: [5]

- Artificial Neural Network (ANN)
- Fuzzy Logic (FL)
- Genetic Algorithm (GA)
- Particle Swarm Optimization (PSO)
- Ant Colony Optimization (ACO)

The nature-inspired approaches are said to perform better when compared to the conventional methods [6]. Some of these methods are briefly discussed in the sub-sections below.

A. Genetic algorithm (GA)

GA is a search-based approach proposed in 1958 by Bremermann [7] that uses natural selection and genetics. GA is an optimization process used to achieve optimal solutions for search problems. It is inspiring by the natural behavior of living things and depends on evolutionary operators (mutation, crossover, and selection).

Most researchers have solved navigation problems in a static environment using GA. Shi et al. [8] proposed the solution in a dynamic environment. A hybrid approach using GA has also been used in oath planning problems to achieve optimal results such as GA-FL [9], GA-NN [10], and GA-PSO [11]. Modification of the obstacle avoidance and optimal path search in a dynamic environment was proposed by Hong et al. Jianjun et al. presents a modified GA by improving the output through the length of the chromosome. To enhance the performance (speed and accuracy) by applying GA, the objective function, selection, and mutation phases are improved. Yit et al. [12] perform a study on the population size of the GA, which the hope that the generation will perform effectively compared to its previous generation to reach the best solution. [13].

In [14], 2D path planning of humanoid robots using GA was presented. GA has been adopted in 3D path planning of both underwater [15] and aerial [16] robots due to its efficient response in both simple and complex environments. Both single and multi-robot path planning using binary code-based GA was in a dynamic environment was presented by Patel et al. GA have been used in path planning of Unmanned Aerial Vehicles (UVA). This has been proposed and presented by numerous researchers: [17]. A significant challenge faced in robot path planning is that of multi-robot planning. GA has been used to address the planning of multi-robots in [18] for obstacle avoidance in a global environment. Also, researchers in [19] address a similar problem, the planning problem. Yang et al. solve multi-robot planning problems in a dynamic environment. The low convergence rate, low optimal solution, time-consuming, and population size characteristics of GA have been researchers [20], [21] to implement a modified version of the algorithm.

B. Fuzzy logic (FL)

FL, introduced in 1965 by Zedah [22], is used in complex, nonlinear, and uncertain areas situations. It is encouraged by the remarkable ability of the human to perceive information.

FL has been used for path planning in static and dynamic environments to solve numerous problems. [23]. Nowadays, a hybrid of FL and other sensor-based approaches [24] have been adapted to achieve an efficient understanding and perception of the environment [25]. Khatib et al. [26] and Lee et al. [27] present a solution for path planning in a local environment using the FL approach. To further improve the moving condition in such an environment, Kang et al. [28] and AL-Mutib et al. [29] also present a solution using a hybrid of FL and stereovision process. The navigation of multiple robots in a local environment using FL was achieved and presented by Hoy et al. [30]. In [31], an FL and filter smoothing approach was used to navigate an autonomous robot in a dynamic environment. [32] presents a Fuzzy Markov Decision Process used to guide a humanoid robot based on the inadequacy of the environment information. The fuzzy Inference System (FIS) method for the navigation of Unmanned Ground vehicles in a clustered environment was presented in [33], [34]. This approach uses fuzzy logic to generate an input to output mapping.

A PSO-FL hybrid approach termed Mamdani-based FL controller was designed and presented by Abadi et al. [35]. Castillo et al. [36] present an FL-ACO hybrid algorithm to effectively prevent premature convergence by maintaining a diverse control in the ACO. In [37], an FL-GA hybrid was used for path planning of a robot to improve the FLC input-output mapping function. Another hybrid approach by Al-Jarrah et al. [38] for the planning of multiple robots using NN and fuzzy controller [39] was presented. Path planning of a 2D humanoid robot using the fuzzy-based method was presented in [40]. Navigation of aerial and UAV robots in a 3D environment is one challenging task [1]. FL approach has been used to address this problem as presented in [41] due to its multi-criteria decision making.

C. Artificial Neural network (ANN)

ANN is an intelligent algorithm made up of numerous interconnected layers of processing nodes (each having an activation function). It has a well-structured mechanism with three layers (input, hidden, and output), as shown below in figure 2. The input layers communicate to the hidden layers through some weighted connections for processing, while the hidden layers connect with the output layers for the output. [1]. Robot path planning in an unknown environment using the NN algorithm was presented by janglova [42]. The algorithm utilizes two mechanisms to achieve a free collision path. NN has been used in the path planning of robots for different applications [43-46].

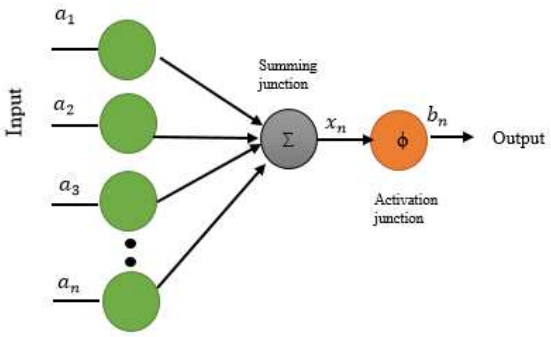

Figure 2: ANN architecture

A hybrid algorithm using NN-FL for navigation of disordered multiple robots in a static environment was presented by Pathal et al. [47]. Similarly, the NN-FL hybrid algorithm was proposed by Abu baker [48]. Optimal activation rules were found, which lessens the total computational time needed in a real-time application. A modified NN algorithm, GAPCNN, was proposed by Syed et al. [49] to navigate in both global and local environments with a high convergence. An algorithm for intelligent systems based on NN was presented by Avci et al. [50]. Using a 2-layered NN (wavelet and multilayer perception), the frequency-time domain and classification features were extracted. Planning in a dynamic environment based on NN

Radial Basis Function (RBF) was presented by Panigrahi et al. [51]. A multilayer feed-forward NN controller with backpropagation was used in an ANN to navigate an autonomous vehicle in [52].

D. Firefly algorithm (FA)

The FA is a metaheuristic algorithm that was introduced by Yang in 2008. The algorithm was inspired by the flashing behaviors of the fireflies. The firefly is a beetle (Lampyridae), also called a lightning bug, capable of producing light through a process known as bioluminescence to glow without any energy loss. The beetle uses the generated light to communicate, find mates or scare off predators amongst them.

The FA algorithm has been widely used in solving path planning problems. A safe, smooth, and shortest robot path planning in a global environment for a was approached based on FA algorithm was presented by Hidalgo-Paniagua et al. [53]. Navigation of robot (s) to achieve a short, collision-free path using the FA algorithm has been presented by researchers [54], [55]. Experiments for path planning in complex environments of multiple robots using FA have been presented in [56].

E. Particle swarm optimization (PSO)

The PSO algorithm was proposed in 1995 by Eberhart and Kennedy [57]. It is a metaheuristic approach that adapts the natural social behaviors of animals (school of fish and flocks of birds) to reach their target by communicating with the members of the population.

Recently, PSO has been used in solving robot path planning problems. PSO has been used by researchers in [58] to tackle the localization problem in robot navigation in a complex environment. An extended version of the PSO, Area Extended PSO (AEPSO), was proposed by Atyabi et al. [59] to solve the path planning problem of robots used in bomb disarming rescue. Navigation of multiple robots using PSO was achieved and presented in [60], [61]. A self-adaptive learning PSO (SLPSO) algorithm was proposed by Li et al. [62] to navigate robots in a dynamic environment. The self-learning mechanism was used to enhance the search for the PSO. PSO has been implemented in the navigation of robots in different environments and applications [63]. Das et al. [64] present a hybrid method using PSO and Improved Gravitational Search Algorithm to find an optimal path in the navigation of multiple robots in a clustered environment.

PSO has been introduced and applied in UAV path planning by several researchers [65]. Different types of PSO [66], [67] presented for robust path planning of UVA in various environments have been proposed.

F. Ant colony optimization (ACO)

ACO algorithm is a population-based method first developed by Marco Dorigo [68]. It is inspired by the ant behavior to find the shortest path from food source to their nest. It originated from the behavior and ability of ants to find the shortest distance from their nest to food (Figure 3). ACO is used to solve mobile robot path planning problems for obstacle avoidance. Real-time planning of mobile robots with fast speed and efficiency convergence was presented by Guan-Zheng et al. [69]. Collision avoidance using ACO between multiple robots in a known environment was presented by Liu et al. [70]. The authors further performed some modifications on the ACO algorithm, presented in [71], to increase the convergence speed.

A hybrid approach using ACO has been presented by researchers such as the ACO-fuzzy method [72], AR- ACO [73], navigation in a dynamic environment using ACO have been proposed by Purian et al. [74]. The ACO algorithm was used for the selection, while the Fussy rules were used in the optimization process. UAV path planning for a collision-free path using the ACO algorithm in a 3D environment was presented by Liu et al. [75]. ACO has been applied in different applications and sectors.

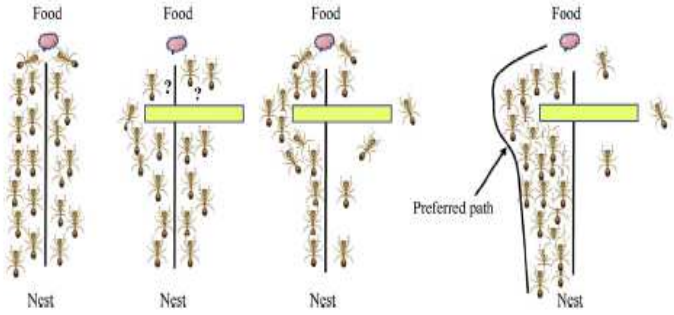

Figure 3: Ant searching behavior [1]

G. Bacterial foraging optimization (BFO) algorithm

BFO is a nature-inspired algorithm proposed by Pasino [76]in the year 2002. It is inspired by the natural behavior of E. coli and M. Xanthus bacteria. The BFO algorithm perceives chemical gradients (chemotaxis) to communicate with each other using four principles (chemotaxis, swarming, reproduction and elimination, and dispersal).

Coelho et al. [77] present robot path planning in a known environment using a BFO algorithm based on Uniform, Gauss, and Cauchy variable velocity distribution. A similar approach has been employed in [78] to navigate robots in an obstacle-prone environment. A modified BFO algorithm is presented by Abbas et al. [79] to improve the performance of the robot. The approaches use APF opposing (attractive and repulsive) forces on the obstacles in order to select the best directions that direct the robot to the target area.

Path planning of multiple robots has been achieved using a hybrid of the BFO algorithm and harmony search [80]. 3D path planning of UAV using BFO with a PID controller have been presented by Oyekan et al. [81]

H. Artificial bee colony (ABC) algorithm

ABC is a nature-inspired algorithm proposed by Kharaboga [82]. It is a fast, simple, and population-based method that is inspired by the honey bees' natural behavior

in search of food. Contreras-Cruz et al. [83] present an ABC approach to path planning of robots in a known environment. A similar method was presented in [84]. To navigate the robot in a dynamic environment, a hybrid approach of the ABC algorithm and time rolling window approach is proposed by Ma et al. [85]. The fitness function is planned in a way that robots successfully navigate in both simple and complex environments without collision. A solution to the problem of navigating multiple robots has been presented in [86] and [87] using the ABC algorithm. ABC has been applied in different sectors for solving robot path planning.

I. Other miscellaneous algorithms [OMA]

Researchers have proposed different intelligent algorithms for robot path planning in the diverse environment under various cases, such as

- Shuffled frog leaping algorithm (SFLA)
- Cuckoo search (CS) algorithm
- Bat Algorithm (BA)
- Differential Evolution (DE) Algorithm
- Harmony Search (HS) Algorithm

After a brief analysis of the reviewed papers, it is observed that the fuzzy logic approach is the popular studied approach among them in path planning of robots. This is followed by GA and NN algorithm, respectively. The FA, ABC, and other new miscellaneous algorithms are growing rapidly as their application in solving path planning is seen in numerous sectors.

The oldest and popular algorithms have been applied in the path planning of robots in unknown environments with dynamic obstacles. However, ABC, PSO, SFLA, and BFO, which are newly proposed by researchers, are successfully used to navigate a known environment with a static goal, navigation of multiple robots, which is a challenging task in path planning been successfully achieved with most popular approaches. To achieve path planning in complex situations, researchers have proposed a hybridization of the methods.

III. CHALLENGES

The intelligent approaches can imitate the natural behavior of living things. They can make decisions in an uncertain situation, thereby providing generalization and learning capabilities. However, they faced some major challenges. For the ANN algorithm, it becomes complex as the number of layers increases. A considerable amount of training data is required in other to achieve an optimal result. In the neuron system, the number of buried layers is difficult to handle. The backpropagation converges quickly to local minima in a non-convex mapping situation. In a complex environment, the PSO has the problem of trapping in a local minimum in a clustered environment. Both the GA and PSO are challenging to handle in an unknown environment and can easily get trapped in the local minima problem. The GA, despite being faster in convergence, can result in a premature convergence. Identifying the factors that affect fast convergence is difficult in ACO.

IV. CONCLUSION

Robot navigation is a process designed with the ability to avoid any hitch or obstacles to aim at a particular position. The choice of an ideal algorithm in every stage of the path planning process is extremely vital to ensure that the navigation procedure will certainly run smoothly. This study analyzes intelligent robot path panning methods by reviewing studies published in major journals and conferences. The analysis is helpful in identifying the key trends and open challenges. The significant observations in the study were that papers published on path planning in a dynamic environment are less than those published on planning in a static environment. Also, the number of studies that present experimental results are fewer than those with the simulation result. The navigation of multiple robots is still a challenging topic as fewer papers are compared to single robot path planning. The newly developed algorithms (BFO, ABC, SLFA, and others) are still left behind in navigation in complex environments

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