A Review of Space Exploration and Trajectory Optimization Techniques for Autonomous Systems: Comprehensive Analysis and Future Directions

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Abstract. Autonomous systems have achieved great success over the last couple of decades. They have bring the revolutionary change in the world, either its ground vehicles, aerial systems or underground vehicles. Number of research papers have been written on the importance of autonomous systems and their applications in different field. Keeping in view the pattern of research done by authors, an effort has been made to provide a single platform for readers to familiarize themselves with applications involved in terrestrial, aerial and undersea systems along with different sets of dimensions involved in achieving these applications. Therefore, the article provides a summary of the main communication methods used by terrestrial, aerial, and undersea space research vehicles. In addition to providing an exhaustive summary of the difficulties encountered in trajectory planning, space exploration, optimization, and other areas, the research also presents optimization methods applicable to aerial, undersea, and terrestrial applications. As the literature lacks extensive studies like this one, hence an effort has been made to fill the gap for readers interested in path design. This study tackles numerical, bioinspired, and hybrid techniques for each of the dimensions given. With this study, we attempted to provide a single repository for a plethora of research on autonomous land vehicles, their trajectory optimization, as well as research on aerial and undersea vehicles. The article ends with the most practical directions for future research.

Keyword: Space exploration · Undersea Vehicle · Aerial Vehicle · Terrestrial Vehicle

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1 Introduction

The significance of driver-less vehicles was initiated dated back in 2007 by DARPA (Defense Advanced Research Projects Agency) Urban challenge [9], the concept was later on extended for the development of underwater and aerial vehicles. In order to increase the flying stability of the aerial system, many concepts were applied to flight dynamics methods [29]. The concept further exploited in numerous ways, which result in development of number of algorithms and opened new areas for research. Since the 1970s, route planning has attracted a lot of interest. It has been applied to a variety of issues, from basic geographic route planning to selecting the best course of action to achieve a specific objective. Path planning uses input from system-mounted sensors to update environmental maps and direct the motions of the robot or planned autonomous vehicle (AV) in environments that are wholly unknown, partially unknown, or both. For both ground and airborne vehicles, numerous techniques have been developed during the past ten years using the trajectory optimization issue. The two categories of these trajectory optimization issues are a) heuristics and b) non-heuristic approaches. In order to produce optimal solutions, the former uses trade-offs, which produce findings that are computationally efficient, whilst the latter requires mathematical derivations, which are computationally expensive. The optimization algorithms used in applications of ground robotics [17] includes numerous applications. Autonomous navigation is an essential component of moving robots or aerial vehicles. It helps them depend less on support from people. It does, however, involve a number of tasks or challenges to overcome, such path planning. Choosing the most effective plan to get a robot from its current state to the desired state is the aim of this assignment. For instance, the objective and the starting point could both be the same condition. This action plan known as a path or route. The robot is guided to the desired location using the path. Path planning algorithms often seek out the ideal path, or a close approximation of it. The optimal route is the best path in the sense that it is the outcome of decreasing one or more objective optimization functions. For instance, this route can be the one that travels the quickest. This is essential in missions like search-and-rescue efforts, as disaster victims may ask for help in life-or-death situations [21]. The robot's energy consumption may be another optimization factor to take into account. This is crucial in the case of planetary exploration because rovers only have a finite amount of energetic resources at their disposal. The purpose of the suggested survey article on these vehicles navigation is to discover the research gaps and potential for innovation in a certain field. The route generation and optimization problem can be tackled using deterministic (numerical) approaches, nature-inspired algorithms, or a combination of these techniques. For calculating the precise solution, there are several deterministic techniques available, including the Iterative method [24], Runge Kutta [14], Newton Raphson method [34], and Bisection method [35]. These algorithms are used to tackle path planning, trajectory optimization, and a variety of other vehicle versions for autonomous vehicles. Swarm based approaches are dependent on the social hierarchy of animals and birds such as ants, bees, and flies. There are great number of different algorithms which are inspired from the nature such as Grey Wolf Optimizer, Whale Optimization, Deer Hunting Algorithm, Slap Swarm

Algorithm, Grasshopper Algorithm, Ant Lion Optimizer, Moth Flame Optimizer, Simulated Annealing, Arithmetic Algorithm, Harmony Search Algorithm, Aquila Optimizer, and Owl Search Algorithm [9] (Fig. 1).

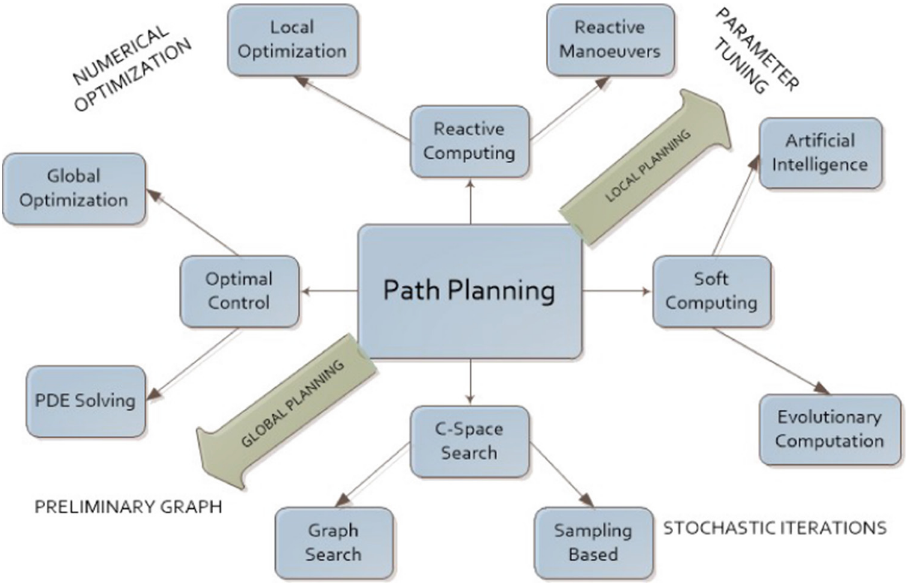

Fig. 1. Schematic showing different Path Planning Methods. (Mir, I., Gul, F., Mir, S., Khan, M.A., Saeed, N., Abualigah, L., Abuhaija, B., Gandomi, A.H.: A survey of trajectory planning techniques for autonomous systems. Electronics **11**(18), 2801 (2022))

1.1 Objective and Contents

The proposed survey paper looks at numerical approaches and nature-inspired strategies for navigation, space exploration and obstacle avoidance used in the literature for land, airborne, and underwater vehicles, as well as how they might be combined or used separately. The goal of the study is to give academics the most recent information required for path optimization, space exploration and environment modeling. The goal of the study is to compare several algorithms and demonstrate how they might be used in different situations. The contributions made by this review are listed below: -

Consolidation of Relevant Work: Amazingly, human being are able to detect their surroundings, maintain control, and make the necessary motor movements all at once. Researchers from all over the world are working on developing intelligent autonomous vehicle which can independently take decisions while exploring the environment. The vehicle may also possess attributes like human beings, and can maneuver while maintaining safety and ensuring that the vehicle's efficiency is not compromised. In order for readers to comprehend the value of land, airborne, and underwater vehicles in industrial research, this essay aims to offer them significant insight.

Limitations with Future Direction: This research's significant additional contribution is its use of numerical and nature-inspired techniques to pinpoint the difficulties in path optimization and obstacle avoidance. The traits that do not help with determining the best trajectory optimization for both ground and aerial vehicles are identified and divided into groups: a) the limitations of numerical methods and those of nature-inspired techniques; and b) the restrictions of numerical methods and those of nature-inspired techniques. Also proposed is a comprehensive course of action.

2 Relevant Studies

We will conduct a thorough study and assessment of the important studies conducted for space exploration, trajectory planning for automatic guided vehicle in this section. As explained earlier, deterministic techniques, swarm-based algorithms, and the fusion of these methods can all be used to handle path planning, space exploration, and trajectory optimization challenges. Numerous numerical techniques based on the Runge Kutta, Newton Raphson, and Iterative methods, as well as the Bisection method, are frequently used. To address trajectory planning, obstacle avoidance, and trajectory optimization, due to growing interest, the research field broadened and swarm-based methodologies based on reptile, aquila, arithmetic algorithm etc.. It is feasible to combine several strategies because no one algorithm or technique can always give the required results. The entire process is referred to as "Hybridization of Algorithms/Techniques" [11].

2.1 Deterministic Techniques Framework

Deterministic analysis includes the application of algorithms to get numerical solutions. It requires theoretical mathematical study. This section introduces the numerical approaches and their utility in all automatic guided vehicles.

Applications to Aerial Vehicles. The performance of the sensors is the key component of any aerial vehicle system. The effectiveness and dynamics of aerial vehicles are influenced by a variety of sensors, including radars, lidars, and sonars. Owen et al. [25] successfully used radar to find moving targets, while [22] used LiDars for airborne use. There are number of areas which can be studied in aerial vehicle. When a collision happens, Mansury et al. developed a penalty function in a planned path [20]. One technique penalizes the goal function when the planned path gets close to an obstruction, whereas the other penalizes the objective function only when the planned path would cause a collision. In place of a single point, obstacles can alternatively be handled as flight-restricted zones. By using a collocation strategy, Zhao et al. [40] used the nonlinear programming solver to numerically resolve the parameter optimization portion of the optimum control problem (NPSOL) [7]. The results of the NPSOL programme show that after a successful convergence, the non-linear programming problem has a locally optimal solution. Z. Czyz et al. [5] the study looks at aluminium beams joined by flat bars and angle irons as a thin-walled support platform for an unmanned aerial vehicle. The building serves as a form of frame for the propulsion system of the created aircraft, a hybrid multicopter-gyrocopter. To explore the stresses and strains that are associated to this construction's profiles, it was tested under a variety of load patterns.The finite element technique (FEM) and Solid-Works software were used to do the numerical computations, and the load patterns are related to different propeller operating condition. The support platform's separate components' ability to operate in an elastic manner was the subject of the research.

Applications to Ground Vehicles. Online route planning frequently uses curve interpolation planners like Clothoid, Polynomial, Spline, and Bezier curves. These planners have a minimal computing cost since the behaviour of the curve is controlled by a limited set of control parameters, comparable to graph search approaches. The final route's optimization cannot be guaranteed because the dynamic restrictions of a robot have not been considered during the planning stage, necessitating the smoothing step. The measure for uncontrollable divergence is cited by Zhang et al. [37]. Using this statistic, a system is developed to switch between various predictive controllers quickly while preserving predictive accuracy. The computer-based dynamical analysis of engineering systems requires robust and effective numerical methods as a prerequisite. For the analysis, simulation, and optimization of the complex dynamical behaviour of vehicles and vehicle components, as well as their interactions with hydraulics, electronics, and control systems, multibody system dynamics methodologies and software tools provide the integration platform. The modelling of vehicles and their parts, which is based on the principles of classical mechanics, yields nonlinear systems of ordinary differential equations (ODEs) or differential algebraic equations (DAEs) of moderate dimension, which describe the dynamical behaviour in the required frequency range and with a level of detail that is characteristic of vehicle system dynamics. The majority of real-world issues in this area can be reduced to standard numerical mathematics issues, such as explicit ODEs or DAEs with a typical semi-explicit structure in dynamical analysis and systems of nonlinear equations in (quasi-)static analysis. The use of sophisticated, publicly accessible numerical software that is based on widely accepted numerical techniques, such as the Newton-Raphson iteration for nonlinear equations or Runge-Kutta and linear multistep methods for ODE/DAE time integration, is made possible by this transformation to mathematical standard problems. Utilizing a particular structure of the mathematical models for vehicle system dynamics, significant speedups of these numerical standard approaches may be accomplished [3]. The Clothoid curve offers a cutting-edge method for shortening routes and changing curvature. This method, which takes into account two points on the plane, yields a solution to join 2-Clothoid sets in-order to determine the location of a waypoint. The technique aids the robot in fast maneuvering, and motion performance is enhanced [16].

Application to Undersea Vehicles. In terms of relevance, autonomous undersea vehicle systems (AUVs) navigation and controls are now on par with those of terrestrial and aerial vehicles. An alternative name for them is ocean vehicle navigation. Path planning is necessary for autonomous underwater vehicles (AUVs), just like it is for ground and aerial vehicles, in order to navigate as efficiently. The water environment, in contrast to ground and airborne vehicles, presents a number of challenges due to limitations in data transmission, sensing range, and power.

Underwater communication is challenging due of the bandwidth channel's erratic changing. Therefore, choosing the best course of action for autonomous underwater vehicles is a challenging task. Using the Normalized Generalized Velocity Components (NGVC) as a tool for analysis, the author [12] proposed a novel technique that entails two steps: (i) the development of a velocity control algorithm, and (ii) its application to the vehicle dynamics investigation. The decomposition of the inertia matrix leads to altered equations of motion, which are used to define the algorithm. Before carrying out an actual experiment, the author suggested that the approach be used to perform numerical testing of the assumed model for fully functional underwater vehicles. The effectiveness of the suggested method is demonstrated through simulation on a 6 DOF underwater vehicle. In [30], a nonlinear MPC is suggested for an autonomous underwater vehicle (AUV). To solve the path planning problem, a receding horizon optimization framework with a Spline template is employed. Combining the path planning outcome and MPC is used for tracking control.

2.2 Swarm-Based Framework

Without the aid of a third party coordinator, swarm intelligence systems are capable of acting in unison. Swarm intelligence adds a new characteristic to artificial intelligence that allows for the study of emergent features and collective behavior of complex systems in predetermined environments. Many scholars have taken on the problem of planning the trajectory of terrestrial and aerial vehicles using an optimization method that imitates the behavior of living creatures [39]. The issue of trajectory tracking is a very active academic topic. Numerous established techniques, including Artificial Potential Field, Neural Network, Distance Wave Transform, A-star algorithm, and D-star algorithm, are used to solve this problem. These algorithms, also referred to as swarm-based approaches, and have been applied in engineering to tackle difficult mathematical problems.

The correct assessment of the landing place in the shortest possible time is made possible by the incorporation of bio-inspiring algorithms in UAV control systems. The Bats Optimization Algorithm, Moth Flame Optimization Algorithm, and Artificial Bee Colony Algorithm are bio-inspired optimization algorithms used in by Ilango et al. [15] to determine the coordinates (points) of the computed path and to determine the best point of landing, ensuring that the aforementioned parameters are within the operational limits of the UAV. The goal of the research project was to quickly locate the best landing point from the computed points and to establish the path from those points. The error rate is defined as the difference between the initial points of the real path and the derived computed points of the estimated path. The accuracy in forecasting the landing site and the computation time are two trade-off factors used to evaluate the performance of the algorithms.

Application to Aerial Vehicles. The notion of intelligent micro drones that are inspired by soaring insects like bees is presented in [4]. The demonstrated micro drones can carry out sophisticated tasks on their own utilizing basic sensors and very little processing power. In particular, we offer a set of algorithms for navigating, flying in swarm formation, avoiding obstacles, and mapping that are all based on sub-gram sensors and suitable for micro drones' on-board computing. We draw the conclusion that many bio-inspired problems can be completed without the usage of high resolution visual sensors using both simulation and field testing. Autonomous micro drones can also participate in a variety of research domains, such as swarm algorithms for search and rescue and mobile sensor networks. The significance of bio-inspired algorithms (BIAs) is growing dramatically as a result of their potential to optimize numerous issues in a variety of domains, including artificial intelligence, medicine, and other professions. Unmanned aerial vehicles (UAVs) are currently using BIAs because of their autonomy in applications like the internet of things (IoT), autonomous area searching and reconnaissance, etc. Usman et al. [33], uses the particle swarm optimization (PSO) algorithm and a few characteristics of the penguin search optimization algorithm were combined to present an UAV reconnaissance strategy. The main goal of the strategy was to use UAVs to locate the rescue targets by maximizing their movement using combined PSO and PeSOA attributes. Analysis of the results is done using PeSOA attributes both with and without grouping scenarios. Majd Saied et al. [27] examined several UAV. The proposed idea calculates velocity using the ABC approach in order to avoid obstacles and keep track of flight data. In MATLAB, numerous case studies were used to execute the simulations.

Application to Terrestrial Vehicles. A form of intelligent computing technology known as a"bioinspired intelligent algorithm" (BIA) has a more realistic biological functioning mechanism than other varieties. BIAs have advanced significantly in their comprehension of biological and neurological systems as well as in its application to a variety of fields. One of the primary applications of BIAs that has gained increasing attention is mobile robot control. This is because mobile robots can be used widely and because general artificial intelligent algorithms encounter a development roadblock in this area due to complex computing and the reliance on high-precision sensors. In order to aid in a thorough and precise knowledge of BIAs, the author Jianjun et al. [23] provides a summary of recent research in BIAs. The research is concentrated on the realization of various BIAs based on various working mechanisms and the applications for mobile robot control. The survey is divided into four main sections: a classification of BIAs from the perspective of the biomimetic mechanism, an overview of several typical BIAs from various levels, a look at the current uses of BIAs in mobile robot control, and a discussion of some potential future research directions.

Application to Undersea Vehicles. Sanchez et al. [28] suggest a restoration technique whose cost function (objective function) is a No-Reference Image Quality measure and estimates the model parameters using bio-inspired optimization metaheuristics (NR-IQA). The Artificial Bee-Colony Algorithm (ABC), Opposition-based Artificial Bee Colony (OABC), Differential Evolution (DE) metaheuristics, Opposition-based Particle Swarm Optimization (OPSO), Repulsive-Attractive Particle Swarm Optimization (RAPSO), and Artificial Bee Colony Algorithm (ABC) have all been put to the test in this case. P^etr‘es et al. [41] a fresh technique based on quick marching that extracts a continuous path from the surroundings while accounting for underwater currents. The path planning problem was put forth as an optimization framework by Yilmaz et al. [36], who combined it with an approach based on integer linear programming. The above-mentioned methods were all tested in two-dimensional (2D) environments, which does not satisfy the actual needs of AUV route planning. Hu et al. [13] researchers created a vision-based autonomous robotic fish with 3D mobility by employing a control rule with an attracting force toward a target and a repulsive force against obstacles.

2.3 Hybrid Techniques Framework

This section provides thorough information on hybridized algorithms and its related to terrestrial, aerial, and undersea applications after elaborating on deterministic and swarm-based methodologies.

Application to Aerial Vehicles. In order to create an ideal path, Xiangyin et al. [38] research provides an upgraded fireworks algorithm (FWA) and particle swarm optimization (PSO) cooperation method. This paper treats the unmanned aerial vehicle (UAV) global path planning as an optimization problem with many constraints. The UAV flight route goal function is modelled to have the shortest length while adhering to stringent multiple threat area constraints. One of the essential presumptions for successful (UWSN) operations is the timely and safe passage of the UAV. Finding a good path in an area with many obstacles and making sure the path can effectively get to the goal location are both important and difficult tasks. In order to ensure that UAVs collect data efficiently in emergency situations, the authors in [26] suggests the hybrid path planning (HPP) algorithm. The probabilistic roadmap (PRM) algorithm and the optimised artificial bee colony (ABC) algorithm are used in the proposed HPP scheme to design the shortest trajectory map and improve various path constraints in a three-dimensional environment, respectively. UAVs offer a platform for carrying out a wide range of jobs, but path planning is essential to every single one of them. It assists in creating a path that is clear of impediments, has a short length, uses less fuel, travels faster, and steers the aircraft and its associated antenna power signature safely around the hostile antenna to avoid detection. B. Abhishek et al. [1] study introduces two novel hybrid algorithms, particle swarm optimization (PSO) with harmony search algorithm and PSO with genetic algorithm, to enhance path planning to take into account all the aforementioned restrictions. In contrast to the current algorithms, which are inclined towards either an exploitative search or an exploratory search, the hybrid algorithms execute both an exploratory and an exploitative search.

Application to Terrestrial Vehicles. Shang Erke et al. [6] introduces different setps, firstly a standard for evaluating algorithms is presented, allowing for the performance of various algorithms to be measured and suitable parameters to be chosen for the proposed method. Second, a global planning or human-generated guideline is used to construct a heuristic function to address the drawback of conventional A-Star algorithms. Thirdly, key points around the obstacle are used to improve obstacle avoidance performance. These points would direct the planning path to avoid the obstacle much earlier than the conventional one. Fourth, to shorten the suggested algorithm's computation time, a novel variable-step based A-Star algorithm is also introduced. Experimental results demonstrate that the performance of the proposed algorithm is robust and stable when compared to state-of-the-art methods.

Rafal et al. [31] Robotic palletizing is a typical use of industrial robotization. The robotic arm may frequently manage more than one production line due to its efficiency. In this situation, choosing the right product from one of numerous production lines will have an impact on total efficiency. In this work, a single robotic arm controlling three production lines is taken into consideration. Each item's cycle time and maximum permitted waiting time are taken into consideration. Constrained multi-objective optimization issues were created as a result of the authors' four separate objective functions they provided in relation to potential requirements in a factory environment. The Artificial Bee Colony algorithm, which is backed by Deb's rules, has been used to tackle this issue. Results have been compared using three fundamental decision-making processes and the Reinforcement Learning methodology. It has been demonstrated that the suggested approach both greatly boosts production rate and satisfies specific requirements, such as minimum energy consumption per palletized item ratio and equal container filling.

Rafal et al. [32] introduces a novel technique for local minimum avoidance. It is based on the establishment of imaginary barriers known as top quarks in crucial locations. The APF-based path planner is further repelled by these barriers. The new temporary objective for APF was chosen with consideration for the projected AGV trajectory that was free of stagnation. Combining these techniques enables one to shorten the distance travelled, enhance its smoothness, and avoid local minima. The Husarion ROSbot 2.0 PRO mobile robot was used to test the suggested Predictive Artificial Potential Field (PAPF) algorithm, and the findings, which are presented as movies, are also included as supplemental files. The proposed path planning algorithm enables a 21.4% reduction in the amount of electricity used when compared to the original APF. Up to 8.73% shorter paths and up to 40.23% faster times to the goal position were made possible by PAPF. When using the proposed algorithm, the AGV moves significantly more smoothly, and the proposed top-quarks-based local minimum avoidance mechanism enables bypassing of the local minima.

Undersea Vehicles. The path planning scenario for an autonomous underwater vehicle (AUV) is presented by Hui et al. [19] as an optimization problem constrained by a mix of hard and soft constraints. The goal of the path planner is to create the best path in both 2D and 3D for navigating an AUV safely through an ocean environment with known obstructions and irregular currents. The path planner employs the selectively Differential Evolution (DE)-hybridized Quantum PSO (SDEQPSO) and Adaptive PSO particle swarm optimization (PSO) algorithms (SDEAPSO). In a series of thorough Monte Carlo simulations and ANOVA (analysis of variance) methods, the performances of the path planners under various restrictions are examined based on their individual solution characteristics, stabilities, and computing effectiveness. Based on the simulation results, it was discovered that the SDEQPSO path planner, which uses a hard constraint for the boundary condition and a soft constraint for obstacle avoidance, is more effective than other algorithms at generating feasible and smooth AUV paths. This is demonstrated by its relatively low computational requirement and excellent solution quality.

Hui et al. [18] the paper describes the use of an open-source system architecture called MOOS-IvP to construct an online path planner in an autonomous underwater vehicle (AUV) system. The path planner used the selective differential evolution quantum-behaved particle swarm optimization (SDEQPSO) algorithm together with a path replanning scheme. The solution was built on a modular structure to guarantee the path replanner's reliability throughout a mission. In hardware-in-the-loop (HIL) experiments, the path replanner interacted with the onboard controllers and actuators of an Explorer AUV to assess and verify its performance under stochastic processes. The experimental findings shown that the path replanner may be used in real time to design and continually improve a safe and practicable path for a dynamic and uncharted environment using technology onboard an Explorer AUV.

3 Challenges, Recommendation and Future Directions

Based on a review of the literature, we provide a quick overview of the difficulties faced during the space exploration process in this section. Then, we'll suggest some fixes and potential future directions.

3.1 Challenges

Despite the fact that there are number of research contributions for land, aerial and underwater vehicles but it is observed that no single method guarantees 100% results. The fundamental disadvantage of all swarm-based algorithms is their inherent tendency to become trapped in local or global maxima or minima. Similar to oscillations, undesired noise, and overshooting, controllers make faults in output. These drawbacks have a significant effect on how an algorithm functions, which in turn affects how well autonomous vehicles operate. Another challenge is that various algorithms rely their navigational predictions on environmental data. Unwanted halt in the vehicle's motion result from this.

3.2 Proposed Solutions

Path planning, which is now further expanded to path optimization, is one of the most researched issues in control engineering for terrestrial, aerial, and undersea vehicles. In order to tackle optimization issues in all three domains, several algorithms using probabilistic and non-probabilistic methods have been used, including A-star, bug, bug2, evolutionary algorithm, probabilistic roadmap, rolling window algorithms, etc. These techniques have variety of versions, including Astar and D-star as well as numerous enhancements to PRM and APF algorithms are available. No method is capable of achieving all objectives, hence method integration and hybridization have become widespread practices. The social behaviours of numerous creatures were imitated in the form of swarm-based algorithms, then they are modelled as full optimization algorithms. Nature-inspired algorithms are frequently employed in this context, including the Aquila Optimizer, Arithmetic Optimizer, Snake Optimizer, and Reptile search Optimizer. Researchers are also combining methods inspired by nature to create controllers with names like sliding mode controller, adaptive controller, and linear quadratic controller. The best strategy is to combine several approaches, keeping in mind the trends involved in the execution of various algorithms, so that numerous objectives can be reached rather than just one [10]. The disadvantage of hybridization is that, it may lead to more noise, increase oscillations in system performance, or more complex computations. Even yet, the additional benefits following integration are incomparable to other shortcomings. Under such circumstances, trade-offs are always there.

3.3 Potential Future Directions

In order to give an insight for the reader to study potential topics for trajectory generation, utilizing the recently created Reptile Search Optimizer, which has widespread potential use, is one possible direction to work in. The Reptile Search optimizer (RSA) is an algorithm with natural design cues [2]. This slightly modified, swarm-based reptile search optimizer combined with a multi-coordinated agent exploring. These techniques for area surfing and trajectory optimization may be of interest to readers. A similar has been implemented and can be found in [8].

Table 1. Benefits and Weakness Involved in Autonomous Vehicles

Algorithms	Benefits	Weakness	Implementation
Fuzzy Logic	(a) Easy tunning of fuzzy rules (b) Easy to learn (c) Integration with other algorithms are easy	(a) Membership functions cannot be easily implemented	Simulated world and Real time
Neural Network	(a) Easy implementation as compared to fuzzy rules (b) Logic building is easy (c) Back-propagation is found beneficial	(a) Understanding of Neuron layers are hard (b) Multiple Layered structure aids in the complexity	Real time and simulation
Genetic Algorithm	(a) Convergence rate is fast (b) Easily to integrate	(a) Local/global minima/maxima problem exists in complex environment (b) Fine tuning is required	Simulated world
ABC	(a) Control variables are less (b) Lesser execution time is needed (c) Integrate-able with other algorithms	(a) Convergence rate is slow	Simulated world

(*continued*)

Table 1. (*continued*)

Algorithms	Benefits	Weakness	Implementation
Arithmetic Algorithm	(a) Easy Implementation	(a) Convergence rate is slow	Simulated world
GWO	(a) Convergence rate is fast (b) Tuning of parameter is easy (c) When integrated with other algorithm performs better	(a) Bit tricky in complex environment	Simulated world
Moth flame	(a) Perform better in complex environment	(a) Suffers from premature convergence	Simulated world and Real time
WOA	(a) Convergence rate is fast	(a) Implementation in dynamic environment is hard	Simulated world and Real time
Aquila Optimizer	(a) Effective in producing good solutions in complex environment	(a) Tuning of variables is hard	Simulated world and Real time

4 Conclusions

For automatic guided vehicles, navigation and trajectory generation are pre- dominantly important. Over the past two decades abundant research has been done in this field. Either its, kinematic, dynamics of actual vehicle or formulation of number of algorithms for path planning, obstacle avoidance etc. With the ever growing interest, this field is unavoidable in daily activities as they are intelligent systems; who does not need any human assistance. The journey started off from numerical approach has now been shifted towards the stochastic approach. Where finding a solution is guaranteed. The article comprehensively summarizes the latest work done in the field of terrestrial, aerial and undersea for autonomous vehicles. Certain benefits of latest approaches and their drawbacks have been mentioned in the Table 1. Different stochastic algorithms, & deterministic methods are also discussed.

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