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A REVIEW PAPER ON WHEELED MOBILE ROBOT USING DIFFERENT NAVIGATION TECHNIQUES

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ABSTRACT

Mobile robots are autonomous agents capable of intelligent navigation anywhere Using sensor actuator control technology. Autonomous application Mobile robots that are active in many fields such as industry, space, defense, transportation, etc., and other social sectors are growing day by day. Mobile robots do many things rescue operations, patrols, disaster relief, and planetary exploration, That's why we need intelligent mobile robots. It can move autonomously in various static and dynamic environments. Several techniques have been applied to mobile robots by various researchers. Navigation and obstacle avoidance. In this article, Intelligent navigation technology can navigate mobile robots Autonomously in static and dynamic environments. Navigating robots in obstacle-filled environments remains a challenge. This work describes the navigational difficulties of WMRs (wheeled mobile robots). WMR navigation mechanisms and strategies to address sub-problems are mappings, localization, and path planning. Planning can be used in all aspects of robot navigation. We will discuss some existing approaches. Accurate robot navigation is very important in agriculture applications . You have to deal with many activities in a complex agricultural environment. Focusing on the complexity of specific agricultural environments, this study anticipates the use of answers to WMR navigation problems in agricultural engineering and demonstrates that this project aims to address the challenges of precise navigation in agricultural areas.

This paper presents a rigorous survey of mobile robot navigation techniques used so far. Here, a stepwise investigation of classical and reactive approaches is undertaken to understand the development of pathway planning strategies under different environmental conditions and to identify research gaps. Classical approaches such as cell decomposition (CD), roadmap approach (RA) and artificial potential field (APF). Genetic Algorithm (GA), Fuzzy Logic (FL), Neural Network (NN), Firefly Algorithm (FA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Bacteria Search Optimization (BFO), Artificial Reactive approaches such as Bee Colony (ABC), Cuckoo Search (CS), Shuffled Frog Leap Algorithm (SFLA), and other miscellaneous algorithms (OMA) are under study.

Keywords: Navigation, Mapping, Localization, Path Planning, Global Path Planning, Agriculture, Path Planning-Local, Locomotion, wheeled mobile robots.

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1. INTRODUCTION

In recent years, robots have been deployed in various fields to replace humans, and good navigation of mobile robots is essential in various operations. Due to the increasing popularity of robotic applications, many researchers have shifted their focus to research on robotic navigation. A major difficulty in robot navigation is determining how the robot should navigate from its origin to its destination based on the localization and environmental information obtained by the robot sensors. Mastering her four building blocks of navigation is a prerequisite for success in navigation [1]. Examples include perception, location, cognition, and motor control. The main difficulties are mapping, localization, route planning, etc. Extensive research and testing have resulted in the creation of a wide range of technical options to help overcome obstacles to precise navigation. Precision agriculture [2] was introduced into agriculture as a new concept in the 1980s. Precision agriculture requires improved utilization of arable land resources, reduced labour costs in production, and improved yields and quality. In this work, we opportunistically explored the use of wheeled mobile robots (WMRs) in agriculture by choosing to summarize his research on key navigational challenges in WMRs over the past three decades. Autonomous robots that operate essentially deterministically and stochastically based on implicit inverse reinforcement learning algorithms under operating conditions in small state space. We focus on high-dimensional state spaces of large IRLs, introduce neural networks to generalize explicit behaviours that do not visit the space, and briefly present his IRL representations by experts from a neutral point of view. In addition, neural inverse reinforcement learning allows you to implement precise guidelines appropriate for your network. An unknown task can be completed in an indeterminate state space without practice using NN, AIRL, and IRL algorithms. unknown state space. Use multi-output and single-output NNs in the unknown state space. This helps us find more ways to reach the state space[3]. Nonlinear neural guidelines inherent in artificial neural networks and NIRL are not accurate for state-space paths. Implement maximum and minimum bound methods to find the exact space and change the nonlinear guidelines used in the training function. With the help of the NIRL algorithm, we proposed fully autonomous navigation tasks safely even in unpredictable environments. He is an expert who can understand. Based on this, we will continue to extract new solution methods by continuously utilizing and implementing NIRL. Autonomous mobile robots play a bigger role in the current situation. This autonomous mobile robot was used in various fields such as automotive, industry, hospital, agriculture, and domestic daily activities to navigate the autonomous mobile robot without physical or electromechanical guidance devices. With new technologies, today's world invites new autonomous convergence of mobile robots but based on applications, we face many challenges to meet the requirements. We are particularly interested in sensors/devices that can be used in fusion-based methods to help detect strengths, weaknesses, and relevance-related navigations of autonomous mobile robots. This fusion process may bring new challenges to the current world situation [4]. Advances in mobile robot applications allow obstacles and ease of work to go hand in hand. This mobile robot will help you significantly expand your business. Promote people's lifestyles and exposure to environmental problems based on this precaution, reduce the assistance of autonomous robots, and minimize the assistance of autonomous robots. Learning this fusion technology is a big challenge for advanced robots. Make your own decisions using artificial neural networks. Integrating these established concepts, sensor-based mobile robots complement the current environment. By using sensor fusion technology, it is possible to discover hybrid and mutation-type future technologies. Autonomous mobile robots are becoming increasingly important in today's context. With new technology, many fields such as automobiles, factories, hospitals, agriculture, and household daily activities are adopting this autonomous mobile robot to navigate it without any physical or electromechanical guidance system. increase. The current world is beckoning new autonomous fusion-engineered mobile robots. However, depending on the application, there are some issues with meeting the criteria. We are particularly interested in sensors/devices that can be used in fusion-based approaches to enable the detection of strengths, weaknesses, and significance of autonomous mobile robots. In the current world conditions, this integration process may pose additional obstacles. Development can compensate for the difficulty and ease of work. A mobile robot that supports the company's rapid growth. The ease of human life and exposure to the environment makes a statement based on this precautionary measure minimized with the help of autonomous robots. Understanding this fusion process can overcome a major obstacle for advanced robotics. Make decisions using artificial neural networks [51]. Combining these known principles, sensor-based mobile robots complement existing environments. A sensor fusion approach can uncover hybrids and mutations of future technologies. Analysis of navigation in static and dynamic situations for single and multi-robot systems showed that reactive solutions are more reliable and outperform traditional approaches on all terrains. As a result, reactive strategies for route planning of mobile robots are increasingly recognized and used. The results of the study are summarized in tabular data and images comparing the prevalence of different navigation methods that can be used in specific robotics applications. This study on mobile robot navigation divides the various methods into conventional and reactive methods[4]. The main findings of the survey are as follows. Reactive strategies are superior to traditional approaches because they are better able to cope with environmental fluctuations. A reactive approach is effective in addressing the challenges of real-time Navigation.

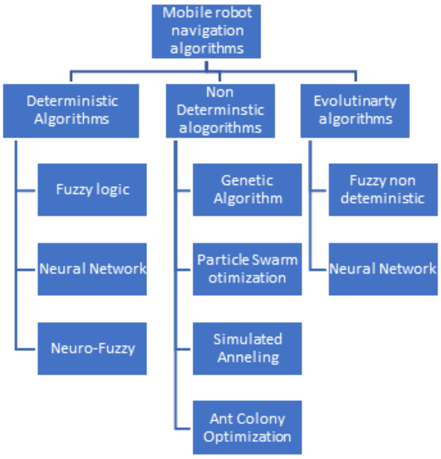

Figure.1 Methods of Mobile robot Navigation algorithms.

Dynamic environment studies have been published in much smaller numbers than static environment studies. There are far fewer studies on the dynamic environment navigation of robots for moving target problems than for moving obstacle problems. Most research today focuses on simulation analysis, with far fewer articles dealing with real-time applications. Working on hybrid algorithms is much less common than working on individual algorithms. Using newly established algorithms such as SFLA, CS, IWO, BA, HS, DE, BFO, ABC, and FA [5] to navigate undetected complex environments with maximum uncertainty, this type of mobile robot use is severely restricted. Today, however, they are used in industries as diverse as entertainment, medical, mining, rescue, education, military, space exploration, and agriculture. The robot is equipped with many smart devices to facilitate navigation. These gadgets are used to simulate the environment, locate the robot, coordinate its mobility, identify obstacles and move around them. The most important part of any navigation approach is safe route planning. This includes recognizing and avoiding hazards en route from your starting point to your destination. Therefore, regardless of whether the robot's journey is built in simple or complex environments, choosing the right navigation strategy is critical. The topic of mobile robot navigation is currently the subject of most research and numerous methods are being developed. His three subcategories of mobile robot navigation are global navigation, local navigation, and personal navigation. The ability to determine how elements in the environment relate to reference axes and move toward the current target is called global navigation. Local navigation relies on recognizing the changing characteristics of the environment and establishing positional relationships between various elements. Personal navigation involves coordinating multiple environmental elements about each other, taking into account their positions. The navigation methods in this study are classified based on the prior information about the environment required for route planning. This can be broken down into two categories: Local and global navigation. Unlike local navigation, which does not require prior knowledge of the environment, global navigation requires prior knowledge of the environment, obstacle locations, and target location by the mobile robot. A fully known environment is central to any global navigation strategy. A local navigation approach is applied when the environment is unknown or only partially understood [6]. CD, RA, AFP first-to-last path movement. These are simple algorithms with little intelligence. Local navigation strategies are called reactive approaches because they are more complex and the strategies can be adjusted and executed autonomously. This proposed research study on mobile robot navigation aims to identify research gaps and areas of innovation in specific topics. Test a single algorithm in static environments, dynamic environments with moving obstacles and targets, simulation analysis, test analysis, navigation of multiple mobile robots, and hybridization using advanced techniques. Other intelligent technologies, applications in three-dimensional (3D) environments, and applications in military or defence equipment [7]. The paper also compares the effectiveness and application of conventional and reactive methods in a variety of situations, including airborne, land, subsea, industrial, and hazardous. It primarily deals with reactive systems based on local sensor inputs, sliding mode control, and distributed MPC-based techniques.

2. NAVIGATION TECHNIQUES USED FOR MOBILE ROBOT NAVIGATION INCLUDE

Over the years, an increasing number of researchers and scientists have offered different strategies for navigational approaches. There are two main types of navigation techniques used in robotic systems. A classic, reactive approach.

2.1. Classical Approaches

For many years, more researchers and scientifical have offered a variety of strategies for navigational approaches. There are two main kinds of navigation techniques used by robotic systems: classical and reactive approaches.

2.1.1. Cell decomposition (CD) approach

In this approach, we divide the area into non-overlapping grids (cells) and use connection diagrams to connect the cells to the next cell to achieve our goal. Travel uses pure tiles (cells with no obstacles) to create a path from a starting point to a destination. It splits a half-broken cell (cell with an obstacle) into two new cells to form a clean cell while calculating the best route from origin to destination. Purified cells were then sequenced.

The start and end cells of the CD method act as placeholders for start and target positions. Appropriate pathways are indicated by pure cell chains connecting these sites [4-5]. There are three types of CD methods: adaptive, approximate, and precise. Cell size and shape are not fixed in the exact cell decomposition shown in Figure.2 [6–7], but can be determined by the map of the environment and the location of barriers within it. This approach uses shared lattices in several ways. The available free space in the environment is first divided into small (trapezoidal and triangular) pieces and numbered. Each component of the configuration acts as a node in the connection diagram [8]. The path in this diagram resembles a free-space circuit delimited by a series of striped cells, after which adjacent nodes can enter configuration space. The sequence of striped cells in this figure represents a free-space network connected by roots. The underlying layout is connected to the target design through the midpoints of the intersections of adjacent cells within channels, transforming the channels into separate paths. Use the planning environment to assemble routine grids of detailed shapes and sizes, making them easy to use with approximate cell divisions. This is called approximation because the boundaries of the objects on the site cannot fit exactly within the preset smartphone boundaries. In this navigation approach, if an object fills the grid space, it is treated as an obstacle. otherwise, it, is treated as a space. The centre of each cell is considered at some stage as a node in the pathfinding method on the search site. It shows structures of 4 and 8 connected nodes when the robot wants to traverse diagonally between them. Normal cytolysis avoids space by following the key principle of adaptive cytolysis, which recognizes substances contained in space. Quadtree adaptive decomposition is proposed with the help of Samet and Noborio[9]. The environment is split into large grid cells, but when a grid mobile is half-occupied it splits into 4 equal sub-parts until it is empty. The work area is a map, with grid cells of various sizes bounded by obstacles. The drawback of this approach is that the application cannot be updated when new statistics (such as barrier roles) are received. As a result, they have to struggle in an ever-changing environment. Ringelbach proved that course planning in high-dimensional static configuration spaces is a difficult task. He found the answer to the problem of route planning for his robot platform, which resembles a chain and a maze. Slimer et al developed a mobile robot orientation planning method using CAD-based data and implemented a hybrid solution.

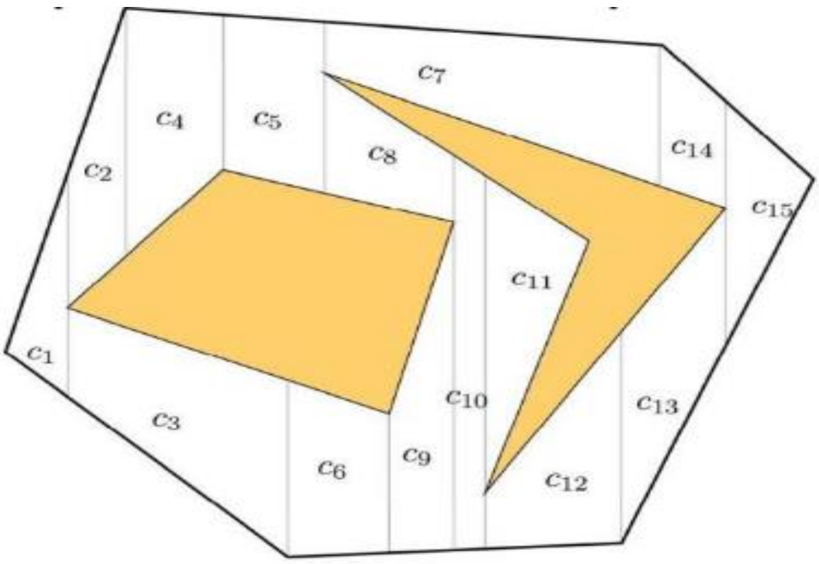

Figure.2. Cell decomposition (CD) Method.

To reduce the amount of computation, we created an APF-based direction planner for proper language decomposition. Tunggal et al. State-of-the-art FL with CD for real-time operation in unsafe environments. We provide a greedy depth-first search strategy and a GA-based phone mining method for manipulator route planning to accomplish many tasks in a market 3D environment. Gonzales et al. We presented a quantitative study of the trajectory of a mobile phone by changing the clandestine dismantling, design weight, and waypoint assignment technique of the mobile phone [10]. His 3D environment, explored in the utility company's Flight Navigation Challenge, is complete. This technical know-how combines phone-breaking technology with fuzzy logic to command-and-control planes.

2.1.2. Roadmap approach (RA)

RA is also recognized as a highway entrance. Nodes in this area are important for providing important paths for robotics. RA is used to determine the shortest path between the robot's initiating factor and its goal function. The roadmap was created using visibility and Voronoi diagrams. The visibility style approach maps start and end locations to map nodes. The visibility diagram is proven in Figure 2. Dotted lines indicate the scenic route from start to finish, and dark areas indicate obstacles. This technique is also used in polygonal boundary environments where nodes act as vertices of polygons and edges act as connections between nodes. Another roadmap technique used for robot course planning is the Voronoi layout.

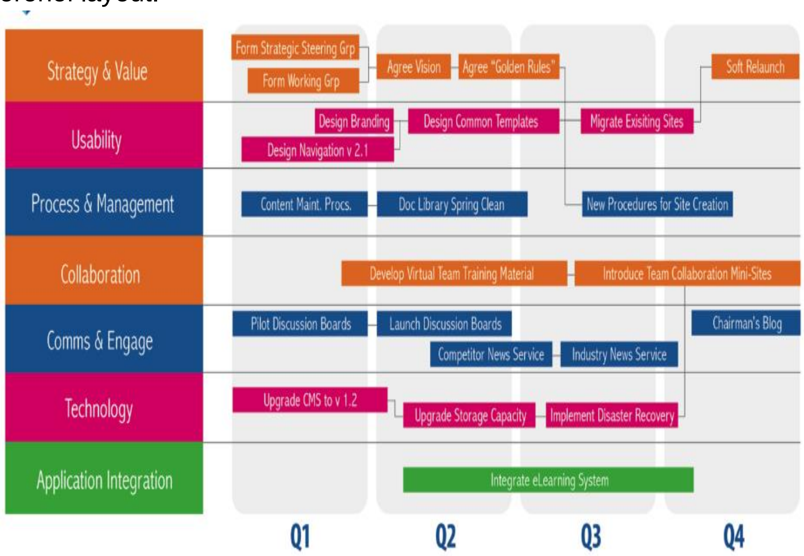

Figure.2. Roadmap approach (RP) Method.

On the boundary of the barrier, he uses points that are equidistant from two adjacent points to form all the edges of the shape using this approach and divide the locations into sub-regions. How the Voronoi Project Works. The use of Voronoi diagrams for obstacle avoidance by mobile robots is discussed in ref. Improved performance and effective path planning for removing obstacles such as sharp turns and large loops in Voronoi sketches. Combining visibility graphs, Voronoi diagrams, and a manageable field approach, a hybrid strategy is developed to achieve optimal routing. I couldn't determine the best method with this method, and I felt that this method was difficult. Yang et al. Excellent path planning was achieved using skeleton maps and Voronoi diagrams[12]. Nakura provides a combinatorial approach for determining the most useful paths by combining visibility maps and Voronoi diagrams. Kavraki et al. We proposed using probabilities to help RAs understand and provide route planning strategies. However, this method is not effective for finding optimal root lengths. With minor modifications by Sanchez et al. [36] extended the probabilistic roadmap approach to the shortest direction determination (PRM) method. To overcome the difficulty of path planning in real environments, their technique offers a delayed collision-checking approach using PRM. Yang et al. We validated unmanned aerial navigation efficiently in a 3D environment. This method provides a probabilistic method of controlling flight direction in addition to road map technology.

2.1.3. Artificial potential field (APF) approach

In 1986, Khatib [38] introduced the APF technique for navigating cellular robots. He argues that the chasing targets and challenges characteristic of charged surfaces, and their total available energy, exert an illusory appeal on robots. As seen in Figure 8, this hypothetical pressure pulls the robot towards the target and keeps it avoiding barriers.

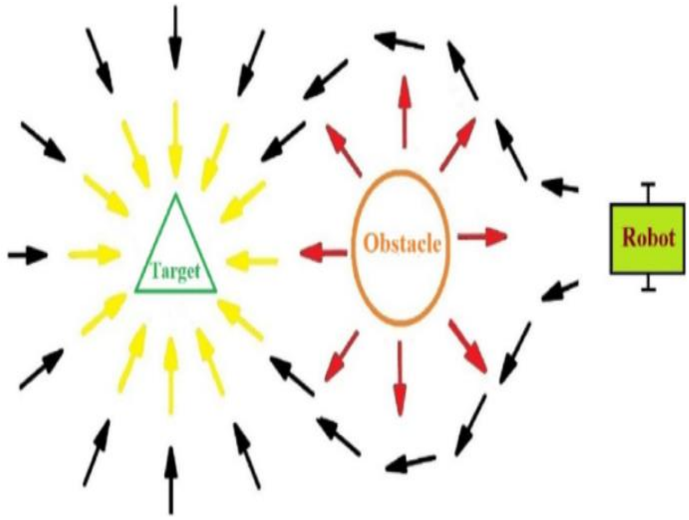

Figure.3. Artificial potential field (APF) Method.

To bypass obstacles and reach the desired position, the robot follows a rough road here. Garibot et al. [39] show how this technique can be used for mobile robot navigation. Kimetto Al. [40] describes a novel obstacle avoidance method in unexplored locations using AFP. To get around the neighborhood minimum problem, they developed harmonic functions. The problem of local minimum situations was further addressed using Borenstein et al. [41]. Their study took into consideration the dynamic navigation properties of the robot. In refs [42-43], APF evaluation is performed in a dynamic environment for obstacle avoidance. The APF approach involves some electrostatic-related improvisations [44]. Using electrostatics makes it easy to generate potential curves and quickly determine collision-free paths. To detect the position and speed of obstacles during the project, Huang designed a speed control system. Shi et al. Create the maximum potential function and achievable repulsive properties to move away from the neighborhood minimum and reach the global maximum. To address the problems identified in cellular robot navigation, Sfeir et al. Rent APF processes such as vibration and conflict. To reduce jitter and contention when the target is close to the barrier, they introduced a larger model of his AFP. Pradhan et al. [48] examined the applicability of his APF to the use of the ROBOPATH simulation program. In special environmental situations, in addition to collision effects, many cellular robots, which are shown to be especially tuned, are taken into account. Used in conjunction with other strategies.

2.2. Reactive approaches

Recently, the reaction process is the best It has a reputation for being a problem solver. Jumping Algorithms, Harmony Search Algorithms, Bat Algorithms, Differential Evolution Algorithms, and many more [13]. They are very knowledgeable in dealing with the uncertainty around them. A lot of reactive methods should be mentioned here.

2.2.1. Genetic algorithm (GA)

It is a popular search-based optimization device sticking to the 1958 Bremermann discovery of genetics and natural selection. The Netherlands first published it in the context of computer science in 1975. Robotic navigation is just one of many areas of science and technology in widespread use today. It focuses on optimizing difficult problems that require maximizing or limiting the value of a target feature within certain bounds. This method requires matching a population[51] (a collection of people with different genetic traits) to a given problem, and each member of the population is assigned a fitness fee based on objective traits. increase. These people are allowed to relinquish their genes to new generations via crossover based on their health status and selected genes. Mutations protect the population spectrum while preventing premature convergence. Once the population has converged, the procedure is complete [14]. Although GA is partially randomized, it is superior to random neighbourhood search because it can also use historical data. See Application of GA to Problems of Cellular Robot-Assisted Navigation in Static Environments. Simulation results are only used to represent searches with polygonal obstacles. Since traditional real-time inspection and optimization techniques are a time-consuming alternative, Shing et al. developed the real-time path planner. GA is a simple search approach that requires a record of the environment to work well in unfamiliar environments. Xiao et al. We used this technique to satisfy navigational desires such as course length, route slipperiness, and obstacle avoidance. The challenge of nonlinear environments of giving up completely in difficult environments is addressed in ref. They have developed online educational software to help you collect the strongest chromosomes and avoid getting caught at all costs. Shi et al.

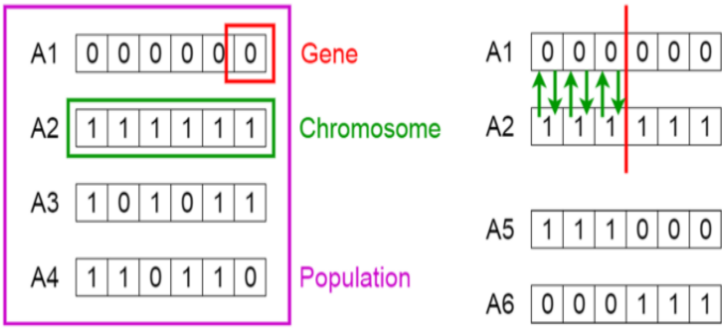

Figure.4. Genetic algorithm (GA) Method.

Most researchers have proposed navigation in static environments using GA alone, but recommend navigation in the presence of transmission barriers in hazardous environments. Hybrid strategies are created by combining GA with another meaningful algorithm such as GA-FL, GA-NN, or GA-PSO [15]. Designing multi-robot routes are one of the most difficult components of robotics. Kala has processed multiple cellular robot orientation planning approaches using GA. In his research, he developed a time-efficient coordination strategy to avoid collisions between a large number of robots in static situations. This demonstrates multiple wishing methods in a static environment equivalent to robot route planning. Yan et al. Consider navigating a multi-mobile robotic machine in a dynamic environment. They examined the effects of both static and moving obstacles. Many studies point to dynamic impairment. Numerous studies have shown that GA has several drawbacks, including: Such as the gradual burden of convergence, the lack of certainty in finding the most important answer, and the time-consuming method of determining mutation price and population size parameters. As a result, Hong et al. [16] provide a modified GA direction planner for robot navigation, including population joint assessment methods. Improving the GA proved to be the gold standard simulation results for multiple robot structures in an unknown environment for obstacle avoidance and optimal orientation. Jianjun et al. There is a modified version of GA for route optimization. Her method alters the size of chromosomes and produces stunning results. Because the GA strategy adapts to the environment efficiently, it is applied to 2D route planning problems for humanoid robots and 3D route planning problems for marine and airborne robots. Peyto et al. To address the moving target problem, we proposed a matrix binary code-based genetic algorithm (MGA) in the complex environment of single- and multi-robot systems. Moreover, this strategy allows the robot to easily and quickly observe moving objects and obstacles to the target. The GA technique is a common smart tactic in defensive gear. creases, etc. We provided a missile control demo based entirely on a mixture of GA methods and fuzzy logic[17]. GA is an integral part of establishing the missile's driving law. Iyer et al. We describe a novel GA-based method for military and maritime surveillance applications. They used GA to determine the optimal deployment strategy for the underwater sensor community and protect high-value military assets.

2.2.2. Fuzzy logic (FL)

Zadeh first introduced the concept of FL in 1965 and used it in all areas of search and development. This method is used when there are excessive concentrations of complexity, nonlinearities, and uncertainties. These include information classification, sample recognition, autonomous control, and decision-making, among many others. Thanksgiving-based people-to-systems awesome features support the concept of the FL framework [18].

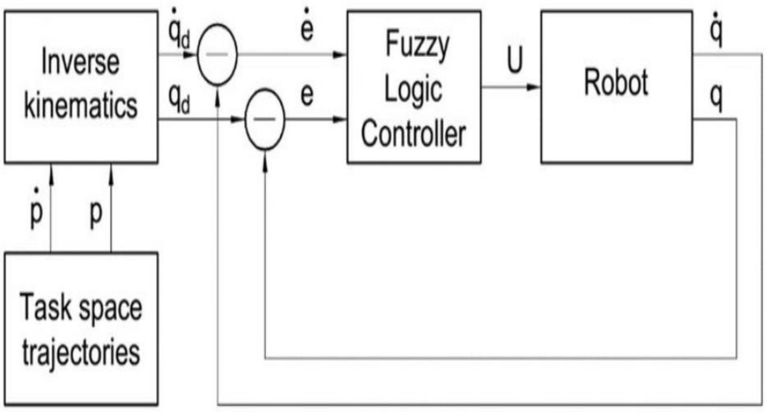

Figure.5. Fuzzy logic (FL) Method

When using human-supplied rules, interpret human-supplied if-then rules as mathematically equivalent. This simplifies the task for device designers and laptops, allowing them to obtain more accurate information about how the system behaves in the real world, which in turn can be used for cell robot trajectory planning. will be If-then rules are used in the basic FL system.Zavrangas et al. It provides a fuzzy (Sugano)-based navigation approach for omnidirectional mobile robots. For ease of navigation, Castellano et al. Created an independent system for developing ambiguous obstacle avoidance guidelines. FL provides a navigation system for unstructured static and dynamic environments. This strategy solves navigation problems such as backtracking, dead ends (U-shapes, mazes, snails), steering from small spots, and curved trajectories. FL is used in conjunction with sensor-based navigation. NN, GA, APF, ACO, and various algorithm-based navigation methods are used to generate optimal environmental perceptions that enable robots to navigate dead ends. Using enhanced navigation to reduce the uncertainty of angles and radii in the environment. By including FL as a data-driven technique, Khatib et al. and Lee et al. I was able to fix the navigation issue in the dynamic environment. A cooperative approach for navigating multiple cellular robots in unfamiliar and crowded environments was previously proposed by Hoy et al., Kang et al., and Al-Mutib et al. I researched how to improve the mobility of robots [19].

The head robot was once exposed to the first-order Kanno fuzzy system for the robot followers to emerge. The partner robotics got a low-level controller and the main robotics got a high-level controller based mainly on his 1st-order Sugano fuzzy system. The learning method was built using NN and the successful fuzzy rules were refined using ANFIS. A fuzzy-based method was developed by Rath et al. Drive a humanoid robot in a 2D area. Abbas et al. and Sho et al. Design trajectories for flying or underwater robots using fuzzy logic. One of the most difficult tasks is navigating the 3D world [20]. FL strategy was used to direct protective personnel. Used by defense companies for information and control of missiles, drones, and underwater robots. Rajasekhar et al. We used fuzzy logic in PNG to generate rocket acceleration commands using closing velocity and LOS rate (line of sight) as input variables. Linet al. We gave you a fuzzy crew selection guide device to choose the awesome ones.

2.2.3. Neural network (NN)

An artificial neural network (ANN) is an intelligent system composed of many small, tightly coupled processing components. These aspects convey information due to their ability to respond dynamically to environmental stimuli. Essentially, NNs are represented by ordered layers of related nodes. Nodes have an activation function. The pattern evidenced below can be recognized from the input layer of the NN mechanism [21]. These patterns are then combined with the embedded layer for the actual processing using weighted interconnection devices. The output layer communicates with the hidden layer to provide the required response. NN properties such as generalization, massively parallelism, distributed representation, learning ability, and fault tolerance can support mobile robot navigation. A NN for navigating a wheeled cellular robot in an unfamiliar environment. He used his two NN-based strategies to create collision-free paths. While the first neural mechanism uses sensory facts to discover unoccupied spaces, the second neural community (NN) computes safe paths by avoiding the nearest obstacles. To keep away from the human direction, Qiao et al. We advocate an independent acquisition of the navigation system [22]. Without human intervention, the NN adapts to the complexity of the environment by inserting and removing new hidden layers at specific training points to perform navigation tasks. Fast Simultaneous Localization and Mapping (Fast SLAM) is a method developed by Li et al. An approach that uses NNs to prevent the accumulation of errors is introduced using bad odometry mannequins and bad linearization of nonlinear SLAM functions. Using NN and Fast SLAM improves the ability of cellular robots to constantly navigate new areas while avoiding collisions with objects. The robot's navigation manoeuvres should obtain satisfactory possible sequences. Many techniques have been integrated into NNs as hybrid mechanisms. Young-gyun et al. Describe a mixed NN and APF effort to achieve cooperative and competitive coordination for behavior-based control [21].

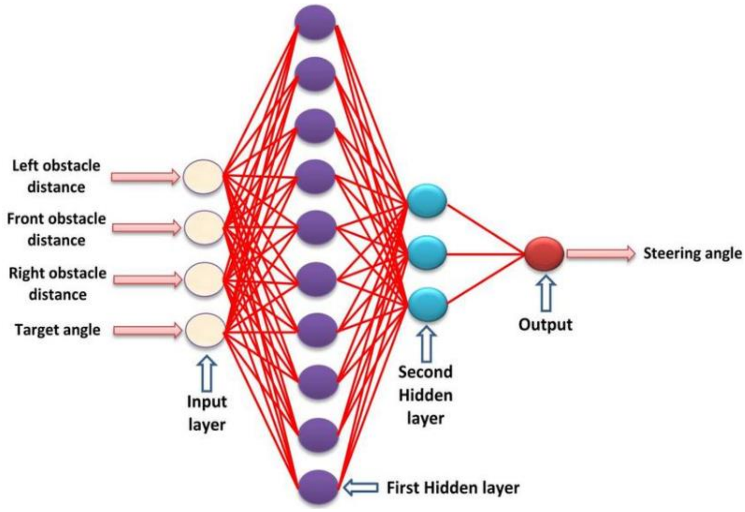

Figure.6. Neural network (NN) Method

post etc. We developed a hybrid approach using NN and FL to combine the advantages of both rational methods for multiple cellular robot navigation in chaotic situations. A recommended project is analyzed if there is a static obstacle structure. Using a combination of FL and NN [23], Abu Baker proposed a new hybrid strategy for cell robot-assisted navigation. NNs effectively identify a top set of activation rules for real-time utilities to constrain their computations. Presentation by Pal et al. How to use sonar and NN for mobile robot navigation. Medina-Santiago has developed a real-time neural manipulation machine for cellular robots using ultrasonic sensors. Said et al. We constructed a GAPCNN by modifying a real NN to achieve fast convergence of parameters for cell robot visits in static and dynamic environments. The method is modified based on directed automatic wave control and a dynamic threshold method using faster neural activity. Markoski et al. It mainly describes the self-learning method of cell robots based on NN. Quinones et al. We show how pattern recognition can be used as a strategy for mobile robot navigation in uncharted territory. NNs are a comprehensive and relevant route-planning approach due to their potential to explore and simulate non-linear and complex interactions. Run the search using the last level of statistical training. It is used to solve path planning problems for humanoid and industrial robots in 2D environments, underwater and airborne robots in 3D environments, and various robots with advanced interactions between structural and independent variables. It also detects and resolves all possible interactions between predictors and offers a variety of training techniques. in the field of protection and aerospace.

2.2.4. Firefly algorithm (FA)

Yang introduced FA in 2008. It is based entirely on Firefly's blink attribute and is also recognized as a meta-heuristic of his algorithm. His basic idea is based entirely on the probabilistic survival of fireflies in nature and their holistic consciousness as a random state. Fireflies, flying beetles of the family Lampyridae, are sometimes recognized as thunder Trojans because of their ability to emit light. Mildness is produced by the rapid oxidation of luciferin in the presence of the enzyme luciferase. To glow without losing warm energy, fireflies use an approach called bioluminescence to produce light[24]. Fireflies use this light to find mates, communicate messages, and sometimes warn of predators. Demonstrates navigating the robot using FA flowcharts and pseudocode. FA is now being used as an optimization tool, increasing its usefulness in almost every technological element, including cellular robot navigation. Hidalgo Paniagua et al. developed a cellular robot navigation method using FA in the presence of static obstacles. All three major navigation goals of headline length, smoothness, and safety were met[25]. Bland et al. proposed a collision-free shortest-path IA for single mobile robot navigation in a pure simulation scenario. Sutton et al. We verified the mechanism by which FA, an underwater mobile robot, deters predators. A flowchart and pseudocode for navigating the robot and using FA are shown in Figure 7. FA has recently been used as an optimization approach and is used by almost everyone today. FA was previously proposed for navigating mobile underwater robots. To eliminate interference and interference from 3D ocean coordination, they developed a swarm-robot scheduling approach. They observe the same light-firefly-based approach to a unique real-world underwater navigation problem in the same partially perceived environment. Christensen et al. Providing an FA-based collaborative approach for inanimate robot detection in multi-mobile robotic systems. Using his FA Wang and his colleagues to create and experiment with his 3D world exploration methods for air navigation. His UCAV route in this experiment is deliberately done using a speeded-up FA model to avoid hazardous locations and minimize gas consumption and complex, congested environments.

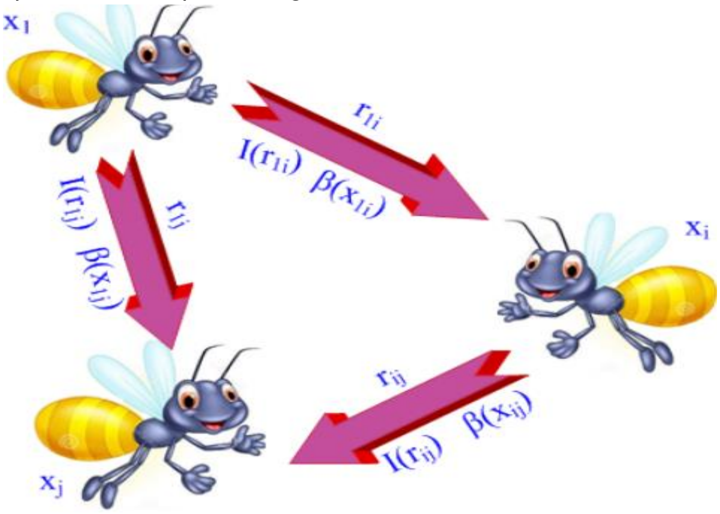

Figure.7. Firefly algorithm (FA) Method

Accelerated FA methods, mainly based on concentric spheres, were developed to prevent fireflies from randomly roaming while using much less computational power. The effects of simulation and testing show a strong commitment to realizing the dream of navigating complex environments. We evaluated FA studies of single and multi-robot structures in the presence of different constraints (concave, zigzag, convex) [26]. Any researcher has access to a large number of experiments, including experiments that increase the paths of robots. FA vision-based structures include the FA-Q mastering technique, the FAABC hybrid approach, and more. Tighzert et al. and Liu et al. We show how FA is specifically used for legged robots and underwater robots respectively. Peyto et al. Specifically, it rested dynamic navigation issues. They use FA to show path-planning strategies in the context of moving targets, and moving careers Yang started FA in 2008. It is based entirely on firefly blink attributes and is also recognized as a meta-heuristic algorithm. The basic idea is based entirely on the probabilistic survival of fireflies in nature and their holistic consciousness as a random state. Fireflies, flying beetles of the Lampyridae family, are sometimes recognized as thunder Trojans because of their ability to emit light[26]. Mildness is produced by the rapid oxidation of luciferin in the presence of the enzyme luciferase. To glow without losing warm energy, fireflies use an approach called bioluminescence to produce light. Fireflies use this light to find mates, communicate messages, and sometimes warn of predators. Demonstrates navigating the robot using FA flowcharts and pseudocode. Sutton et al. We verified the mechanism by which FA, an underwater mobile robot, deters predators. A flowchart and pseudocode for navigating the robot and using FA are shown in Figure 7. FA has recently been used as an optimization approach and is used by almost everyone today. FA was previously proposed for navigating mobile underwater robots. To eliminate interference and interference from 3D ocean coordination, they developed a swarm-robot scheduling approach. They observe the same light-firefly-based approach to a unique real-world underwater navigation problem in the same partially perceived environment. Christensen et al. Providing an FA-based collaborative approach for inanimate robot detection in multi-mobile robotic systems [27]. I used FA Wang and colleagues to create and experiment with a 3D world exploration method for air navigation. His UCAV route in this experiment uses a deliberately accelerated FA model to avoid hazardous locations and minimize gas consumption and complex, crowded environments. Accelerated FA methods, mainly based on concentric spheres, were developed to prevent fireflies from randomly roaming while using much less computational power. The effects of simulation and testing show a strong commitment to realizing the dream of navigating complex environments. We evaluated his FA studies of single and multiple robot structures in the presence of various constraints (concave, zigzag, convex). Any researcher has access to a multitude of experiments, including experiments to augment the pathways of the robot. FA vision-based structures include the FA-Q mastering technique, the FAABC hybrid approach, and more. Tighzert et al. and Liu et al. We show how FA is specifically used for legged robots and underwater robots respectively. Peyto et al. Specifically, addressed dynamic navigation issues[28]. They used FA to demonstrate path-planning strategies in the context of moving targets and barriers.

2.2.5. Particle swarm optimization (PSO)

This metaheuristic algorithm is inspired by nature and mimics the social behaviour of communities of species such as fish feathers and flocks of birds. In 1995 he discovered an unexpected increase in optimization devices developed by Eberhart and Kennedy to overcome various engineering and scientific difficulties. PSO mimics animal social behaviour but does not require a crew leader to function. A flock of birds no longer needs a leader when foraging[29]. Instead, cater to the member closest to the meal. Flocks of birds, therefore, interact efficiently with other individuals in the population, resulting in favourable solutions. The PSO equation consists of several particles, each representing a potential. PSO has emerged as a prominent technology for cellular robot navigation. Tang X et al. We used multi-agent particle filters to address the challenges of mapping and localization of mobile robot navigation in unfamiliar environments. PSO is used because it has good steady-state convergence properties and is computationally useful. . Shure et al. used the PSO strategy in combination with his MADS algorithm to generate accurate trajectories and avoid turning to hitch neighbourhood optimization. Compared to the Extended Kalman Filter (EKF) and GA, the PSO MADS algorithm guarantees high-quality results. Area Extended PSO (AEPSO) is an adaptation developed by Atyabi et al

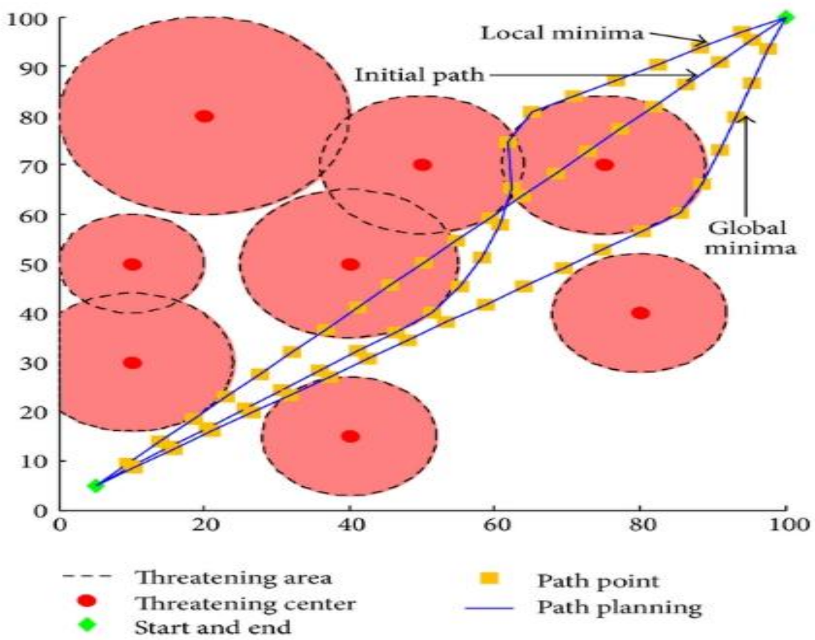

Figure.8. Particle swarm optimization (PSO) Method

. Use Critical PSOs to address issues related to dynamic and time-dependent constraints of mobile structures [30]. AEPSO approaches are useful for bomb disposal and survivor search and rescue. Tang et al. Joint locomotion route planning in challenging environments involve navigation of multi-mobile robotic systems. We then use PSO to consider the fault tolerance of the proposed method together with multibody device dynamics, including features such as robot-like acceleration, mass, force, and inertia. Cuseiro et al. Made changes to the actual navigation of some mobile robots. To solve the communication and obstacle avoidance problems, they modified his PSO and Darwin PSO (DPSO) systems. They found that the device with 12 real robots reached up to 90% for maximum communication range and universal ideal effectiveness. Che et al. We sought to construct a human expert management approach with learning-based skills for hazardous environments using a multi-category classifier. PSO is used to improve accuracy quickly. Higher accuracy as opposed to standard grid search. Li et al. The method developed to optimize the particle swarm (SLPSO) is self-adaptive. was created to solve robotics route planning problems in complex environments while meeting many constraints. They initially carried out the navigation intent of path planning by transforming the direction planning problem into a multi-objective minimization optimization problem. The searchability of his PSO in multi-constraint environments was enhanced using a self-adaptive mastering strategy that considers criteria such as directional length, collision probability level, and smoothness [31]. Das and his colleagues developed a hybrid technique for successful route planning. They combined the Accelerated Gravity Search Algorithm (IGSA) with his PSO to develop a hybrid technique that determines the best course of action for a large number of cellular robots in crowded environments. He considers using his PSO to solve the difficulty of underwater navigation in his difficult 3D environment. In this study, we used a hybrid PSO-U Fast SLAM technique to improve estimation accuracy while reducing particle size. Flying robots, humanoid robots, and industrial robots in unfamiliar 3D environments all navigate PSO technology as well as underwater robots. Algebra M et al. Various techniques such as GA, PSO, NN, and FL were studied to find the optimal navigation control. They found that combining FL and PSO [32] yielded the greatest results in terms of distance travelled. PSO can be used for more than just mobile robot navigation in the military industry. bank etc. studies using his PSOs for non-deterministic navigation of UAVs so that they can work together to protect large areas from air attacks.

2.6. Ant colony optimization (ACO)

In 1992, Marco Dorigo developed this swarm intelligence technique for his Ph.D. paper. A population-based approach was employed to solve the combinatorial optimization problem. Ant's ability to find the shortest route from the nest to the food source was used to stimulate the ACO algorithm [33]. ACO methods are used in graph colouring, square project problems, car routing, vendor visit problems, work schedules, and many other scientific and technical areas. ACO is used to tackle the challenge of cellular robot navigation to determine subtle paths and avoid obstacles. Guan-Zheng et al. We asked ACO to plan the route of cellular robots in real-time. ACO was established. Compared to other techniques such as GA, ACO improves convergence speed, response variation, processing efficiency, and dynamic convergence behaviour. Liu et al. We demonstrate the application of ACO in multi-mobile robot navigation. They created a collision avoidance system for several static robot designs. They used special features to improve their decision-making process. If the ant dies, a penalty is added to the depth of the path the robot rides on. Castillo et al. We propose a hybrid ACO fuzzy technique for static mobile robot navigation. Kumar et al. We provide a humanoid robot navigation approach based on his RA-ACO, mainly for crowded environments. They used Petri nets to study a proposed approach for real-time navigation of multiple humanoid robots and observed reasonable agreement between simulation and real-time results.

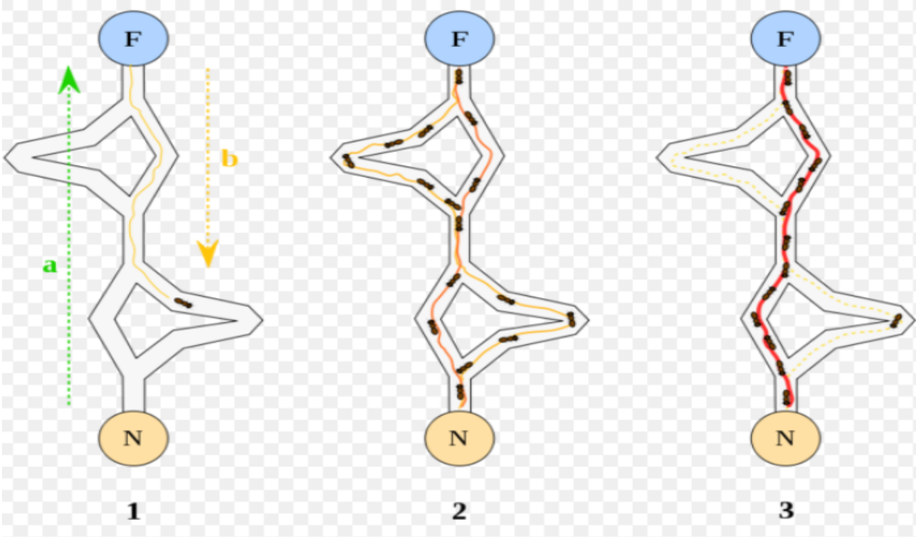

Figure.9. Ant colony optimization (ACO) Method

If the ant dies, a penalty is added to the depth of the path the robot rides on. Castillo et al. We propose a hybrid ACO fuzzy technique for static mobile robot navigation. Kumar et al. We provide a humanoid robot navigation approach based on his RA-ACO, mainly for crowded environments. They used Petri nets to study a proposed approach for real-time navigation of multiple humanoid robots and observed reasonable agreement between simulation and real-time results. Liu et al. We propose a modification of the current ACO approach in static environments [34]. They explain that the key to impacting performance is convergence speed. They combined pheromone diffusion and geometric local optimization to determine the most useful pathways. Ali decides to search a larger health subspace and the search area for patterns narrows by clipping his path, allowing the pheromone to diffuse into viable disciplined force paths during the search. Rajput et al. There is an additional charge for dynamic environments. We also developed a unique pheromone update system to eliminate unnecessary loops and speed up convergence. According to Puritans et al. His ACO algorithm for mobile robots was used. The idea of Brand and his colleague Liu et al. His 3D route planning for underwater vehicles uses an ACO-based search algorithm to find a collision-free route from one of his websites online to another of his websites. To overcome the stagnant behaviour and lack of speed of their ant colony algorithm, Chen et al. developed ACO technology to address the routing problem of unmanned aerial vehicles on the battlefield. The Ant Colony Algorithm is also used in military equipment. Advanced. He recommends using ACOs for missile route planning with improved performance [35]. That is the acceleration method for determining the most desirable route length and exact direction.

2.2.6. Bacterial foraging optimization (BFO) algorithm

In 2002, Passino introduced an advanced, nature-inspired optimization approach based primarily on the behavior of E. coli and M. Xanthus bacteria. These microbes make the most of their available energy per unit of time to find nutrients. Chemotaxis, a function of the BFO algorithm, detects chemical gradients by the way microbes pronounce specific signals. Its four compelling ideas include chemotaxis, swarming, breeding and extinction, and dispersal. We describe and demonstrate microbial replication exploring trophic zones.Bacteria are constantly migrating to other parts of the world in search of new resources. Bacteria in nutrient-rich environments multiply and die, while bacteria in nutrient-poor environments live longer and divide in half [36]. Bacteria in larger, nutrient-rich environments are attracted to bacteria in nutrient-poor environments by chemical phenomena, and the latter bacteria use their signals to inform the former of their presence. Bacteria form nutrient-rich compartments on the map. Bacteria spread across the map again, creating new trophic zones.

First, Coelho et al. We demonstrate the implementation of variable-paced BFO strategies based on uniform, Gaussian, and Cauchy distributions for cellular robot navigation in static environments. reference Shows identical steps given different constraints for navigating in a static environment [37]Gaspari et al. Support real-time navigation in hallways and lobbies and create floor settings using a single cellular robotic system. Abbasi et al. Developed his multiplied BFO algorithm to improve direction planning and overall performance of wheeled robots.

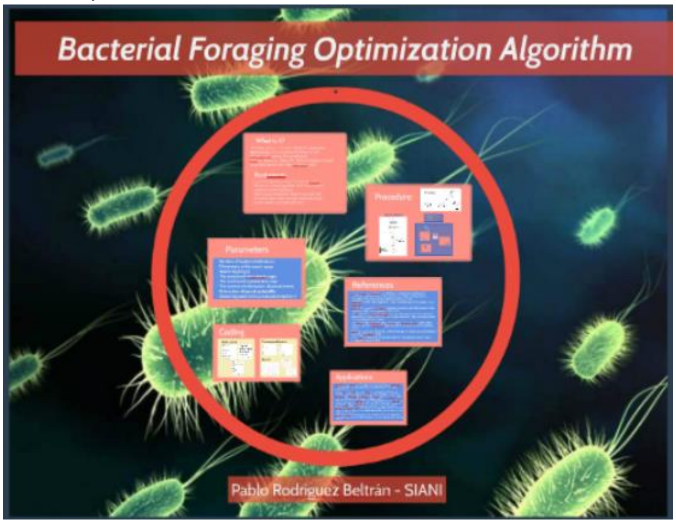

Figure.10. Bacterial foraging optimization (BFO) algorithm Method

The provided strategy uses the APF approach to represent the environment through the application of two opposing forces. Attractive force on goals and repulsive pressure on obstacles. This method looks at bad inputs to the algorithm and chooses a nice route vector that pushes the search method into promising areas for good local search. Jayty et al. It offers a BFO strategy to deal with navigation in the presence of some robots, which is itself a difficult proposition. In their research, they combined BFO with a harmony search algorithm. Apart from the fact that his BFO method was used correctly on a wheeled robot for industrial manipulators. See Coelho et al. For additional information observe that the modified BFO outperforms the preferred BFO [38]. Oikan et al. You have set up a UAV BFO navigation task. This approach uses a proportional necessary by-product (PID) controller to provide gold standard search parameters in 3D space and avoid modelling difficulties when fine-tuning the UAV BFO's controller.

2.2.7. Artificial bee colony (ABC) algorithm

Kharaboga developed the ABC algorithm, an intelligent swarm-based method stimulated by honeybee foraging behaviour. The population of the population-based ABC algorithm consists of unique solutions. It is a population-based probabilistic search strategy in the field of swarm algorithms that is particularly easy to use and analyses data quickly. The ABC Meal Search Cycle consists of three parameters as shown below [39]. Guide staff bees to a food source while examining nectar (exception) After receiving records from worker bees and assessing nectar quality, observers select a food source. Select Scout Bees and guide them to viable food sources Contreras-Cruz et al. We demonstrate how to use the ABC algorithm for cellular robot navigation in static environments. The developed method uses an evolutionary algorithm to find the optimal path and ABC for local search. Real-time testing in a closed context is provided to validate results figure.11. Safari etc. Their results relate entirely to the simulation scenario but describe equivalent procedures in a static context. Horse et al. Provides an ABC-based method for navigating dynamic real-time environments. These are strategies hybridized by combining the ABC algorithm and the time-rolling window method. It is difficult to operate cellular robots in certain regions. Implementing ABC is a difficult task. However, Bhattacharjee et al. and Liang et al. ABC ran successfully in a static environment. The ABC algorithm is used for challenges common to air navigation, underwater navigation, and self-sufficient vehicles. g. Mobile robot navigation on wheels. UCAV route planning attempts to construct optimal flight directions in a 3D environment, taking into account battlefield threats and limitations. Please read al. Solve the UCAV navigation problem using an extended ABC approach

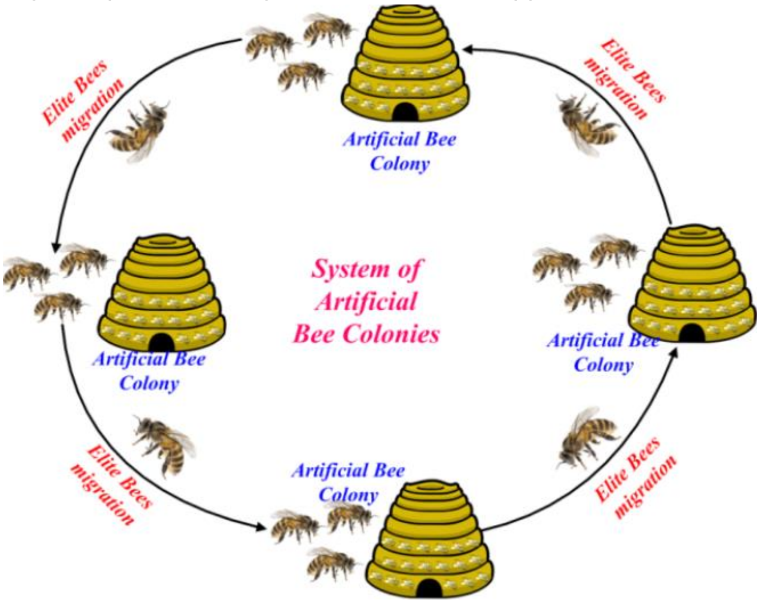

Figure.11. Artificial bee colony (ABC) algorithm Method

. An improved version of the ABC algorithm, the Balance Evolution Approach (BES), takes full advantage of the convergence data collected at some point in the iterations to change the precision of exploration and improve local and global exploration capabilities. achieve balance. Applications for demanding tasks such as data acquisition, precision measurement, and boundary detection patrol [42]. They developed a special discriminative strategy using an ABC controller and a chaos operator to discover unknown parameters of two separated linear models based on flight data collected from experiments. Based on experimental flight facts, we use an ABC controller and a chaos operator to identify the unknown parameters of two decoupled linear models.

2.2.8. Cuckoo search (CS) algorithm

A host's nest probability is set, and host chickens have a chance to find a cuckoo's egg. The host chicken can either remove the eggs or get out of this state. However, since the CS algorithm is a new approach, there are not many research papers using it to create cellular robot paths. Mohanty et al. There are now steering methods wheeled robots in static environments [43]. Even though the area is unknown, simulations and real-time experiments of wheeled robots traversing the area have been proven. There is a high degree of agreement between the simulation and test effects as the deviation error is greatly minimized. CS-based techniques work well when used in conjunction with other navigation tactics.

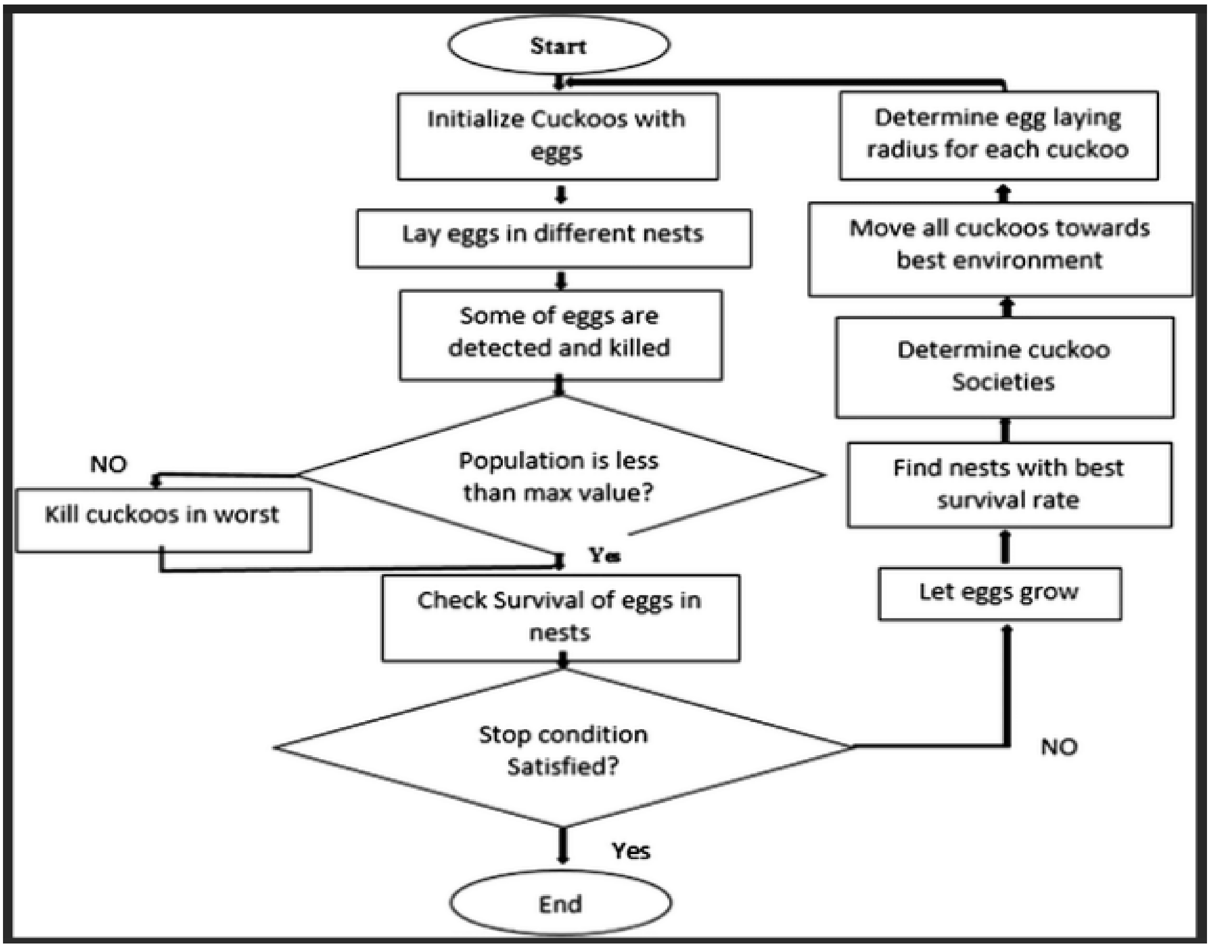

Figure.12. Cuckoo search (CS) algorithm Method

Mohanty et al. We introduced a hybrid of CS and ANFIS in this approach to decorating navigation effects in insecure environments. Another hybrid path planning technique for unknown 3D worlds is the idea of Wang et al., which combines a differential evolution algorithm with CS to accelerate global convergence [44]. Fast convergence allows the flying robot to see his 3D world better. Apologize. The proposed implementation of CS algorithms for navigating 3D environments, especially battlefields. In their paper, they validated that a hybrid approach combining CS and differential evolution algorithms could handle the difficulty of his 3D airway planning. We use differential evolution. problem. The updated CS model uses differential evolution to speed up the cuckoo's selection process, allowing birds to choose the highest quality direction to act as agents.

2.2.9. Shuffled frog leaping algorithm (SFLA)

Eusuff and Lansey's metaheuristic optimization strategy was originally developed based on the foraging behaviour of frogs. SFLA has made a name for itself in the field of technical optimization. Unlike other metaheuristic algorithms, it converges faster, is easier to implement, has fewer parameters, has a higher success rate, and has better search capabilities in the face of uncertainty [45]. Today, SFLA is widely used to address technical optimization problems such as B. Cell robot navigation. The median strategy is used by Ni et al. Used to work around the problem of local most efficient solutions.

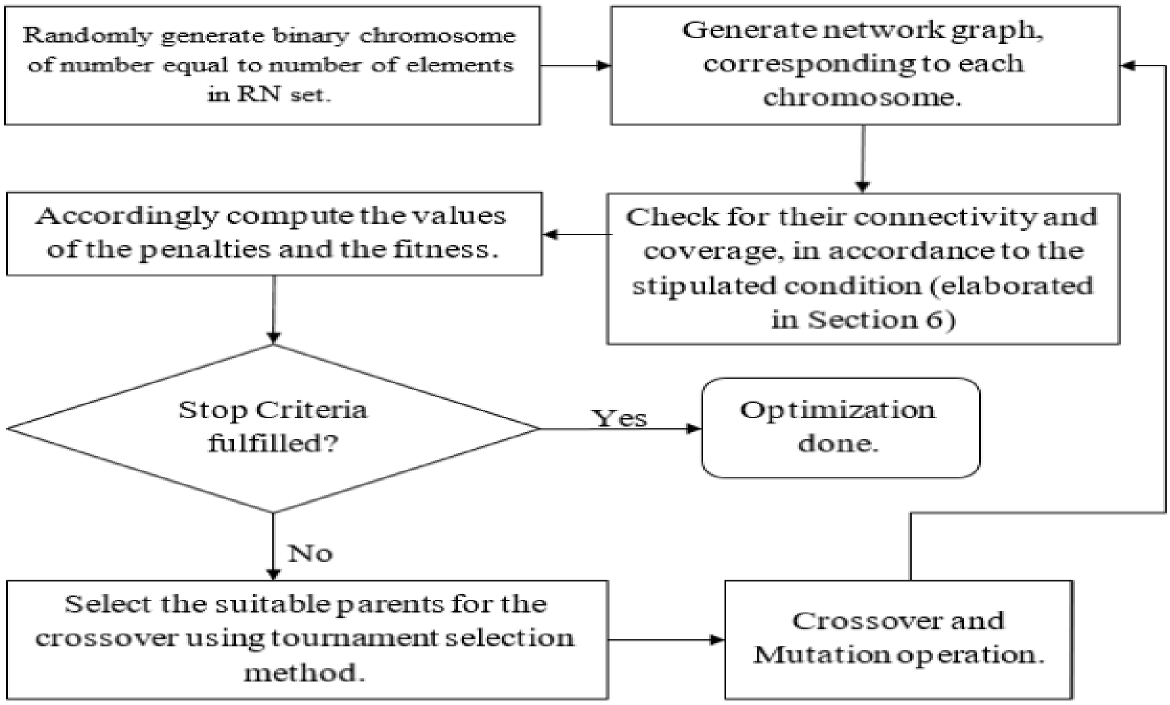

Figure.13. Shuffled frog leaping algorithm (SFLA)

They modify the health algorithm to provide a comfortable course while piling up large frogs in the world and use their position to guide the robot's movements in the presence of static and moving barriers. Hidalgo-Paniagua et al. We tested that the multi-target SFLA-based approach can also achieve large navigation desires such as course length, directional safety, and route smoothness. will be His current SFLA produces significantly smoother root-sized output. Guideline Research and presentation of techniques for 3D aquatic environments. The adaptive approach uses local minimum situation steering to optimize direction and required navigation time. Verification in a chaotic context is provided by the very good agreement between simulation and experimental results [46]. In addition, he can work on his 3D route planning and vehicle routing of UAVs using a modified SFLA approach for cellular robotic navigation. Liang et al. Developed his SFLA-based flight management gadget for military air-breathing hypersonic vehicles. To provide climb, cruise, and descent control, a modified SFLA is constructed using a proportional-integral-derivative approach that includes peak information, velocity, and pitch angle loops.

3. DISCUSSION

Classical and reactive approaches are two types of navigation strategies that emerged from a detailed study of referenced articles in the literature. Decades ago, most robotic searches were done using a naive approach. Traditional approaches have various drawbacks, such as computational complexity, local minima trapping, inability to deal with maximum uncertainty, the need for explicit environmental information, and the need for accurate real-time navigation detection mechanisms [47]. As a result, using historical methods, a solution is never identified or suspected of being found. There is no face like an answer. These techniques are unpredictable and unstable, making them dangerous to use in real-time. Despite efforts by various researchers to expose the weaknesses of typical strategies and to develop a variety of state-of-the-art strategies, B. APF, and some hybrid algorithms, these techniques perform well in real-time scenarios. is not better than the reactive technique of Traditional strategies for navigating the legacy environment are often used because they require prior knowledge of the workspace [48]. Reactive strategies, on the other hand, are used to navigate uncharted territory. This is because it can deal with the high level of uncertainty that prevails there. They are used in real-time because they are easy to use, smart, and more. Outperforms traditional methods and addresses the navigation problem Reactive strategies are best suited to standard approaches, but they suffer from long computation times, sophisticated designs, the need for training periods, and large memory requirements, It has many shortcomings, including impracticality for affordable robots. The percentage of articles published for each of the classical and reactive approaches is used for comparison. Reaction systems are more economical than traditional methods. The APF method has proven to be particularly successful with traditional methods of robot movement around static objects. Unlike CD and RA, it can be used in real-time and is used in various mobile robotic systems. Dynamic Objective Conditions, Dynamic Obstacles, and Dynamic Objective Instances Speech decomposition approaches have been used more frequently than APF and RA in hybrid navigation systems. In contrast to CD and RA, APF methods for solving the challenges of robot navigation in partially known and unfamiliar environments have gained credibility over the last two decades. This figure shows that reactive strategies are used much less often than dynamic boundaries and targets, navigation by multiple robots, and real-time applications [49]. Reactive methods are becoming increasingly popular because they can quickly and computationally efficiently deal with unforeseen situations. Figure 29 shows the use of both basic and post-processes for robot navigation. This shows that between 1970 and 2018, the acceptance of passive tactics increased from 0% to 95%, while the popularity of traditional techniques declined from 95% to 5%. In the 21st century, the usefulness of reactive algorithms in mobile robot navigation has evolved rapidly [50]. Reactive algorithms are currently the only algorithm used to get the job done, and more than 95% of them use it. Many teachers learn fuzzy-based reactive methods of observed trajectory planning using GAs and NNs.The 3D workspace explored the use of traditional reactive methods for orientation planning of airborne and underwater engines. Table 2 suggests using a proprietary algorithm for 3D path planning. As evidenced by the data, more reactive methods than traditional methods were frequently used to explore 3D environments in the presence of most uncertainties. Traditional methods lack the intelligence required for standalone path planning in a 3D environment, so they have been hybridized with FL, GA, and other strategies to improve overall performance. Almost all reactive and classical methods are used to solve course planning problems. Avoiding trouble in air situations Reactive obstacle avoidance, which is based entirely on boundary tracking, is one exception. These three techniques are sliding mode control, harmony search, differential evolution, and these three procedures. He no longer uses CD, RA, BFO, CS, IWO, or BAT algorithms for underwater course planning as well as mobile robots [51]. Using GPS with good paths and controls can help you reach your destination. Army equipment such as submarines, anti-missile defence systems, tanks, guns, drones, current wartime aircraft, missiles, and helicopters are used in today's dangerous situations, and all these structures are based on reactive ingenuity. is largely or completely reminiscent.

4. CONCLUSION

This exploration of cellular robot navigation divides different methods into classical and reactive approaches. Here are the basic results of the study: Reactive methods are superior to traditional methods because they can better deal with environmental uncertainty. The reactive approach is of high quality and is used for real-time navigation challenges. The dynamic environment research centre is far less than the static environment research. Dynamic environment navigation of robots has been less studied for target transfer problems than for obstacle problems. Most research today specifically provides simulation analysis, and far fewer articles obscure real-time applications. Navigation in multicellular robotic structures has been less studied than in single-celled robotic systems. In contrast, the Ones in the hybrid algorithm is significantly less canonical than its behaviour in the solo algorithm.

5. REFERENCES.

[1] Patle BK. intelligent navigational strategies for multiple wheeled mobile robots using artificial hybrid methodologies. Thesis NIT Rourkela; 2016.

[2] Hoy M, Matveev AS, Savkin AV. Algorithms for collision free navigation of mobile robots in complex cluttered environments: a survey. Robotica 2015;33(Issue 03):463-97.

[3] Yang L, Qi J, Song D, Xiao J, Han J, Xia Y. Survey of robot 3D path planning algorithms. J Control Sci Eng 2016:5.

[4] Seda Milos. Roadmap methods vs. cell decomposition in robot motion planning. In: Proceeding of the 6th WSEAS international conference on signal processing, robotics and automation. World Scientific and Engineering Academy and Society (WSEAS); 2007. p. 127-32.

[5] Regli W. “Robot Lab: robot path planning,” Lecture notes of department of computer science. Drexel University; Oct 2007.

[6] Schwartz TJ, Sharir M. "On the "Piano Movers" Problem I. The case of a two-dimensional rigid polygonal body moving amidst polygonal barriers. Commun Pure Appl Math 1983;36(3):345-98.

[7] Weigl M, Siemiaatkkowska B, Sikorski AK, Borkowski A. Grid-based mapping for autonomous mobile robot. Robot Autonom Syst 1993;11(1):13-21.

[8] Zhu D, Latombe JC. New heuristic algorithms for efficient hierarchical path planning. IEEE Trans Robot Autom 1991;7(1):9-20.

[9] Conte G, Zulli R. Hierarchical path planning in a multi-robot environment with a simple navigation function. IEEE Transactions on Systems, Man and Cybernetics 1995;25(4):651-4.

[10] Samet H. "An overview of quadtree," octrees and related hierarchical data structures. 1988. NATO ASI Series, F40.

[11] Noborio H, Naniwa T, Arimoto S. "A quadtree-based path-planning algorithm for a mobile robot. J Robot Syst 1990;7(4):555-74.

[12] Lingelbach F. Path planning using probabilistic cell decomposition. IEEE International Conference on Robotics and Automation 2004. https://doi.org/ 10.1109/ROBOT.2004.1307193.

[13] Rosell J, Iniguez P. Path planning using harmonic functions and probabilistic cell decomposition. IEEE International Conference on Robotics and Automation 2005. https://doi.org/10.1109/ROBOT.2005.1570375.

[14] Sleumer Nora, Tschichold-Gurmann, Nadine. "Exact cell decomposition of arrangements used for path planning in robotics", technical report/ETH zürich. Department of Computer Science; 1999. https://doi.org/10.3929/ ethz-a-006653440.

[15] Cai Chenghui, Ferrari Silvia. Information-driven sensor path planning by approximate cell decomposition. IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics) June 2009;39(3). https://doi.org/10.1109/ TSMCB.2008.2008561.

[16] Dugarjav Batsaikhan, Lee Soon-Geul, Kim Donghan, Kim Jong Hyeong, Chong Nak Young. Scan matching online cell decomposition for coverage path planning in an unknown environment. Int J Precis Eng Manuf 2013;14(9):1551-8.

[17] Dusan Glavaski, Volf Mario, Bonkovic Mirjana. Robot motion planning using exact cell decomposition and potential field methods. In: Proceedings of the 9th WSEAS international conference on Simulation, modelling and optimization. World Scientific and Engineering Academy and Society (WSEAS); 2009.

[18] Tunggal, Padang Tatiya, et al. Pursuit algorithm for robot trash can based on fuzzy-cell decomposition. Int J Electr Comput Eng 2016;6(6):2863-9.

https://doi.org/10.11591/ijece.v6i6.10766. [19] Mark A, Gill C, Albert Y, Zomaya. A cell decomposition-based collision avoidance algorithm for robot manipulators. Cybern Syst 2010;29(2): 113-35. https://doi.org/10.1080/019697298125759.

[20] Gonzalez R, Kloetzer M, Mahulea C. Comparative study of trajectories resulted from cell decomposition path planning approaches. In: System theory, control and computing (ICSTCC), 21st international conference on. IEEE; 2016. p. 49-54.

[21] Wahyunggoro O, Cahyadi AI. Quadrotor path planning based on modified fuzzy cell decomposition algorithm. Telkomnika 2016;14(2).

[22] Choset, Howei Burdick, Joel. Sensor-based exploration: the hierarchical generalized Voronoi graph. Int J Robot Res 2000;19(2):96-125.

[23] Lulu L, Elnagar A. A comparative study between visibility-based roadmap path planning algorithms. In: 2005 IEEE/RSJ international conference on intelligent robots and systems; 2005. p. 3263-8.

[24] Berg MD, Kreveld MV, Overmars MM, Schwarzkopf OC. Computational geometry, vols. 1-17. Springer Berlin Heidelberg; 2000.

[25] Choset H, Lynch KM, Hutchinson S, Kantor G, Burgard W, Kavriki LE, Thrun S. Principles of robot motion. Cambridge, MA: MIT Press; 2005.

[26] Takahashi O, Schilling RJ. Motion planning in a plane using generalized Voronoi diagrams. IEEE Trans Robot Autom 1989;5(2):143-50.

[27] Dunlaing CO, Yap CK. A retraction method for planning the motion of a disc. J Algorithms 1985;6:104-11.

[28] Garrido S, Moreno L, Blanco D, Jurewicz P. Path planning for mobile robot navigation using Voronoi diagram and fast, marching. Int J Robot Autom 2011;2(1):42-64.

[29] Masehian E, Naseri A. Mobile robot online motion planning using generalized Voronoi graphs. J Ind Eng 2010;5:1-5.

[30] Shkolink E, Tedrake R. Path planning in 1000þdimension using a task-space Voronoi bias. In: IEEE international conference on robotics and automation; 2009.

[31] Bhattacharya P, Gavrilova ML. Roadmap-based path planning-using the Voronoi diagram for a clearance for a clearance-based shortest path. IEEE Robot Autom Mag 2008;15(2):58-66.

[32] Masehian E, Amin-Naseri MR. A Voronoi diagram-visibility graph-potential field compound algorithm for robot path planning. J Robot Syst 2004;21: 275-300.

[33] Yang DH, Hong SK. A roadmap construction algorithm for mobile robot path planning using sleton maps. Adv Robot 2007;21(1e2):51-63.

[34] Wein R, Van Den Berg JP, Halperin D. The visibility-voronoi complex and its application. Comput Geom 2007;36:66-87.

[35] [35]

LE, Svestka P, Latombe JC, Overmars MH. Probabilistic roadmaps for path planning in high dimensional configuration spaces. IEEE Trans Robot Autom 1996;12:566-80.

[36] Sanchez G, Latombe J. A single-query bidirectional probabilistic roadmap planner with lazy collision checking, vol. 6. Springer Tracts in Advanced Robotics; 2001. p. 403-17.

[37] Yan F, Liu YS, Xiao JZ. Path planning in complex 3D environments using a probabilistic roadmap method. Int J Autom Comput 2013;10(6):525-33.

[38] Khatib O. Real time obstacle avoidance for manipulators and mobile robots. In: IEEE international conference on robotics and automation, Missouri, vols. 25-28; Mar 1985. p. 500-5. [39] Garibotto G, Masciangelo S. Path planning using the potential field approach for navigation. In: Fifth international conference on advanced robotics, pisa, Italy, vols. 19e22; June 1991. p. 1679-82.

[40] Kim JO, Khosla PK. Real-time obstacle avoidance using harmonic potential functions. IEEE Trans Robot Autom 1992;8(3):338-49.

[41] Borenstein J, Koren Y. Real-time obstacle avoidance for fast mobile robots. IEEE Transactions on Systems, Man and Cybernetics 1989;19(5):1179-87.

[42] Ge SS, Cui YJ. Dynamic motion planning for mobile robots using potential field method. Aut Robots 2002;13(3):207-22.

[43] Montiel Oscar, Orozco-Rosas Ulises, Sepúlveda Roberto. Path planning for mobile robots using Bacterial Potential Field for avoiding static and dynamic obstacles. Expert Syst Appl 2015;42(Issue 12):5177e91. https://doi.org/10. 1016/j.eswa.2015.02.033.

[44] Valavanis KP, Hebert T, Kolluru R, Tsourveloudis N. Mobile robot navigation in 2D dynamic environments using an electrostatic potential field. IEEE Trans Syst Man Cybern A Syst Hum 2000;30(2):187-96.

[45] Huang L. Velocity planning for a mobile robot to track a moving target-a potential field approach. Robot Autonom Syst 2009;57(1):55-63.

[46] Shi P, Zhao Y. An efficient path planning algorithm for mobile robot using improved potential field. In: IEEE international conference on robotics and biomimetics, guilin, China, december, vols. 19e23; 2009. p. 1704-8.

[47] Sfeir J, Saad M, Saliah-Hassane H. An improved artificial potential field approaches to real-time mobile robot path planning in an unknown environment. In: IEEE international symposium on robotic and sensors environments, montreal, Canada, september, vols. 17-18; 2011. p. 208-13.

[48] Pradhan SK, Parhi DR, Panda AK, Behera RK. Potential field method to navigate several mobile robots. Appl Intell 2006;25(3):321-33.

[49] Orozco-Rosas U, Montiel O, Sepúlveda R. Parallel bacterial potential field algorithm for path planning in mobile robots: a gpu implementation. In: Fuzzy logic augmentation of neural and optimization algorithms: theoretical aspects and real applications. Springer; 2018. p. 207-22.

[50] Raja Rekha, Dutta Ashish, Venkatesh KS. New potential field method for rough terrain path planning using genetic algorithm for a 6-wheel rover. Robot Autonom Syst October 2015;72:295-306. https://doi.org/10.1016/j. robot.2015.06.002.

[51] Kuo Ping-Huan, li Tzuu-Hseng s, Chen Guan-Yu, Ho Ya-Fang, Lina Chih-Jui. Migrant-inspired path planning algorithm for obstacle run using particle swarm optimization, potential field navigation, and fuzzy logic controller. Knowl Eng Rev 2017;32(e5):1-17. https://doi.org/10.1017/ S0269888916000151. Cambridge University Press.