



Bio-inspired techniques for robots autonomous navigation: A Survey

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Abstract

This paper presents the current robot automatic navigation methods based on bio-inspired techniques. An autonomous robot has to be able to acquire the information it needs to reason and to provide it with a locomotion capacity adapted to its environment. However, it is necessary to understand the basic functions that are required for robots to think and work like humans, it involves complex systems in the realization, on the one hand, technological where this mechanical system capable of navigating anywhere using sensor-actuator control techniques.

And on the other hand scientific is how to transform this normal mobility into intelligent navigation the basis of the functions of planning, action, monitoring, perception, and reasoning. These functions help the robot to develop its skills, which can control a mobile robot autonomously in a static and/or dynamic environment and avoid obstacles based on information about its position and the environment in which it is operating.

1. Introduction:

Nowadays, mobile robots are widely used in many fields. The artificial intelligence brings to those machines the ability to think in an analytical way to accomplish different tedious tasks efficiently and without any human intervention.

Autonomous robot navigation is one of the most difficult problems encountered in robot realization. Navigation is the set of methods, knowing the position of mobile in relation to a reference system or a fixed point, allow the calculating or the measuring of the path to follow to reach another well-known coordinate point [1].

In literature, a great number of automatic robot navigation approaches are proposed. The aim of most of them is to improve the performance of time calculation and/or the quality of the proposed solution. Only the researches based on bio-inspired approaches published since 2011 are discussed in this paper.

In the continuation of this paper, section 2 explains different bio-inspired techniques used for automatic robot navigation. Section 3, compares the studied navigation approaches. Finally, Section 4 gives a summary of this literature review.

2. Bio-inspired Navigation Strategies

The navigation strategies allowing a mobile robot to trace a trajectory and automatically reach an objective using its abilities to

- build a representation of its static or dynamic environment
- analyze collected information and,
- give a decision about the direction it has to take to near its objective or to avoid obstacles.

Several bio-inspired approaches are used in this field. We will discuss the most famous methods based on Neuroscience, evolutionary algorithms and swarm intelligence. Figure 1 flows the most used bio-inspired techniques applied to robot navigation approaches.

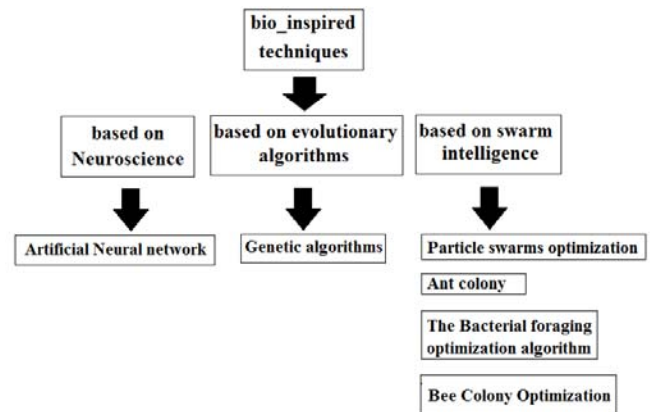


Figure 1: Bio-inspired techniques applied to robot navigation approaches.

2.1. Genetic Algorithms (GA)

Genetic algorithms belong to an Evolutionary Algorithm [2]. These algorithms are stochastic optimization techniques inspired by Darwin's Theorem of evolution, whose goal is to obtain an approximate solution at an acceptable time.

Genetic algorithms are the result of the research of John Holland and his colleagues and students at the University of Michigan who, as early as 1960 [3], worked on this subject. Genetic Algorithms use techniques inspired by genetics and natural evolution: crosses, mutations, selections, etc. The novelty introduced by taking into account the crossover operator in addition to mutations is that this operator makes it possible to approach the optimum of a function by combining the genes contained in the different individuals in the population.

Genetic algorithms are based on the notion of natural selection and apply it to a population of solutions to a given problem. They represent a stochastic optimization method of "0" order, which means that neither continuity nor differentiability is necessary for the method to work properly, only the knowledge of the value where the proximity of the function to be optimized is sufficient. Thus, the efficiency of a genetic algorithm depends on a good knowledge of the problem to be treated.

The steps in the execution of a genetic algorithm are:

1. Initial population:
2. Ability function:
3. Selection:
4. Crossing and mutation:
5. Mutation
6. Stop Test: If this criterion is not met, go to step (2).

In [4] the authors proposed a new mutation operator for a genetic algorithm (GA) and applied it to mobile robotic navigation in a dynamic plane. In conventional GA, the random mutation can generate infeasible pathways, and this new node modified by the mutation can present an obstacle and therefore produce an infeasible pathway. In [4] technique, random points are chosen from the free points close to the mutation gene. The selection of these points is guided by the direction forward determined by a comparison of the coordinates of the starting point and the target. If this direction is impossible, a random selection of points is repeated until the process finds a possible direction or the set of points is finished. Besides, the authors tested their approach in various simulation environments and compared it to conventional genetic algorithms. They found that their proposed GA is more efficient than the traditional GA.

In [5] the authors combined crossing in genetic algorithms with dynamic chromosome coding to propose a multi-objective method. The proposed method

objective is to find a feasible and achievable routing between two points through the whole distance to the arrival point and of course, avoiding obstacles. The proposed method respects distance, security and computation time, and it optimizes certain criteria such as distance (length), safety (the trajectory must be as far as possible from obstacles). The authors applied modifications so that the chromosomes are coded on a variable length and also avoid premature convergence and avoid the state of ergodicity.

Table 1. Genetic algorithm approaches for mobile robot navigation

Approach	Used methods	Contributions
[4]. 2017	GAs	Propose a new mutation operator
[5]. 2018	MGAs	Combine crossing in genetic algorithms with dynamic chromosome coding

2.2. Artificial Neural Network (ANN)

The neural network approach is a method of modeling intelligence. These networks are capable of solving problems in different areas. Their strength lies in their ability to learn, and in this framework.

Artificial neurons are a formal abstraction of the behavior of the biological neuron [6]. They are an ideal solution for certain problems that require reasoning or are highly complex. This is due to their learning capacity. A neuron is a non-linear, parameterized function with a limited value (figure 2). A neuron contains two main elements:

- The weights associated with the connections of the neurons.
- An activation function.

Learning can be understood as a change in an organism's capacity or behavior caused by experience. The learning algorithm will formulate explicit rules that will allow it to be generalized [7].

The formulation of the rules is done by changing the synaptic weights that lead to the change in the behavior of the network; the change is made by a set of iterations that make these networks capable of reacting with new situations based on experience.

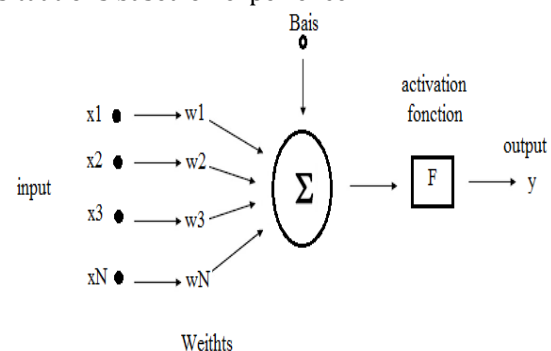


Figure 2: Artificial Neuron.

In [8] the authors conceded that current neural network approaches to navigation are limited to one type of robot platform and distance sensor, and are not scalable to other types of robots and distance sensors. Therefore, to add another type of sensor it is necessary to modify the network structure. They proposed a general method for interpreting data from various types of two-dimensional distance sensors and a neural network algorithm to perform the navigation task. Their approach can produce a global navigation algorithm that can be applied to various types of distance sensors and robot platforms. Also, this method contributed to reducing the time required for network formation and, designed a direct-powered multi-layer neural network, which controls the steering angle of the robot autonomously in static and dynamic environments. The different obstacle distances are the inputs to the four-layer neural network, and the steering angle is the result. However, real-time collision-free path planning becomes more difficult when the robot moves in a dynamic and unstructured environment.

In [9] Offer an autonomous navigation system provided by a fuzzy logic controller, a neural network and an adaptive neuro-fuzzy inference system (ANFIS) with a safety limit algorithm. In this search, the method targets obstacle avoidance and at every moment improve the robot's performance. The inputs of the controller are the signals of the sensors fixed on the front, left and right panel. The controller output signal adapts the angular velocity of the two front driving wheels of the robot. The shortest path is designated using fuzzy logic, neural networks and the adaptive neuro-fuzzy inference system with an integrated safety limit algorithm. The authors prove that the adaptive neuro-fuzzy inference system with a safety limit algorithm gives better navigation performance in case the obstacles are curved and/or irregular.

In [10], the authors describe a new method of mobile robot navigation in a dynamic environment containing static and moving obstacles. They use an artificial neural network (multilayer perceptron) to select a collision-free segment from a set of segments. This network monitors the speed for each movement and calculates the time required to reach its local destination at each collision-free segment and uses the time taken by critical obstacles. The authors say that the results of this simulation show that the neural network gives an optimal trajectory with shorter computation time. The main idea of their work is to use this approach in an automatic car driving.

Table 2: Artificial Neural Network approaches for mobile robot navigation

Approach	Used methods	Contributions
[8]. 2011	MLP	<i>Robot and distance sensor</i> platform expandable without changing the neural network structure
[9]. 2017	ANNs, Fuzzy logic, ANFIS, safe boundary algorithm.	<i>Designate the shortest path</i>
[10]. 2018	MPL	<i>Divide the trajectory into several segments</i>

2.3. Swarm intelligence

Because of humanity's attachment to the natural environment in which it evolves, human tends to want to inspire, by adopting an analogical process to solving the problems that arise in his daily life.

like of what ethology proposes (i.e. the study of animal behavior in its natural environment), and to formalize utilitarian approaches to adapt to solve an optimization problem consisting of seeking a solution of sufficient quality among a set of solutions with regard to one or more criteria and objectives to be achieved.

a. Ant Colony (ACO)

The algorithms of the ant colonies (ACO) aim at optimizing a path for mobile robots. They are used for a task that requires the collaborative work of several mobile robots. The objective is to solve a concrete navigation problem.

The ants move using complex combinations of information, as a vector of integration and visual cues [11].

Ant colonies' navigation approaches are developed first on a simulator, then it is implemented for a real robot. As a first step, a simulator was realized to evaluate navigation strategies directly inspired by the behavior of ants. Figure 3 gives a simulation example. Then, the simulation ant's navigation concepts are adopted for a set of robots.

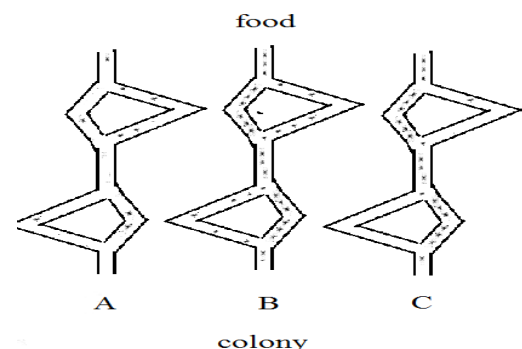


Figure 3: Ant colony

[12] Proposed and improved a method based on ant colonies for planning trajectories for mobile robots in complicated environments. This method uses the characteristics of the A* algorithm and the MAX-MIN Ant system. The first method step builds the grid model environment. It introduces an evaluation function of A* and the bending suppression operator to enhance the heuristic information that accelerates the speed of convergence and increase the global smoothness of the path. The second method step introduces a retraction mechanism to solve the deadlock problem. It transforms the MAX-MIN ant system into a local diffusion pheromone and adds the best solution of the iteration tests to update the pheromones. The pheromones help to drag forces and to avoid premature convergence.

In [13] the authors proposed an ant colony algorithm improved by the genetic operator and merged it with the traditional ant colony algorithm. They wide the search space of the solution and introduced a function of aptitude for respecting the safety distance. Then, they introduced the optimization operator to eliminate redundant nodes and improve fluidity.

Table 3:Ant Colonyapproaches for mobile robot navigation

Approach	Used methods	Contributions
[13]. 2019	MAX-MIN Ant System, ACO, A* algorithm	<i>Introduce an evaluation function of A* and the bending suppression operator to enhance the heuristic information that accelerates the speed of convergence and increase the global smoothness of the path</i> <i>Transform the MAX-MIN ant system a local diffusion pheromone</i>
[12]. 2019	ACO	<i>Ant colony algorithm improved by the genetic operator to widen the search space of the solution</i> <i>The used function of aptitude respect the safety distance</i> <i>Used optimization operators to elimi redundant nodes and improve fluidity</i>

b. Particle Swarms Optimization(PSO)

PSO algorithm aims at maximizing or minimizing a set of fitness functions while respecting constraints related to the problem being addressed. It is one of the methods inspired by animal behavior and considered a good technique to find a good solution much faster and more efficient for multidimensional research spaces. The PSO

process is schematized in figure 4. A PSO solution characterizes are:

- The number of particles in the swarm.
- The maximum velocity of a particle.
- The topology and size of the neighbors.
- The inertia of a particle.
- Confidence coefficients.

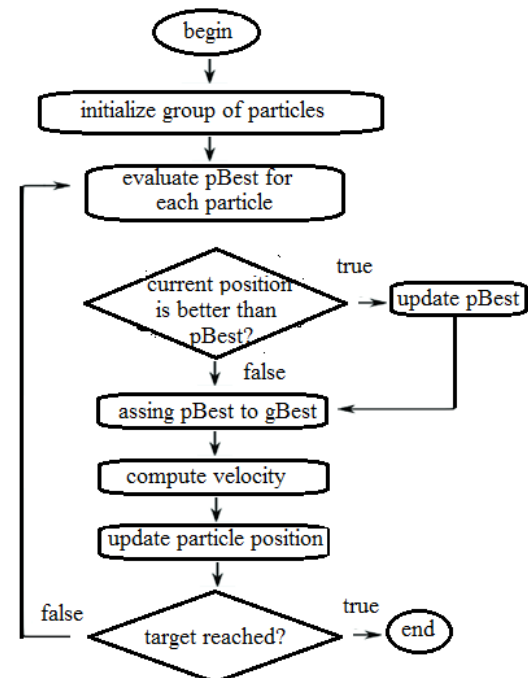


Figure 4: Particle swarmsoptimization process.

Autonomous navigation for mobile robots consists of searching for an optimal or quasi-optimal trajectory with several types of constraints in different complex environments.

In [14], the authors proposed a self-adaptive learning PSO with different learning strategies. They transformed the trajectory-planning problem into a multi-objective minimization optimization problem and they formulated a fitness function that respects three objectives: distance, the degree of collision risk and regularity. They developed a new self-adaptive learning mechanism to select the most appropriate search strategies at different stages of the optimization process that improved the capability of PSO. They applied a new violation processing schemes to restrict the speed and position of each particle to improve the feasibility of the generated paths.

In [15], the authors improved the performance of the classical potential field algorithm to a new method based on the combination of a modified potential field algorithm with fuzzy logic. This algorithm is designed to overcome classical potential field problems (local minima) and improves navigation in dynamic environments. The fuzzy logic controller is used for motion control with membership functions that are optimized by the PSO algorithm. This method of

trajectory planning and motion control reacts much faster in static and dynamic environments and effectively avoids obstacles according to the authors.

Table 4: Particle swarms optimization approaches for mobile robot navigation

Approach	Used methods	Contributions
[15]. 2017	PSO, Potential Field, Fuzzy Logic	<i>Uses fuzzy logic to improve AFP performance</i> <i>Use of fuzzy logic to avoid the problem of local minimums</i> <i>Optimizing fuzzy logic membership functions with the PSO algorithm</i>
[14]. 2018	PSO	<i>Fitness function respects three objectives: distance, degree of risk of collision and regularity.</i> <i>Self-adaptive Learning</i> <i>Improve the feasibility of the trajectories generated with the application of violations to restrict the speed and position of each particle</i>

c. The Bacterial foraging optimization algorithm (BFO)

This approach is inspired by the mechanisms of real bacteria, which undergoes chemotaxis, where it propagates towards a gradient of nutrients and avoids harmful environments. In general, the bacteria move over a greater distance in an ergonomic environment.

This technique of biomimetics for bacterial research strategy has been considered in the development of a mobile robot navigation strategy. Bacterial research approaches have been proposed to plan the path of a robot. This last mimics the behavior of bacteria to determine the optimal path without collision between the starting point and the target point in a dynamic environment.

Hossain and Ferdous [16] applied Bacterial Search Optimization (BFO) for navigation of mobile robots to find the optimal path in minimum time from the start position to the end position between moving obstacles, using particles that are randomly distributed on a circle around a robot. The criterion on which it selects the best particle is the distance between their position and the goal and also the Gaussian cost function of this particle. A high-level decision strategy is used for the selection and

proceeds to the result. It works on the local environment using a simple robot sensor. Thus, no additional map is needed, which adds costs. Moreover, it can be implemented without the need to adjust the algorithm and make complex calculations.

Liang et al [17] have developed a bacterial food search algorithm to develop a biologically inspired navigation strategy for a robot. In the proposed model, the behaviour of bacteria is applied to search for an optimal collision-free path from the start node to the target node in an environment with obstacles.

Table 5: Bacterial foraging optimization approaches for mobile robot navigation

Approach	Used methods	Contributions
[16]. 2015	BFO	1. Finding an optimal path in the shortest possible time between the start and finish position between moving obstacles. 2. Distributing random particles on a circle around a robot. 3. The robot sensor is used
[17]. 2018		the authors simply use this biologically inspired technique for a mobile robot to find an optimal collision-free path in an environment with obstacles.

d. Bee Colony Optimization (ABCO)

The artificial bee colony optimization algorithm is an intelligent swarm-based approach inspired by the activities of honeybees in search of food and proposed by Kharaboga [18]. The ABCO algorithm is a population-based technique that consists of a population of inherent solutions (food source). It is simple to use, quick to process and based on a stochastic population-based approach in the field of swarming algorithms.

The food search cycle of the Artificial Bee Colony Optimization Algorithm consists of three rules:

- Send the employed bees to a food source and evaluate the quality of the nectar.
- The viewers choose the food sources after obtaining information from the employed bees and calculating the nectar quality.
- Identify the scout bees and send them to possible food sources.

Contreras-Cruz et al [19] present the application of the artificial ABCO to the navigation of the mobile robot in a static environment. This approach uses ABCO for a local

search and an evolutionary algorithm to find the optimal path. Saffari et al [20], and Bhattacharjee et al. [21] develop another approach in a static environment in a simulation environment. The problem designed here attempts to determine the path of mobile robots from known initial positions to fixed target positions on a map, with the ultimate goal of minimizing the path length of all robots. In these approaches, the authors supposed that each channel consists of several straight segments passing through specific points. The selection of these points leads to paths with different distances. They used ABCO to find these points and to select the shortest possible path.

Table 6: Bee Colony Optimization approaches for mobile robot navigation

Approach	Used methods	Contributions
[21]. 2011 [19]. 2015 [20]. 2019	ABCO	The difference in these methods lies in the way that defining the environment, and modeling the robot and obstacles.

3. Comparison of the different Techniques

Recent bio-inspired approaches for autonomous robot navigation studied in this paper are summarised in table 7. These approaches aim to determine the optimal trajectory from a start point to a target point in a static or dynamic environment.

GA, ANN, ACO, PSO, BFO, and ABCO are the bio-inspired technique used by the researchers to solve the optimal path research with avoided obstacles.

From table 7 we can see that no bioinspired technique is preferred from the others. All works assume and proved that bioinspired techniques appropriate for robot navigation. Most of these works used simulation strategies before application on a real robot.

Table 8 gives the advantages and disadvantages of each studied approach

Table 7: Summary of some bio-inspired methods for mobile robots autonomous navigation.

Ref	GA	ANN	Swarmintelligence			
			ACO	PSO	BFO	ABCO
Tuncer A and Yildirim M, [4]	M.					
Lamini C et al, [5]	J.					
Singh M and Parhi D, [8]		D.				
Rao A.M et al, [9]		.				
Singh N.H and Thongam K, [10]		R.				
Yang L et al, [12]			.			
Xiaolin D et al, [13]			.			
Guangsheng L and Wusheng C, [14]				.		
Turki Y et al, [15]				J.		
Hossain M.A and Ferdousand I, [16]					.	
Anish P and Abhishek K.K, [17]					W.	
Contreras-Cruz M.A et al, [19]						.
Patle B.K et al, [20]						.

Bhattacharjee, P et al, [21]						
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Table 8 gives the advantages and disadvantages of each studied approach

Techniques	High Points	Low Points
Based on Evolutionary Algorithms	- The evolutionary algorithms use the coding of the parameters - evolutionary algorithms are working on the population of points - The use of probabilistic transition rules to avoid local optimizations - Synthesis of aerodynamic shapes and structures and composite materials - Better exploration of the research space	- Problems of timetables, industrial and network scheduling (steel, food processing, railway schedules, positioning, sewerage circuits, etc.). - Pattern recognition and learning (by reducing these problems to an optimization) - Pattern detection in bioinformatics, imaging, - Synthesis of electronic circuits
Based on Neuroscience	- Building a solution in a simple way - The ability to calculate an exact navigation path	- Deficits in finding a reliable representation knowledge.
Based on SWARM Intelligence	- They are very robust. - They are flexible - They are fast good solutions so the parallel work and the use of heuristic information, among other things. - Highly effective in the search for optimal solutions. - Overcomes the problem of the local optimum. - The use of several adjustable parameters. - Good solutions in a time much shorter. - works on the local environment using a simple robot - can be implemented without the need to adjust the algorithm and perform complex calculations	- A blocking state can arrive. - Execution time sometimes long. - Does not apply to all type of problems. - a mechanism for evolution and diversification - High values can trap the algorithm for several cycles and can eliminate a solution before the operation. - Sensitive to complex problems - converge prematurely - stochastic approaches have a problem of dependency, everything change in one of their parameters may have an effect on the operation of the algorithm as well as on the solution obtained - prematurely converge - a metaheuristic approach is sure we'll find the right solution

4. Conclusion

This paper presents an overview of different bioinspired approaches used for autonomous robot navigation. For each approach, we start by giving the principles of the bioinspired technique. Then we explain the navigation approach based on the bioinspired strategy. The advantages and disadvantages of each studied approach are cited.

The main challenge in this area of research is to build robot navigation systems capable of simulating the human system. Finding and evaluating such systems and adapting them to appropriate software processes remains the main challenge of autonomous navigation planning.

References

- [1] Sgorbissa A., Renato Z., "Planning and Obstacle Avoidance in Mobile Robotics", Robotics and Autonomous Systems, Vol. 60, pp. 628-638, 2012.
- [2] Benmachiche A., Makhlof, A., Bouhadada T. "Evolutionary learning of HMM with Gaussian mixture densities for Automatic speech recognition", 9th International Conference on Information Systems and Technologies, ICIST'2019, Cairo, Egypt, pp. 1-6, 2019.
- [3] Xin-She Y., "Bat algorithm for multi-objective optimization", Bio-Inspired Computation, Vol 3, pp. 267-274, 2011.
- [4] Tuncer A., Yildirim M., "Dynamic Path Planning of Mobile Robots with Improved Genetic Algorithm", Computers and Electrical Engineering, Vol. 38, pp. 1564-1572, 2012.
- [5] Lamini C., Benhlima S., Elbekri A., "Genetic Algorithm Based Approach for Autonomous Mobile Robot Path Planning", Procedia Computer Science, Vol. 127, pp. 180-189, 2018.
- [6] Kala R., Shukla A., Tiwari R., "Robot path planning using dynamic programming with accelerating nodes", Paladyn, Vol. 3, pp. 23-34, 2012.
- [7] Hassam A., Boucetta K., Boubezoula M., "Planning of a Trajectory Along with Avoiding the Obstacle Based on Fuzzy Logic Method for a Unicycle Mobile Robot", 13th International Arab Conference on Information Technology, ACIT'2012, Abu Dhabi, United Arab Emirates, pp. 448-452, 2012.
- [8] Singh M., Parhi D., "Path Optimisation of a Mobile Robot Using an Artificial Neural Network Controller", International Journal of Systems Science, Vol. 42, pp. 107-120, 2011.
- [9] Rao A.M., Ramji K., Sundara Siva Rao, B.S.K., Vasu V., Puneeth C., "Navigation of non-holonomic mobile robot using neuro-fuzzy logic with integrated safe boundary algorithm", International Journal of Automation and Computing, Vol. 14, pp. 285-294, 2017.
- [10] Singh N.H., Thongam K., "Mobile Robot Navigation Using MLP-BP Approaches in Dynamic Environments",

- Arabian Journal for Science and Engineering, Vol. 43, pp. 8013-8028, 2018.
- [11] Ming-Ru Z., Lu X., Ai-Min X., "The free step length ant colony algorithm in mobile robot path planning", *Advanced Robotics*, Vol. 30, pp.1509-1514, 2016.
- [12] Yang L., Jianwei M., Shaofei Z., Yibo M., "Dynamic Path Planning of Mobile Robot Based on Improved Ant Colony Optimization Algorithm", *Proceedings of the 2019 8th International Conference on Networks, Communication and Computing, ICNCC'2019, Luoyang, china*, pp. 248-252, 2019.
- [13] Xiaolin D., Shuai L., Zhiwen Z., Dawei G., "Mobile Robot Path Planning Based on Ant Colony Algorithm With A* Heuristic Method", *Frontiers in Neurorobotics*, Vol. 13, pp. 1-15, 2019.
- [14] Guangsheng L., Wusheng C., "Path planning for mobile robot using self-adaptive learning particle swarm optimization", *SCIENCE CHINA Information Sciences*, Vol. 61, pp. 1-18, 2018.
- [15] Turki Y., Ali A., Alaa A., "Mobile robot navigation using PSO-optimized fuzzy artificial potential field with fuzzy control", *Journal of Intelligent and Fuzzy Systems*, Vol. 32, pp. "3893-3908, 2017.
- [16] Hossain M.A., Ferdousand I., "Autonomous Robot Path Planning in Dynamic Environment using a New Optimization Technique Inspired by Bacterial Foraging Technique", *Robotics and Autonomous Systems*, Vol. 64, pp. 137-141, 2015.
- [17] Anish P., Abhishek K.K., "Different Nature-Inspired Techniques Applied for Motion Planning of Wheeled Robot: A Critical Review", *International Journal of Advanced Robotics and Automation*, Vol. 3, pp. 1-10, 2018.
- [18] Karaboga D., "An idea based on honey bee swarm for numerical optimization", *Erciyes university, engineering faculty, computer engineering department, Technical report-tr06*, 2005.
- [19] Contreras-Cruz M.A., Ayala-Ramirez V., Hernandez U.H., "Mobile robot path planning using artificial bee colony and evolutionary programming", *Appl Soft Comput*, Vol. 30, pp. 319-328, 2015.
- [20] Patle B.K., Ganesh Babu L., Pandey P., Parhi D.R.K., Jagadeesh A., "A review: On path planning strategies for navigation of mobile robot", *Defence Technology*, Vol. 15, pp. 582-606, 2019.
- [21] Bhattacharjee, P., Rakshit P., Goswami I., Konar A., Nagar A., "Multi-robot path-planning using artificial bee colony optimization algorithm", *Third World Congress on Nature and Biologically Inspired Computing, NaBIC'2011, Salamanca, Spain*, pp. 219-224, 2011.