



# Mobile Robot Path Planning Approaches: Recent Developments

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## Abstract

Robotics is the current growing technology with various applications in many fields practiced so far. The bit-by-bit strategies are assembled to know the growth of way arranging systems in different environmental situations and to spot the research gap. It reviews the most important contributions to the mobile robot path planning field from classical approach to heuristic approaches. The classical approaches include cell decomposition method, road map method, artificial potential field method; heuristic approaches such as genetic algorithm (GA), neural network (NN), ant colony optimization (ACO), and particle swarm optimization (PSO) are studied. Because of the numerous computational problems, heuristic methods outperformed the classical methods and gained great reputation. The navigation of static and dynamic surroundings is also examined and it has been remarked that the heuristic approaches have executed efficiently in all aspects when differentiated with classical methods. The paper ended up with tabular knowledge, and graphs analyzed the regularity of separate navigational policies which can be utilized for particular implementation during robot navigation.

## Keywords

Classical approach • Heuristic approach • Path planning

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## 1 Introduction

Robots soon will quickly be involved in day-to-day lives of humans as research is now moving toward mobile robots that can help us in our daily lives. Robots are machines which mimic human productivities in which sensor are used for sensing, actuators for decision making, and effectors for output.

### 1.1 Robot Navigation

Navigation is one of the most important process of robotics. Navigation is the process of precisely determining one's location and moreover, it is a desperate need and necessity for all mobile robots to plan and follow the path. Two main categories by which robotic navigation has been solved are deterministic algorithms and non-deterministic algorithms, and nowadays evolutionary algorithms which are hybridizing of both deterministic and non-deterministic algorithms are being used to solve the problems. In robot route, way arranging is one of the significant undertakings and hence, pulled in numerous researchers in the ongoing time in Hidalgo-Paniagua et al. (2016). Worldwide way organizer and nearby way organizer are the two primary pieces of the route arrangement of independent robot. The route cycle can be subisolated into two sections, worldwide route and nearby route. Worldwide route strategy is utilized to discover internationally ideal way based on the environment. Anyway without satisfactory cloister data, the worldwide route technique is not appropriate consequently nearby route strategy can likewise be applied when the environment is obscure or priory obscure. In robot navigation, obstacle avoidance is one of the significant assignments (Kumar & Vámosy, 2018c). Hindrances in the robot's way can be sorted as static and dynamic. Static are those which do not change their position and direction. Dynamic changes their position or direction after the beginning of route measure,

different necessities of impediment shirking can be fulfilled for the changing separation among robot and the hindrances (Mousazadeh et al., 2018). The scope to analyze in uncertain environment is important in people. Like, if we human need to cross a road, if there is no movement of objects or things moving from the road, we cross the road safely. But if there is movement of objects, our focal point is on the objects coming toward us, then we stand by and mark the actual time to move to the other point. Then we choose whether to cross the road or not. In order to copy human, so the robot has potential to navigate in dynamic environment without colliding with the objects. For mobile robot to move in dynamic environment, where there are number of objects and human is challenging task due to the difficult structure of given environment. To overcome the situation of path planning, various algorithms based on deterministic, non-deterministic, and neural network are developed (Pandey, 2017) now robot can maintain and can take their own decision without human manipulation.

### Navigation components

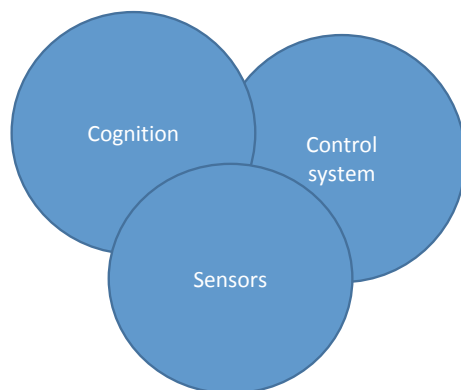
The components that a navigation robot needs are shown in Fig. 1.

- Sensors to obtain impressions of the current locations.
- Cognition to perceive sensed data. A control system to execute the required behavior.
- A control system to execute the required behavior.

## 2 Literature Review

The author of the paper mainly focused on the following problems in robot navigation:

- I. Optimal path planning
- II. Collision prevention.



**Fig. 1** Navigation components

For mobile robots good path planning of versatile robots can spare a ton of time, yet in addition lessen capital speculation of portable robot (Zhang et al., 2018). Right now, the path planning issue is one of the most investigated points in independent advanced mechanics. That is the reason finding a protected way in troublesome climate is a significant necessity for the accomplishment of any automated undertaking (Hassani et al., 2018). In Hassani et al. (2018), in addition to this also find shortest path from start to goal position. Mobile robots, having to navigate in a dynamic environment, are too demanding a job as the position of obstacles is not known before the navigation process begins. Many of the researchers have put up with collision-free robot navigation, after path planning was proposed to avoid obstacles (Khan & Ahmmmed, 2016). The authors have used range sensors as the sensing element for localization. The issue of way arranging in obscure climate does not have any data of its current circumstance yet approaches past aggregated from route measure (Saha & Dasgupta, 2017). To address the navigation process, the authors in Saha and Dasgupta (2017) proposed a novel, machine learned-based algorithm called semi-Markov decision process. The robot's distance range sensors can acquire the path of various objects in the robot's navigation path. Application of this variety of obstacles is to keep the robot from catching (Mousazadeh et al., 2018). In static obstacles of random shapes, the collision-bound robot navigation in a static environment, the persistent-bug algorithm to stop global and local loop trapping are considered as testing of the algorithm. A Simulink model for robot navigation in an unknown environment with obstacle avoidance is presented in (Kumar & Vámosy, 2018c). In Kumar and Vámosy (2018c), a robot position, laser scanning, and scanning period algorithm are executed to recognize the recurrence of obstacles during the navigation phase. Different scientists are attracted to fuzzy logic for obstacle avoidance in robot navigation process. An etiquette-based fuzzy logic architecture for mobile robot navigation in dynamic environment is presented in Bao et al. (2009). Moreover, the authors in Bao et al. (2009) have designed and implemented four basic behaviors for mobile robot navigation in complex environment which include tracking behavior, obstacle avoidance, deadlock disarming behavior, and goal seeking. Optimal solution and large operational qualities of the organization would be characterized dependent on the potential and the idea of neurons interconnections. An epic organically inspired neural organization approach exists for impact-free constant robot way arranging in a powerful climate. This model can be useful to car like robots and multirobot systems. The state space of the neural organization is the arrangement of the robot, and the enthusiastically changing environment is spoken to by the dynamic movement scene of the neural organization. The objective was universally

pulled in towards the robot, whereas obstacles push the robot away to avoid collisions. In Kozakiewicz and Ejiri (2002), a neural network approach to path planning was developed for 2D robot. The robot moves from initial to final location if its neighboring point closer to goal location is vacant. A far less expensive four wheel mobile robot platform has the potential to travel as a line follower robot in a two-dimensional setting with obstacle avoidance (Oltean, 2019). The robot successfully recovers from the collisions and the deterrent evasion can be dealt with by utilizing the bumper functions of the turtlebot (Kumar et al., 2016). In Kumar et al. (2016), the main disadvantage of the work is that the work does not lead to collision-free navigation. Consequently, the methods based on sensors which lead to obstacle avoidance without collision during navigation can be taken for future work. Fuzzy interference system with rotation angle for robot inputs and space between the robot obstacle is built in Singh and Thongam (2018). Anyway the fuzzy surmising framework created in Singh and Thongam (2018) is not applicable in dynamic environment but only to static environments. A model in Simulink is developed with unadulterated interest and fuzzy rationale regulators in Kumar and Vámosy (2018b). In Singh and Thongam (2018), the pure pursuit controller seeks a straight path from the start to the next target position and the controller used avoids robot navigation obstacles. The proposed work in Kumar et al. (2017) is based on pure pursuit algorithm, and the probabilistic guides in robot path and the guide of the robot's path is created as inhabitancy lattice. In this map, the probabilistic guides are acquired. An efficient path from begin to end, robot course is procured from probabilistic aides. Test work is performed on turtlebot robot in gazebo test system. MATLAB is utilized as programming language. The bondage of the work is that it is appropriate to the condition with static impediments. For future work, there is opportunity to build this work for the dynamic condition with dynamic or moving items. In Gupta and Nesaraj (2016), the work is focused on to find the shortest distance from start to goal without any collision. Also, obstacles of various dimensions are considered. So the main algorithm is partitioned into three subframes.

**Subframe of path length:** If no object is present in the given environment, this subframe calculates the diagonal length between source and goal point.

**Subframe of path authorization:** If there is some object present in the path, then path length will not be same. Then obstacle avoidance function is to be used.

**Subframe for levelness:** This subframe is used to find the levelness of given environment and calculates the levelness curve angle twist points that are recovered through Biezer

curve method. In Patle et al. (2018), robot navigation in uncertain environment is explained, where dynamic objects are also present. The proposed paper is based on firefly algorithm. Fuzzy controllers explore minimum time instants. By using these controllers' dynamic objects gets recognized without any difficulty. This algorithm is powerful over all other algorithms. It reduces seeking time and robot easily navigates in the environment. Distance can be computed through Euclidian distance. In Kumar and Vámosy (2018a), the author proposed that laser scan is executed for localization and mapping. Various computations have been showed to achieve the laser scanning. The foremost computation was proposed to collect and reserve the laser examined features obtained from the robot scan. The next computation is to perform matching and map building. By making use of good output matches, a neural network is developed.

### 3 Path Planning Approaches in Robot Navigation

Path planning is the necessary component in navigation of mobile robots. It is one of the most researched topics in mobile robotics. Path planning is the action to plan a route in a given environment by reducing the total cost associated with the path. Path planning of mobile robot can be restricted based on the environment and type of algorithm used. It can be concluded in both static as well as dynamic environments. Path planning is mainly based on two divisions as follows:

- I. Local path planning
- II. Global path planning.

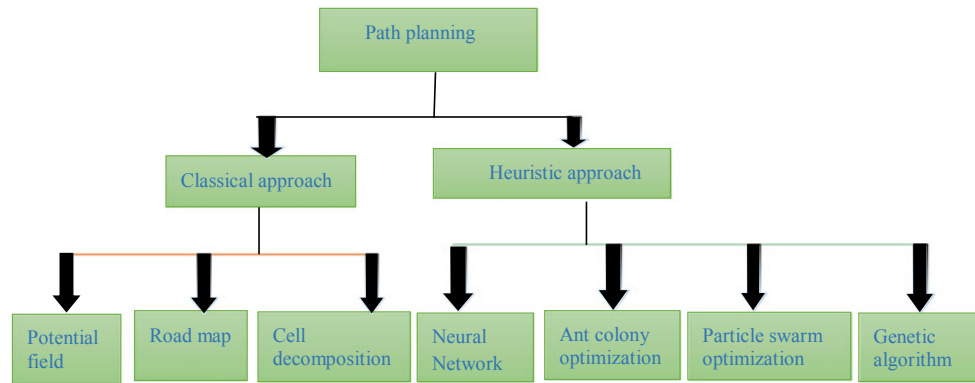
Numerous methods employed for navigation of mobile robot are broadly classified into two divisions that are classical approaches and heuristic approaches (Kosser & Kumar, 2019) (Fig. 2).

#### 3.1 Classical Approaches

In this approach, either an answer would be found or it would be demonstrated that such an answer does not exist. The primary impediment of such techniques is their computation intensiveness and inability to cope with unpredictability. Such disadvantages make them exquisite in real world. Methods, such as cell decomposition, potential field, and roadmap, are categorized as classical methods:

**Cell decomposition:** It is mostly used in literature survey in path planning approaches. In this, the thought is to decrease the hunt space by utilizing portrayal dependent on cells.

**Fig. 2** Classification of path planning algorithms



The idea behind this approach is to decay the free space into set of simple regions called cells. The aim of this is to reach the end point safely. the basic path planning algorithm based on cell decomposition are in Zafar and Mohanta (2018). Following are the steps used for cell decomposition as motion planner for robot:

- i. Split the search space to connected regions called cells.
- ii. Construct a chart through neighboring cells. In such a chart, vertices signify cells and edges associate cells and have a typical limit. Give a path from the obtained cell sequence.

The limitations of this approach are:

- i. No passage way among narrowly spaced obstacles.
- ii. Oscillations in narrow passages.
- iii. Oscillations in the existence of obstacles.

**Road map:** It is also called as high way method. It is an approach to get starting with one point then onto the next and the association among the free spaces is spoken to by a bunch of one dimensional bends. Here, hubs assume a vital function in getting the ideal way for the robot. It is mostly used to locate the briefest way from the robot's underlying situation to objective position. Visibility and Varoni diagram are two mainstream strategies for creating guides. Visibility diagram is the chart whose vertices comprise of the beginning, target, and the vertices of polygonal impediment of the deficiency of visibility chart is that the subsequent littlest ways contact hindrances at the vertices or even at edges and afterward are undependable. Varoni charts are equipped for tending to this disadvantage.

In the Varoni diagram, roads stay as far away as possible from obstacles; therefore, it has the tight path and little longer than visibility graph.

**Potential field method:** In this method, repulsive and attractive forces are assigned for the obstacles. Attractive

field is generated which moves inward to goal. In each time stamp, a different potential field is generated across the free space.

The attractive force is given by

$$U_{att} = 0.5 * K_{att} \rho (\text{goal})^2 \quad (1)$$

The repulsive force is given by

$$U_{rep} = 0.5 * K_{rep} * (1/\rho(q) - 1/\rho_0)^2 \quad (2)$$

where  $K_{att}$  and  $K_{rep}$  are positive constants.  $\rho_0$  is the potential function.

Resulting force is given by

$$U(q) = U_{att}(q) + U_{rep}(q) \quad (3)$$

where  $U_{att}$  is the attractive potential and  $U_{rep}$  is the force of repulsion. Barriers are avoided while moving toward target. It is based on the method where map is predefined.

### 3.2 Heuristic Approaches

The main algorithms in heuristic approach are genetic algorithm (GA), ant colony optimization (ACO), and particle swarm optimization (PSO).

**Genetic algorithm:** It is the global search and optimization method. This calculation mirrors the cycle of regular choice where the fittest people are chosen for propagation so as to deliver posterity of people to come. This technique was proposed in 1975 by professor J. Hull and from Michigan University. In each algorithm (Zhu et al., 2015), path improvement is applied. The smoothness function is calculated through path length and smoothness function. This shows exceptional results as compared to other algorithms (Zhu et al., 2015). The population is the sequence of strings known as chromosomes. First specific multiplication is applied to the current populace so that string makes various duplicates relative to their own wellness which is a halfway

populace. Second, GA selects “guardians” from the ongoing populace with a predisposition that better chromosome is probably going to be chosen. Third, GA recreates kids (new strings) from those guardians utilizing hybrid or change administrators. Hybrid is fundamentally comprising in an arbitrary trade of pieces between two strings of the transitional populace. This algorithm rectifies the problem of premature convergence and the length of the path obtained is shorter and the convergence speed is near to genetic algorithm.

**Ant Colony Optimization:** Ant colony optimization (ACO) is a populace based all-inclusive scanning technique for the arrangement of complex combinatorial issues, which is motivated by behavior of real ant colonies which was developed by Marco Dorigo in the 1990s. This technique is acceptable where source and goal are predefined. This style is based on multigoal path planning problems in the presence of obstacles. This technique is based on following algorithm:

- i. Create ants.
- ii. Iterate for each ant until entire task is completed.
- iii. Place pheromone on visited sites.
- iv. Daemon actions.
- v. Vanishing pheromone.

These techniques are used for path planning (Zhu et al., 2015; Bartecki et al., 2018) and obstacle avoidance.

**Particle swarm optimization:** Particle swarm optimization was presented by Eberhar and Kennedy (1995) which was roused by the scrounging conduct of winged creatures. It is nature-based metaheuristic calculations which influence the social conduct of animals, for example, fish schools and fowl rushes. The calculation mimics the scavenging conduct of flying fowls and accomplishing their objectives through a joint collaboration between winged animals. Every molecule of multitude advancement look in a gathering led by particles which was introduced haphazardly. The particles move its stance and speed as indicated by the measurements of the gathering. Particle update its speed and position as indicated by the equation introduced in Wang et al. (2017). The robot path planning with obstacle avoidance using particle swarm optimization was proposed in Bartecki et al. (2018), and this algorithm solves the problem of incomplete convergence.

**Neural networks:** Neural organization or neural network (NN) is the investigation of understanding the interior usefulness of the cerebrum. It has been for the most part reused in looking through enhancement, learning, and example acknowledgment issues because of its capacity to give straightforward and ideal arrangement. By and large

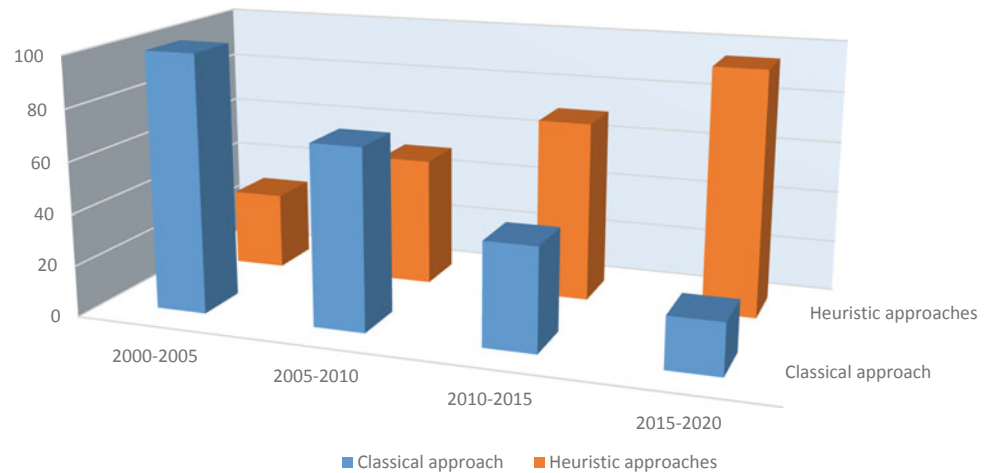
operational qualities of the organization would be characterized dependent on the potential and the idea of neurons interconnections. A tale organically persuaded neural organization access that exists for crash free continuous robot way arranging in a powerful climate. This model can be helpful to vehicle like robots and multirobot frameworks. The state space of the neural organization is the arrangement of the robot, and the overwhelmingly changing climate is spoken to by the dynamic action scene of the neural organization. The objective was universally pulled in toward the robot, while hindrances drive the robot away to dodge crashes. In Kozakiewicz and Ejiri (2002), an NN way to path planning was progressed for two-dimensional robot. An automation learning policy gives in Qiao et al., (2009). The nature of their exertion is that, as indicated by the intricacy of the environmental factors, the NN changes addition and cancellation of new concealed layers during the preparation with no communication to achieve the route work. Li et al. (2015) introduced the utilization of NN to quick concurrent limitation and planning procedure (Fast SLAM) to dispose of the mistake collection created by a wrong odometry model and off base linearization of the SLAM nonlinear capacity. The utility of the NN with quick SLAM develops the versatile robot to explore without crash with the snag in the obscure climate or dynamic climate. Following a steady assessment of the exploration papers referenced in the writing survey, the navigational arrangement is sorted as traditional methodologies and heuristic methodologies. A couple of years back, the majority of the effort in the control of advanced mechanics was raced to utilize old style moves toward as it were. Old style systems have numerous deficiencies like computational issues, failure in dealing with numerous vulnerability, detecting issue for constant route, and substantially more. Henceforth in the suspicion of the old style approach, each time there remains question if the arrangement got will be precise. Albeit heuristic methodologies are reused for route in an obscure climate. They are anything but difficult to actualize, canny and more proficient for robots; thus they are utilized continuously route issues. Furthermore, given the best result over old style draws near, Table 1 gives a definite investigation of these methodologies utilized for route of robots till now (Fig. 3).

Table 1 shows complete analysis of different algorithms of path planning approaches (Patle et al., 2019). The utilization of the two methodologies, old style and heuristic methodologies, has been considered over a three-dimensional workspace for way arranging of airborne and submerged vehicles. In Table 1, the use of an individual calculation for three-dimensional way arranging is depicted and, from the information, clearly heuristic methodologies have been applied all the more broadly for investigating the three-dimensional climate within the sight of most



**Table 1** Comparative analysis of classical and heuristic algorithms

Navigation	Aerial navigation	Underwater navigation
Cell decomposition	Yes	No
Road map	Yes	No
Potential field	Yes	No
Genetic algorithm	Yes	Yes
Ant colony optimization	Yes	Yes
Neural network	Yes	Yes

**Fig. 3** Applications of classical and heuristic approaches

noteworthy vulnerability in correlation with traditional methodologies. The traditional methodology is not plentiful savvy for self-governing way arranging in three-dimensional climate, henceforth to improve their quality and execution they have been hybridized with GA, ACO, and so on. Practically all heuristic and traditional methodologies are utilized to handle the way arranging issue in an elevated climate too.

Different algorithms considered in literature review until now are winded up in Table 2 on the basis of different framework. These algorithms are mainly centered on path planning and their navigation environment. Like form of environment that is static, dynamic, inside, and outside. Moreover, identity of obstacle is also described whether it is static, dynamic, or both static and dynamic.

## 4 Challenges

After review of literature, various challenges occur during navigation. Path planning, which is great subject that how robot marked which path is suitable to come to the final point? There is no collision of robot in the navigation environment. In a given environment, the different number of static and dynamic objects may be present in the navigation environment. Keep away from such obstacle and to

resolve that which path is acceptable for robot is a challenging task.

Localization is one more matter in robot navigation that is how to consider itself in the given environment. A map of domain is specified to the robot for navigation. This approach is suitable, if there is only one robot in static environment. But if there is dynamic environment and for multirobot system then this is much more challenging task.

Mapping is one of the most challenges in robot navigation that how robot report where it is presently and what it has to reflect to navigate in the navigation environment. And how robot decided in which location it has to move is suitable in the particular environment.

## 5 Conclusion

The paper reviews some of the classical and heuristic methods for robot path planning. Between classical algorithm and heuristic algorithm, classical approach has more limitation than heuristic approach in terms of path cost and time execution. The execution of classical methods can be enhanced by mixing with heuristic methods. Further research task can be expanded to switch the obstacle shape and location to verify convergence of heuristic approaches. The hybrid algorithms which integrate the classical and

**Table 2** A comparative analysis of various algorithms

Algorithm	Year	Static system	Dynamic system	Simulation	Real system	Authors	Navigation
Fuzzy logic and pure pursuit	2016	Yes	Yes	Yes	Yes	Kumar and Vamossy (2018c)	Unknown
Standard deviation-based algorithm	2018	Yes	Yes	Yes	Yes	Singh and Thongam (2018)	Unknown
Path plan with subfunction	2016	No	Yes	Yes	Yes	Kumar et al. (2017)	Unknown
Firefly algorithm	2018	Yes	Yes	Yes	Yes	Gupta and Nesaraj (2016)	Unknown
Laser scan algorithm	2018	Yes	No	Yes	Yes	Patle et al. (2018)	Unknown
Path planning using bumper event	2016	Yes	Yes	Yes	NO	Oltean (2019)	Unknown
Goal-oriented algorithm	2016	Yes	Yes	Yes	Yes	Saha and Dasgupta (2017)	Known

heuristic methods can be used to find the collision-free optimal path. The execution of classical methods is being refined by hybridizing with heuristic approaches. The main problem focused is on robot navigation and path planning. We conclude that path planning with complete obstacle avoidance is still major challenge in robot navigation. Most of the work which has been done on single robot. In future, we have to implement multirobotic system.

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