Journal of Optimization in Industrial Engineering,
Vol.17, Issue 1, Winter & Spring 2024, 175-182
DOI: 10.22094/QJIE.2024.951231

Research Article

Navigation of mobile robot motion

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Received: 24 September 2023; Revised: 16 April 2024; Accepted: 16 April 2024

Abstract

As one of the fastest-growing fields in engineering, robotics is designed to perform in dangerous and difficult work environments while easing labor-intensive duties. One of the major issues in robotics is the need to design a fast and effective procedure for the navigation process. Mobile robots have been used to execute tasks such as vital medical patrol, rescue, material handling, etc. Therefore, it is important to develop intelligent mobile robots capable of moving independently in different environments. Thus, in this work, a study on the navigation of mobile robots with methods applied was carried out..

Keywords: Robotics, Effective Procedure, Navigation Process, Methods.

1. Introduction

There is a fundamental problem considered in the navigation of mobile robots in the robotics field, especially when accompanied by obstacle avoidance motion. Several researchers have dealt with and attempted to solve this problem in the past two decades. Navigation aims to find an optimal or suboptimal route between a start location and the target destination with the ability to avoid (Pandey A, Pandey S, 2017). Many researchers have studied mobile robot navigation (M. Hoy, 2015)(L. Yang, J. Qi, D. Song, J. Xiao, Han, J. and Xia, 2016)(Patle, B. K., Babu L, G., Pandey, A., Parhi, D. R., & Jagadeesh, 2019), as well as several of its applications (Dongbing, G and Housheng, 2006) (Erin, Abiyev and Ibrahim, 2010). In mobile robotics, global navigation and local navigation are the two main categories of navigation processes (Ni J, Wu L, Fan X, 2016). Several methods are improved for global navigation(Bhattacharya P, 2008)(Chandra, 2007). Several researchers have employed and presented various methods (BESİME ERİN, 2011)(Pandey A, Pandey S, 2017).(Zhu A, 2007)(Ghorbani A, Shiry S, 2009)(Miao H, 2013) that deal with the local navigation problem. The mobile robot in local navigation can control its movement and orientation autonomously(Roland Siegwart, 2004) using equipped sensors. Next, Section 2 discusses the navigation of a mobile robot, while section 3 presents the various navigation processes. In section 4, a review of the various methods employed in robot navigation is presented. Section 5 describes several mobile robot navigation algorithms. Section 6 gives a comparison between different navigation methods. Finally, the conclusion is drawn in Section 7.

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2. Mobile Robot Navigation

Mobile robot navigation has become a challenging issue with increasing complexity. A mobile robot works in different static and dynamic environments. In a static environment, the mobile robot encounters various stationary objects, while in a dynamic environment, it is required to rapidly change its path through various moving obstacles. The objective of a mobile robot is to follow the predefined routes as accurately as possible and to reach a prescribed destination at a given rate(M. Yousef Ibrahim, 2004). [15]. Basically, the task consists of several sub-tasks that involve identifying the current positioning of the mobile robot and objects in its environment, avoiding any direct collisions, and determining the best route to the target. A mobile robot attempts to traverse a trajectory in the shortest possible period. However, it is subject to an achievable maneuver based on the separation from the obstacles (Kala, 2014). To achieve these tasks with maximum effectiveness, comprehensive approaches to applicable techniques for solving a wide range of problems capable of functioning in any environment are necessary. One of the major issues in robotics is the need to design an accurate procedure for navigation. The navigation algorithm is capable of determining whether movement from the initial configuration toward the final configuration exists and locating such movement (Besime Erin, 2011).
Successfully steering the robot to its destination without colliding with any obstacle is the function of the navigation system. Designing and developing a robot requires the combination and synchronization of many actuators and sensors, because any autonomous robot must be able to avoid obstacles. Robots use a variety of sensors that provide information about their surroundings, and in most cases, obstacles are detected by using a

variety of audio or visual [cameras] (Abiyev, Ibrahim and Erin, 2010).

3. Navigation Methodologies

Several robot navigation systems have been developed by researchers and are broadly classified into two, depending on the surroundings of the robots: global navigation and local navigation. Prior information on the surroundings of the robot and its destination must be known, and the best route to avoid obstacles must be chosen in global navigation. This implies that global navigation strategies work in a known environment (Algabri, Mohammed, Hassan Mathkour and Alsulaiman, 2015). Graphical maps with information on obstacles used to determine selected routes are excellent examples of global navigation systems. Local navigation, on the other hand, does not require prior details of the surroundings (Siegwart Roland., 2004) which implies that it works in unknown and partially known environments. Furthermore, local navigation identifies the dynamic conditions of the environment and establishes positional relationships between various elements. Local navigation approaches are more intelligent and capable of autonomously controlling and executing a plan. Hence, they are known as reactive approaches. As an advantage over global navigation methods, which are only able to detect nearby obstacles, local motion planning methods direct robots according to locally detected obstacles because they require less prior knowledge about the environment. This limits the application of global navigation methods. Local navigation systems are many and of different varieties (Zafar, M. N., & Mohanta, 2018)(Han, J.; Seo, 2017).

4. Review of Navigation Methods

Navigation of mobile robots has become an interesting topic for many researchers and, therefore, several methods have been developed for both global and local mobile robot navigation. Despite the work that has been done and the methods that have been developed in this field, the available knowledge on navigation methods is still insufficient (Patle, B. K., Babu L, G., Pandey, A., Parhi, D. R., & Jagadeesh, 2019). Route planning deals with the movements of a robot from an initial point to a final location without colliding with the physical objects present in its workspace (S. K. Pradhan, D. R. Parhi, A. K. Panda, 2006). Controlling the motion of the robot to avoid collision on its path to a final target from an initial position in a dynamic environment is a major problem in the motion planning of multiple mobile robots(S. K. Pradhan, D. R. Parhi, A. K. Panda, 2006) (Sgorbissa, 2008). The design of the robot’s surrounding area is normally based on the robot's task and then protected from external influences (Goris, 2005). Among the tasks being efficiently completed by these robots are welding, drilling, assembling, painting, and packaging. Robotics is an exciting field that continues to be of great interest to people. Robotics has a wide variety of applications and has been a major drive to study contributing to this domain (R. Tiwari, A. Shukla, 2013). Excellent mobility is an important characteristic to be considered while building a robot.

Mobile robots adapt their behavior to their surroundings, unlike most stationary robots, where the surrounding space adapts to the robot's tasks (Goris, 2005). It is compulsory for mobile robots to develop some awareness of their surroundings through collaboration with different kinds of sensors instead of performing a fixed sequence of actions. The robots decide on the best action to take using onboard intelligence. The development of intelligent navigation systems in mobile robots, which guarantee efficient and collision-free movement, continues to be the focus of several research projects(Geerinck, 2004).

4.1 Mobile robots

Mobile robots refer to robots that can travel across the ground from one location to another, and mobility confers on a robot the advantage of greater flexibility to carry out challenging, novel, and entertaining jobs. Robots are designed to execute more organic duties even in settings not specifically made for them. For instance, rather than integrating robots’ user interface with a touch screen, the robot can be designed to collaborate with humans, integrating which could range from sharing a workspace to a cleaning mechanism in a human-centered (Goris, 2005) (Holmberg, 2000) (Jones, 2006).

Mobile robots have been used to take care of disabled people. ROBCO 11 is an example of a mobile robot that has shown it can live with disabled persons, helping them by reminding them to take their drugs, feed and drink, operate electronic devices, etc. It also alerts in case of deteriorating health and connects automatically with a doctor or an emergency ambulance (Chivarov, N., Paunski, Y., Angelov, G., Radev, D., Penkov, S., Vladimirov, V., 2012).

The robot navigated autonomously. Its scanning included essentially following a straight corridor with a slight curve to the right, which is significantly simpler when compared with the general scanning problem of scanning several diverse corridors (W. Burgard, D. Fox, M. Moors, R. Simmons, 2000)(R. Simmons, D. Apfelbaum, W. Burgard, M. Fox, D. an Moors, S. Thrun, 2000)(G. Thrun, S., Thayer, S., Whittaker, W., Baker, C., Burgard, W., Ferguson, D., 2004).

Navigation systems give robots the ability to move between given locations. None of the various metrics used to assess the performance of a navigation system is capable of indicating the quality of the entire system. The ability of a robot’s navigation system to follow a path that aims to reach the goal while avoiding both mobile and stationary is very important in defining its quality(R.Ceballos, N. D. M., Valencia, J. A., & Ospina, 2010) (Sfeir, J., Saad, M., & Saliah-Hassane, 2011) (Pilarski, T., Happold, M., Pangels, H., Ollis, M., Fitzpatrick, K., & Stentz, 2002). kinematic and dynamic limitations of a mobile robot must be taken into consideration in order to achieve excellent results for smooth and practical path planning. This is because, as navigation systems become more cohesive, a significant increase in the overall robustness of the harvesting operation is observed (V. Sathiya and M. Chinnadurai, 2019). Autonomous navigation has become a very interesting topic in recent years (Jean-François Bonnefon, Azim Shariff, 2016)(Takafumi Taketomi, Hideaki Uchiyama, 2017). The importance of navigation for mobile robots cannot be overestimated, as they require it to perform their main tasks such as carrying loads, inspecting, exploring, or interacting with the environment and objects in (Yuri D. V. Yasuda, Luiz Eduardo G. Martins, 2020) (Nelson David Munoz-Ceballos, 2022). Mobile robots' navigation is one of the top most tasks in robotics. The major difference in many navigation approaches is the hardware used in motion control algorithms for robots (Alexander A. Gridnev, Alexander A. Dyumin, Timofei I. Voznenko, Gleb A. Urvanov, 2017).

Navigating robots must achieve two important purposes: reaching the final goal and avoiding collisions with obstacles on the way to the goal. Of the two broad methods [global navigation and local navigation] used in achieving the said purposes, global navigation has limitations such as incomplete data, unexpected real-world situations, and the real-time operation of the robot (Marhaban, 2012) (Xiong, 2012).

A mobile robot path planning problem is usually formulated in steps as follows (Yap Chee K., 1987):

i. giving a robot a description of the environment

ii. ii. drawing a path between two specific locations that are collision-free

iii. satisfying certain optimization criteria; adaptive evolutionary planner/browser for mobile (J. Xia, Z. Michalewicz, 1997).

Information from sensors, in addition to being used for navigation, is also used to generate a map of the environment (H. Choset, K. M. Lynch, S. Hutchinson, G. Kantor, W. Burgard, 2005). Autonomous navigation is performed when a robot is moving without interference from external controls [a person or a central system] and it solves four major problems: localization, mapping, route planning and locomotion(H. Choset, K. M. Lynch, S. Hutchinson, G. Kantor, W. Burgard, 2005).

Control is the process of determining how a robot should move and transmitting the respective commands from the navigation system to the locomotion hardware. Control is considered part of the locomotion problem because it is responsible for the robot's motion and determines its movement. It is described by location (interior, exterior, or mixed), terrain type, area structure (e.g., interior building features, pathways, or landmarks), obstacle type (static and possibly dynamic), lighting sources and changes, and other details that may affect the robot's navigation(Yuri D. V. Yasuda, Luiz Eduardo G. Martins, 2020).

5. Mobile Robot Navigation Algorithms

This paper discusses several methods of navigation, such as the potential field method [PFM], artificial potential field [APF], evolutionary artificial potential field [EAPF], multi-objective evolutionary algorithm [MOEA], edge detection method and force field method vector.

A navigation method is used to investigate the mobile robot's motion toward its destination while avoiding obstacles in its path. The route planning method for a moving robot is based on the idea of finding an optimal route consisting of many points that are close enough to each other yet avoid collision.

5.1 Potential field method (PFM)

The path planning process is greatly influenced by the dynamic features of robots and the law of navigation (Arai T, Pagello E, 2002), Information about the obstacles' location is used to determine a desirable path (Abiyev, Ibrahim and Erin, 2010). The Potential Field Method [PFM] is one of the path determination methods whose viewpoint is that mobile robots move in a force field with the target position to be reached having an attractive potential and each obstacle creates a repulsive potential. The potential field can be viewed as an energy field, so its gradient at each location is a force. It is used in path planning and route determination, and control steps are performed instantaneously(Gomez EJ, Martinez Santa F, 2013). Obstacles exert a virtual repulsive force on robots while also having the target generate a virtual attraction force based on a similar concept that considers the speed of the robot around the obstacle (Abiyev, Ibrahim and Erin, 2010). The design is achieved such that when the repulsive force exceeds a defined threshold, the robot stops, and then the resultant force vector direction is changed. The robot then continues the motion in a forward direction. However, for the tele-autonomous process, it is not suitable for the robot to engage in such intermittent movements. The Potential value for each grid point based on this algorithm is estimated using Laplace's equation. The field value at the target is a given set value -2127 [representing the lowest negative number the compiler can process]. The limit point is selected at zero. The potential values of each grid point explained above are known as grid values, a two-dimensional array. The grid size is used to obtain both the width and length of the grid cells, while the field values for each point in the workspace are estimated by utilizing linear interpolation.

5.2 Artificial potential fields (APF)

In this approach, a mobile robot applies a force generated by the artificial potential field as the control input to its driving system. It is often purely reactive and does not optimize the path traveled. Modified potential field with robust and improved (Marta C. Mora and Josep Tornero, Prahlad Vadakkepat and Liang., 2000).

It is regarded as one of the strategies employed in robot obstacle avoidance, the APF. It was first developed by Khatri and used a repulsive potential field around obstacles [and forbidden regions] to force the robot away and an attractive potential field around the goal to attract the robot (Synodinos A, 2010). The simple APF method has highlighted numerous main problems, which are:

- Where there are several obstacles within the robot's area, the field may include a local minimum that can trap the robot.
- The algorithm is a gradient descent that cannot hide its smallest local values.
- The pattern of travel of the robot might be oscillatory.
- Movable locals are made smaller because moving obstacles direct the robot far away from its goal.

By reducing the side obstacle's repulsion, the response method was improved by Bornstein. The result is the complete avoidance of such obstacles by decreasing the quantity of wobble, albeit ensuring the avoidance of obstacles on its route. There have been several attempts to handle these issues in the APF. The attempts comprise virtual obstacles that are generated at low values, and the distance transformation without local minima. The global methods are dependent on the information obtained from the workspace, which is normally a function of the robot's dimension. In global methods, two main problems must be addressed: mapping the obstacles within the workspace structure and establishing a route through the shape of the workspace from point to point and with respect to smooth maneuver of the obstacles. To make these routes, artificial potential methods surround configuration space obstacles with repulsive potential energy functions and place the target point at a global energy minimum. The target point in the shape of space indicates the robot is acted upon by a force up to the negative gradient of this potential field and changes path away from the obstacles to the mini (Hameedah Sahib Hasan, Mohamed Hussein, Shaharil Mad Saad, 2019).

Application of artificial evolution to APF optimization is a successful approach for the autonomous navigation of a mobile robot.

5.3 Evolutionary artificial potential field (EAPF)

In the deployment of a traditional APF scheme, a point of higher potential is considered as the obstacle, while a point of lower potential is set as the goal. An evolutionary artificial potential field [EAPF] scheme is utilized for real-time navigation of robots with considerations of moving obstacles and target positions (Marta C. Mora and Josep Tornero, Prahlad Vadakkepat and Liang., 2000). The traditional APF approach does not involve any optimization process, which means the generated path is safe. However, it is often not optimal. In the EAPF scheme, an evolutionary algorithm is deployed to optimize the potential field functions of the obstacle. Different potential roles are defined for the obstacles, unlike the traditional approaches (Cao Qixin, Huang Yanwen, 2006).

5.4 Multi-objective evolutionary algorithm (MOEA)

It incorporates selection criteria for its performance to assist in the navigation guide. In doing this, the expected population attributes are continuously optimized (Wenlan Huang, 2019). In 2004, Zitzler and Kunzl Proposed and posited that IBEA remains the first well-known indicator-based MOEA (Zitzler E, 2004), The preference of decision makers is defined by the binary indicators offered by IBEA with two sets of approximate solutions compared in terms of relative quality. Pareto fitness allocation is used to calculate the fitness factor for MOEA, as the indicator offered by MOEA is dependent on the Pareto rule. For indicator-based MOEAs general frameworks are provided. This area has attracted increased study. An optimal solution does not apply to cases where all the objectives share some vital importance. In such a scenario, multi-objective optimization is chosen. This implies that for convergence, two or more ideal goals are required for a multi-objective optimization problem. A set of diverse solutions was first obtained for the entire range of the Pareto optimal front (Kalyanmoy Deb, 2015). Researchers for many years ignored the decision-making aspect of MOEA with concentration on the multi-tradeoff solution-based efficient algorithms. Gradually, focus is gradually shifted to both decision making and optimization. The decision-making task largely involves considerations from a generic point of view, while a subjective consideration is explored for the development of the EMO framework (Kalyanmoy Deb, 2015)

5.5 Edge detection method

In edge detection methods, the edges of target objects are the input points and can be deployed in different environments and scenarios. Different methods exist by which edge detection computations are carried out, although each method has its own approach. The maximum variation at a certain edge on an intensity map using a derivative approach as was deployed by Sobel, Prewitt, and Robert's (Boris Crnokić, Snježana Rezić, 2016). To improve the localization of all identified edges, a canny algorithm can be applied to eliminate almost all non-edges for a low error rate (C. Gentsos, C. L. Sotiropoulou, S. Nikolaidis, 2010). Numerous researchers have utilized edge detection methods and have compared their outcomes from different scenarios of performing various tasks. While the canny edge detection algorithm gives detailed edges in some examples of the rover on and around the lunar surface (Iqbal, 2012), it remains inadequate for a defined textured scene; for edges of high concentration, good results of edge detection are obtained using the Sobel operator.

In robot navigation edge detection allows the extraction and visualization of key features, which may help for easy identification of objects. These features include lines, curves, and angles. Edge-represented images offer great simplicity in the process of image identification and interpretation and are deployed in mobile robot navigation systems with the use of a camera as its main sensor. In image processing, the goal of edge detection also includes the identification of edges or regions with a sharp color difference. The mathematical operator corresponding to spatial differences and interruptions in the set of grayscale pixels in a given image can be termed the edge detector (Boris Crnokić, Snježana Rezić, 2016) (A. Q. Mahdi, G. A. QasMarrogy, 2014).

Edge detection provides flexibility and helps in the recognition of location properties with high accuracy, especially in aerial photos taken from satellites. Differentiating shapes or other features from a given image could pose a significant problem without edge detection. It has equally addressed the achievement of both analyses of an image by rendering the lines or circles with their edges. With the edges detected, it becomes easy to differentiate and perceive the elements of the image. The accuracy of the identification depends on the effectiveness of the algorithms in specific cases. Many researchers had to develop new edge detection methods to search for the best results in totally different applications (A. Q. Mahdi, G. A. QasMarrogy, 2014).

5.6 Vector force field method

It is similar to a magnetic field around the desired lane attracts the autonomous vehicle (Boroujeni *et al.*, 2018). The vector fields are calculated offline to efficiently obtain the force vector for each point. Online route planning and route generation are computationally complex tasks. Vector fields are problem specific and this is its popular shortcoming. In robotic navigation, there is a wide range of applications that Vector fields can be used for examples are mobile robots (F. Bounini, D. Gingras, H. Pollart, 2017), air vehicles (D. R. Nelson, D. B. Barber, T. W. McLain, 2007), spacecraft (N. Bloise, E. Capello, M. Dentis, 2017), and more recently autonomous vehicles (Y. Rasekhipour, A. Khajepour, S. K. Chen, 2017)(D. A. De Lima and G. A. S. Pereira, 2013). A useful comparison between various potentially new and well-established approaches to field path planning is presented (Montiel and , Ulises Orozco-Rosas, 2015). There has been a lot of focus on the application of field vector methods to the route planning and navigation of autonomous vehicles. The essence of autonomous vehicle navigation is to achieve an organized road map. Depending on the mission of the autonomous vehicle, a route planning subsystem is used to plan the required route, at first, then the force field is used to implement the path that follows the task. Vector fields are computed to follow the path in real-time, at a very low computational overhead while performing the task (Boroujeni *et al.*, 2018).

6 Comparison Between Navigation Methods

Table 1 shows a comparison of the listed methods for mobile robotic navigation: Probable Field Method [PFM], Artificial Potential Field [APF], Evolutionary Artificial Potential Field [EAPF], Multipurpose Evolutionary Algorithm [MOEA], Edge Detection Method [EDM], and Vector Force Field Method [VFFM].

Table 1
Comparison between navigation methods

A Potential Field Method (PFM) (Zafar, Mohanta and Keshari, 2021) (Rainer Palm∗ Abdelbaki Bouguerra, 2011)(J. L. Baxter, E. K. Burke, J. M. Garibald, 2009) (S. S. Ge and Y. J. Cui, 2002).	Artificial Potential Field (APF) (Borenstein J, 1989)(Of, 1990)(Hwang YK, 1988) (Sfeir, J., Saad, M., & Saliah-Hassane, 2011)	Evolutionary Artificial Potential Field (EAPF) (Cao Qixin, Huang Yanwen, 2006)(Marta C. Mora and Josep Tornero, Prahlad Vadakkepat and Liang., 2000) (BESİME ERİN, 2011)	Multi-Objective Evolutionary Algorithm (MOEA) (Wenlan Huang, 2019)(Kalyanmoy Deb, 2015)	Edge Detection Method. (Boris Crnokić, Snježana Rezić, 2016)(A. Q. Mahdi, G. A. QasMarrogy, 2014)	Vector Force Field Method (Fedosin, 2016)
PFM is designed to enable real-time automated maneuvers with fast mobile robots. In this application, the robot's workspace is filled with an APF which helps attract	One of the strategies employed in robot obstacle avoidance is the APF. This technique helps to eliminate any local trap set within its domain as well as mitigate the vibrating effect. The mitigation	EAPF algorithms are also applied to a real-time robot's path planning. In this approach, the APF is combined with genetic algorithms to obtain an optimal APF function. In EAPF, the potential field functions are	MOEA is applied to achieve the optimal potential field functions. MOEA utilizes fitness functions for its selection criteria. These fitness functions include the obstacle factor, minimum-path	EDM has become one of the most popular algorithms applied for obstacle avoidance in robotics. In this approach, obstacles are identified by the position of the vertical edges to help steer the robot around the visible	The VFFM is another widely utilized approach for robot navigation. VFFM offers smooth, continuous, and fast motion of the vehicle for all obstacles [expected and unexpected]. Also, the robot is not required to stop in front of

the robot to target positions while it is repulsed from obstacles.	is not limited to parameter adjustment alone. APF also helps in achieving early arrival targets. Although APF potential is artificial, it is deployed to generate an artificial force field. It is implemented to achieve instantaneous reference control, which can be generated from a virtual velocity and acceleration determined by the robot's state and artificial dynamics.	defined for both obstacles and goal points and are highly suited for robot navigation in situations of moving obstacles. Potential field functions for obstacles and goal points are defined..	length factor, goal factor, smoothness factor, etc. MOEA addresses the problem of the local minimum present in the application of EAPF.	edges. The boundaries in this instance are deemed to be the lines connecting any two visible edges. In some EDMs where ultrasonic sensors are utilized, the robot takes a panoramic scan of its environment from a stationary position. Sensory information is gathered while the robot stands in front of the obstacles. The major drawback of EDM is its high sensitivity to sensor accuracy.	obstacles. Obstacles are represented by a two-dimensional Cartesian histogram grid, with each cell holding a certainty value, which indicates the confidence signaling the presence of an obstacle at that location.
The simplicity of PFM and its elegant mathematical analysis make it very attractive. The PFM comes with the shortcoming of the possibility of space configuration with certain unfavorable conditions, which may not satisfy the stability criteria of the robot, thereby causing the robot to oscillate. Also, the stability factor [defined as the ratio between the repulsive and target force constants has to be determined experimentally, which ultimately means the existence of unstable conditions for the environmental model.	APF offers the significant advantage of a relatively fast and efficient mode of solving safe trajectories around stationary and moving obstacles.		It was introduced to avoid the local minimum associated with EAPF.		

In In practical mobile robot navigation problems, it is difficult to achieve the perfect precision of a dynamic area prototype in practical mobile robot navigation. Mobile robots respond to instructions by navigating a given surrounding for a specified task, depending on the sensory data in real-time (Zitzler E, and K. S. (2004). The restriction offered by the sensory data is the main drawback, as the robot could deviate from the path even in the presence of an objective.

6. Conclusion

Robotics is one of the most attractive fields in engineering. The major objective of robotics centers on the design of fast and efficient navigation in the presence of all forms of obstacles. Its core advantage is to ease human tasks, especially when such tasks are labor-intensive and dangerous. This study presented the various navigation algorithms, their applications, and the various associated drawbacks.

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