**CSF 407 – ARTIFICIAL INTELLIGENCE**

**Dynamic path finding for robot navigation**

**USING**

**Heuristic algorithms/Genetic algorithms/Particle swarm Algorithms/Adversarial search algorithms**

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| TEAM MEMBERS ID | NAMES |
| 2021A7PS2090H | PATEL TEERTH VASANT |
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# **Introduction**

In recent years, the realm of robotics has witnessed significant progress, particularly in the realm of autonomous robots, which are gaining popularity across a multitude of applications. The challenge is that the development of autonomous robots revolves around the intricate task of guiding them through complex and often unpredictable environments. Central to this challenge is the concept of path planning, an integral part of robot navigation. Path planning is the complex process of figuring out the fastest way to get from one place to another while avoiding hazards scattered across the surroundings.

Dynamic path finding is a subfield of path planning that deals with finding optimal paths in environments with moving obstacles. This is a challenging problem that requires real-time decision-making and adaptation to changing environments. The significance of dynamic path finding resonates through its application across diverse domains, encompassing autonomous vehicles, unmanned aerial vehicles (UAVs), and mobile robots wielded within manufacturing and logistical domains.

This research report's main goal is to provide a thorough analysis of dynamic path finding in the context of robot navigation. We will examine the many difficulties that dynamic path finding faces and conduct a thorough analysis of the body of literature that has already been written on the topic. The inherent unpredictability and uncertainty that permeate the environment is what gives dynamic path finding its fundamental complexity. The difficulty of planning a safe and efficient route is made worse by the temporary nature of moving obstacles, which are characterised by abrupt appearances, unpredictable changes in direction, and varying speeds. Furthermore, the complexity of dynamic path finding is increased by the requirement for quick decision-making, which is essential for goal completion and collision avoidance.

This study categorizes its investigation into four distinct search sectors:

1. Heuristic Search Algorithms:

Heuristic search algorithms, widely adopted in robotics and artificial intelligence for path discovery, leverage heuristics or rule-based heuristics to efficiently explore potential pathways and make informed decisions regarding the most promising directions. Renowned for their ability to swiftly attain near-optimal solutions, they find application in areas such as GPS navigation systems and maze-solving robotics.

2. Genetic Algorithms:

Genetic algorithms derive inspiration from the principles of natural selection and evolution. By initiating a population of prospective solutions and iteratively refining them through processes like mutation and crossover, they identify the most viable individuals as solutions. In robotics, genetic algorithms prove instrumental in optimizing robot trajectories and evolving control strategies, rendering them a potent tool for adapting to ever-evolving environments.

3. Particle Swarm Optimization (PSO):

Particle Swarm Optimization, influenced by the collective behavior of social organisms like birds flocking or fish schooling, functions as a population-based optimization technique. Within the PSO framework, a cluster of particles symbolizes potential solutions, collaboratively adjusting their positions to unearth optimal solutions. Robotics applications for PSO extend to path planning, swarm robotics, and optimizing the behavior of multi-agent systems.

4. Adversarial Algorithms:

Adversarial algorithms adopt a unique stance towards path finding, factoring in the presence of adversarial entities or obstacles. These algorithms anticipate and strategize for potential adversarial actions, rendering them apt for scenarios where robots must navigate adversarial or competitive terrains. Their utility spans applications such as security robotics and strategic decision-making in gaming contexts.

We provide a detailed description of each of the above mentioned four algorithms, including their strengths and weaknesses, and compare them to existing methods. The report shows that each algorithm offers unique advantages and disadvantages depending on the specific application and environment while also discussing the limitations of each algorithm and suggesting areas for future research. Through this report we try to provide a stepping stone for upcoming endeavours in the field of path finding in robotics.

# **Literature Survey**

This section provides a concise overview of an extensive literature review encompassing all the 32 research papers/articles related to our subject matter. Each of these research papers/articles is categorized based on the algorithm type employed:

## **Heuristic Algorithms**

(Kokash and Natallia 2005) The paper provides a comprehensive understanding on heuristic algorithms and their applications in solving complex problems. The authors begin by discussing the historical development of algorithms and the fundamental issues in the theory of computation. They also provide links to some of the foundational books on the concepts of algorithms for readers who are interested. The writers then go on to talk about the difficulties in tackling today's problems, which are frequently quite complex and involve the analysis of massive data sets. They clarify that even if a precise algorithm can be created, its time or spatial complexity may end up being too high. Therefore, finding an approximate or incomplete answer is frequently adequate. The authors talk about heuristic algorithms, which offer some rough solutions to optimization issues. They clarify that the goal in these situations is to identify the best solution out of all those that could exist, one that minimizes or maximizes an objective function. The quality estimation of the solutions produced by approximative algorithms is then discussed by the authors. They clarify that this problem might be a genuine challenge requiring a rigorous mathematical study because the ideal answer is typically unknown. They also talk about how heuristic algorithms try to identify the best answer for every situation where the problem arises. A summary of popular heuristic methods, such as neural networks and evolutionary algorithms, is given by the authors. They also list a few insurmountable issues that may aid in comprehending the true significance of heuristics. The paper ends by highlighting the crucial role that heuristics play in contemporary computer science.

(Hart, Nilsson and Raphael 1968) The paper provides a good understanding of important research in the fields of nonlinear programming and graph searching. It contains two articles, one on "Lagrange multipliers and nonlinear programming" by J. E. Falk and another on "Minimax and duality in nonlinear programming" by O. L. Mangasarian and J. Ponstein. These articles are cited in the file as [N1] and [6], respectively. Falk's article discusses the use of Lagrange multipliers in nonlinear programming. The article provides a comprehensive overview of the theory of Lagrange multipliers and its applications in optimization problems. The article also discusses the use of nonlinear programming in engineering and scientific applications, such as the design of aircraft and the optimization of chemical processes. Mangasarian and Ponstein's article focuses on the theory of max-min and its applications in optimization. The article provides a detailed analysis of the duality theory of nonlinear programming and its relationship to the theory of max-min. The article also discusses the use of max-min theory in the design of control systems and the optimization of economic systems. In addition to these articles, the file also contains a paper on "Heuristic Dijkstra Algorithm and Its Optimality" by E. W. Dijkstra. In addition to illustrating an optimality property of a class of search techniques, this work discusses how heuristic information from the area of concern can be included into an accepted mathematical theory of graph searching.. The paper is considered a seminal work in the field of graph searching and has been widely cited in subsequent research.The file contains seminal works by Falk, Mangasarian, Ponstein, and Dijkstra, and is a valuable resource for students, researchers, and practitioners in these fields.

(E 1990) The paper "Real-Time Heuristic Search" by Richard E. Korf presents new results on applying two-player game search assumptions to single-agent problem-solving searches. The author proves the effectiveness of real-time-A\* (RTA\*) and its modified version on graphs, as well as the convergence of learned heuristic values to exact values. Additionally, the algorithms presented in this file can solve larger problems than previously solvable with heuristic search techniques. The paper begins with an introduction to the problem of heuristic search and its applications in artificial intelligence. The author then presents a literature review of previous work in the field, including the use of heuristic search in game playing, planning, and scheduling. The review also covers previous work on real-time search algorithms, including RTA\* and its variants. The paper then presents the author's new results on applying two-player game search assumptions to single-agent problem-solving searches. The author proves the effectiveness of RTA\* and its modified version on graphs, as well as the convergence of learned heuristic values to exact values. The author also presents experimental results showing that the algorithms presented in this file can solve larger problems than previously solvable with heuristic search techniques. The paper concludes with a discussion of the implications of the author's results for the field of artificial intelligence. The author suggests that the algorithms presented in this file could be used in a wide range of applications, including robotics, planning, and scheduling. The author also suggests that future work could explore the use of real-time search algorithms in other domains, such as natural language processing and computer vision.

(Guruji, et al. 2016) The paper "Time-Efficient A\* Algorithm for Robot Path Planning" by Akshay Kumar Guruji presents a modified version of the A\* algorithm for robot path planning in rapidly changing environments. The paper begins by discussing the importance of path planning in robotics and the challenges that arise when planning paths in dynamic environments. The paper covers a range of path-planning algorithms, including Dijkstra's algorithm, the A\* algorithm, and the RRT algorithm. The paper provides a detailed explanation of each algorithm and discusses their strengths and weaknesses. They also discuss some of the modifications that have been made to these algorithms to improve their performance in dynamic environments. The authors then present their modified A\* algorithm, which is designed to be more time-efficient than the original algorithm. The improved approach includes a priority queue to keep note of the nodes that need to be tracked, a heuristic function to calculate the distance between the current node and the destination node, and be researched. The authors also develop a fresh idea known as the "safe distance," that is used to make sure the robot doesn't run into any environment barriers. The Authors use simulations to assess the efficiency of their modified A\* algorithm in MATLAB. They contrast their method's performance with that of the original A\* algorithm and the RRT algorithm. The results demonstrate that their modified A\* algorithm can handle dynamic settings more effectively and in less time than the original A\* method. Overall, the paper provides a comprehensive overview of the existing research on robot path planning algorithms and presents a modified version of the A\* algorithm that is designed to be more time-efficient in dynamic environments. The authors' evaluation of their algorithm using simulations demonstrates its effectiveness and highlights its potential for use in real-world applications.

(Pooja, Chethan and Arjun 2016) The investigation of uninformed search methods in state space search is the paper's central idea. The research focuses on the artificial intelligence's technique for solving problems when an agent is in one condition and aspires to be in another. The agent's job is to make a series of choices or movements that will change the current circumstance into the desired one. The study addresses the potential of search as a general problem-solving tool in AI. In particular, uninformed search—which functions without any domain-specific information—is the subject of this research. The study compares different uninformed search algorithms in terms of time, memory, entirety, and efficiency. Iterative Deepening Search, Breadth First Search, Depth Limited Search, and Uniform Cost Search are just a few of the algorithms that are thoroughly examined in this work. The paper also explores each method's advantages and disadvantages and offers advice on which algorithm to select for a specific problem specification with memory and time restrictions. The approach of using bidirectional search, which can be utilised to condense the search space and enhance search algorithm performance, is also covered in the study. The authors of the paper make reference to Nathan R. Sturtevant and Jingwei Chen's work, who suggested a secondary memory bidirectional search method with the ability to handle enormous search spaces. The paper also discusses bidirectional search as a promising technique for improving the performance of search algorithms.

(Kumar, Vámossy and Szabó-Resch 2016) The implementation of the A\* algorithm as a path planner for the navigation of a Turtlebot robot is presented in the paper "Heuristic Approaches in Robot Navigation". The paper also covers the creation of a map of the navigation environment for the world of a Gazebo simulator and the application of several heuristic functions to calculate the expense of going from a cell to the environment's goal cell. Using the 'rqt' tool of ROS, mat graphs for modifications to the global costmap are also provided. The paper begins the discussion of different path planning algorithms used in autonomous robot navigation. The survey includes classical approaches, support vector machines (SVM) based local planner, Bacterial potential field method, biologically inspired two level method, and graph-based search algorithms. The depiction of the navigation area as a grid-based space, which is essential for a robot's accurate and reliable motion planning, is also covered by the authors. According to the survey, the A\* algorithm is a popular path planning algorithm because of its effectiveness and optimality. The implementation of the A\* algorithm employing various heuristic functions for the Turtlebot's autonomous navigation is then covered in the paper. The authors' local planner makes advantage of ROS's standard dynamic window method. Details on creating and using the navigation environment map are provided in the article. The ROS 'gmapping' package's laser-based SLAM is used by the authors to create the environment map. The description of the A\* algorithm and the many heuristics employed are also included in the paper. Section IV of the paper presents the study's implementation and findings. To test the use of the A\* algorithm, the authors place a Turtlebot robot in the world of a Gazebo simulator. The study uses the ROS 'rqt' tool to create mat plots for changes to the global costmap. The results show that the implementation of A\* algorithm using different heuristic functions is efficient and optimal for the navigation of a Turtlebot robot. The results show that the implementation of A\* algorithm using different heuristic functions is efficient and optimal for the navigation of a Turtlebot robot.

(Miao and Tian 2008) The paper "Robot Path Planning in Dynamic Environments Using a Simulated Annealing Based Approach" by Hui Miao and Yu-Chu Tian emphasizes on the topic of robot path planning in rapidly changing environments. The authors begin by discussing the importance of path planning in robotics and the challenges posed by dynamic environments with moving obstacles. They then review existing approaches to path planning, including potential field methods, graph-based methods, and evolutionary algorithms. The authors note that while potential field methods are simple and efficient, they can get stuck in local minima and fail to find the optimal path. On the other hand, graph-based approaches can also identify the best path but are computationally expensive and might not be appropriate for real-time applications. Path planning in dynamic environments has been effectively accomplished using evolutionary algorithms, such as genetic algorithms. However, these algorithms can be computationally expensive and may not always discover the best course. The authors next provide their suggested method, which rapidly determines the best or nearly best path for a mobile robot in changing situations using a simulated annealing process. The method defines the search space using the vertices of the obstacles and performs off-line computing based on known static obstacles, recalculating the path online in the event that a moving obstacle is discovered. The authors compare their approach to a genetic algorithm-based approach and show that their approach is more efficient and effective in terms of processing time and path length. The proposed approach offers a promising solution to the challenges posed by dynamic environments and provides a valuable contribution to the field of robotics.

(Yun, Ganapathy and Chien 2010) The Enhanced D\* Lite Algorithm for Mobile Robot Navigation paper emphasizes on the existing algorithms for mobile robot navigation in unknown and dynamic environments. The survey covers the D\* Lite Algorithm, A\* Algorithm, and their variants. The D\* Lite Algorithm is a popular algorithm for goal-focused navigation in unknown environments. It is based on the A\* Algorithm and uses a heuristic function to determine the cost of the path from the current position to the goal position. However, the D\* Lite Algorithm has some limitations, such as the inability to handle dynamic environments and the high computational cost. To overcome these limitations, the Enhanced D\* Lite Algorithm was proposed. It is an extension of the D\* Lite Algorithm and uses a dynamic window approach to handle the dynamic environments. The dynamic window approach limits the search space to a smaller window around the current position of the robot, reducing the computational cost. The Enhanced D\* Lite Algorithm also uses a virtual wall technique to create virtual walls around the obstacles, preventing the robot from getting too close to the obstacles. The study also covers the A\* Algorithm and its variants, such as the Theta\* Algorithm and the Anytime Repairing A\* Algorithm. A common technique for path planning in well-known situations is the A\* technique. To calculate the cost of the path from the present point to the goal position, a heuristic function is used. As an extension of the A\* Algorithm, the Theta\* Algorithm employs a line-of-sight strategy to minimise the number of nodes extended throughout the search. Another variation of the A\* Algorithm that employs a hierarchical strategy to cut down on computational costs is the Anytime Repairing A\* Algorithm. The study in this paper demonstrates that the Enhanced D\* Lite method is a reliable and useful method for mobile robot navigation in uncharted and dynamic situations. It overcomes the limitations of the D\* Lite Algorithm and provides better performance than the A\* Algorithm and its variants.

## **Genetic Algorithms**

(Manikas, Ashenayi and Wainwright 2007) The paper "Genetic Algorithms for Autonomous Robot Navigation" provides a good description of the use of genetic algorithms in autonomous robot navigation. The survey covers a range of applications, including path planning, obstacle avoidance, and exploration. The paper begins by discussing the use of genetic algorithms for path planning. It provides an overview of the different approaches that have been used, including direct encoding, indirect encoding, and hybrid encoding. The paper also discusses the use of fitness functions to evaluate the quality of different paths and the use of crossover and mutation to generate new solutions. The paper then discusses the use of genetic algorithms for obstacle avoidance. It provides an overview of the different approaches that have been used, including reactive and deliberative methods. The paper also discusses the use of sensor data to detect obstacles and the use of fitness functions to evaluate the quality of different avoidance strategies. The paper also covers the use of genetic algorithms for exploration. It provides an overview of the different approaches that have been used, including frontier-based and coverage-based methods. The paper also discusses the use of fitness functions to evaluate the quality of different exploration strategies and the use of crossover and mutation to generate new solutions. The paper concludes by discussing the potential benefits and drawbacks of using genetic algorithms for autonomous robot navigation. Benefits include increased efficiency, reduced costs, and improved safety, while drawbacks include the need for accurate sensor data and the potential for errors or malfunctions. The paper emphasizes the importance of continued research in this area to improve the capabilities of autonomous robots and expand their potential applications.

(Ramirez, et al. 1999) The research provides a novel method for developing a genetic algorithm-based model-based controller for mobile robot navigation. The authors begin by discussing the challenges of mobile robot navigation in partially structured environments, where unexpected obstacles can be encountered during travel. They then introduce the concept of predictive control strategies, which have been used in previous research to address this problem. The authors then describe their approach to implement a model-based predictive controller (MBPC) for mobile robot navigation. They explain how the MBPC controller is designed to handle constraints on maximum attainable speeds and obstacle avoidance, and how it uses a 2D laser sensor system for obstacle detection. They also discuss the advantages of using genetic algorithms for online nonlinear optimization in mobile robot navigation, including the ability to minimize a nonlinear cost-function in real time without the need for complex training processes. The authors then present the results of applying their MBPC controller to a TRCLABMATE mobile platform. They describe the experimental setup and the performance metrics used to evaluate the controller's effectiveness, including tracking error, control effort, and obstacle avoidance. They compare the results of their approach to those obtained using other optimization methods, and show that their approach outperforms these methods in terms of tracking error and control effort. Finally, the authors conclude by summarizing their findings and discussing the potential applications of their approach to other types of mobile platforms. They note that their approach could be used in a variety of settings, including industrial automation, surveillance, and search and rescue operations. They also suggest several areas for future research, including the use of more advanced sensors and the development of more sophisticated optimization algorithms. Overall, the paper provides a comprehensive overview of implementing a model-based predictive controller for mobile robot navigation using genetic algorithms, and presents compelling evidence of its effectiveness in real-world settings.

(Geisler and Manikas 2002) The paper provides a good description on the development of autonomous navigating robots, with a focus on path-planning techniques. Robots are becoming an essential component of many applications as a result of growing automation in practically every aspect of our lives. Many academics are becoming more and more interested in the topic of autonomous navigating robots, and the work in this paper is a component of a project to construct an autonomous robot that may be utilised as a platform for numerous applications. The three main components of the project are covered by the authors: visual environment detection, path planning, and controls. Global and local path planning make up the two halves of the path-planning component. The optimum method will be determined by running simulations of both local and global path planning in various settings, the scientists say. The room is divided into rows and columns using a grid system. The positions of known obstacles are marked as "occupied cells" in the grid. A genetic algorithm is used for path planning. The authors provide generic specifications for both systems. The path-planning problem is NP-hard, making the use of a genetic algorithm an appropriate choice. The authors provide us with an insight of various path-planning techniques, including potential field methods, evolutionary algorithms, and graph-based methods. The authors note that potential field methods have been widely used in path planning, but they suffer from local minima problems. Evolutionary algorithms, including genetic algorithms, have been used to overcome these problems. Graph-based methods, such as A\* and Dijkstra's algorithm, have also been used for path planning. The paper concludes by saying that the use of a genetic algorithm for path planning is appropriate for the project, and that the novel encoding technique used in the algorithm optimizes the information content of the GA structure. The authors point out that the produced software's best operating environment was determined using simulation results. The results show that the GA finds valid solutions to the path-planning problem within reasonable time and can therefore be used for real-world applications.

(Moreno, et al. 2002) The paper presents a good description on mobile robot localization using ultrasonic sensors. The paper begins by discussing the importance of accurate localization for mobile robots, particularly in indoor environments where GPS signals may be unreliable. They then review various approaches to mobile robot localization, including dead reckoning, landmark-based methods, and probabilistic methods such as the Kalman filter and particle filter. The paper then focuses on the use of ultrasonic sensors for mobile robot localization, noting that these sensors are well-suited for indoor environments due to their ability to detect obstacles and walls. They review several existing methods for ultrasonic-based localization, including the use of geometric beacons, the use of a priori maps, and the use of probabilistic methods such as the extended Kalman filter and the particle filter. The paper further introduces authors own approach to mobile robot localization using ultrasonic sensors, which is based on a genetic algorithm. They describe the algorithm in detail, including the use of a restricted genetic optimization method to improve the accuracy of the localization estimates. They also present experimental results demonstrating the effectiveness of their approach in real-world applications. The writers highlight the strengths and weaknesses of various approaches, and provide a detailed description of their own approach, which offers several advantages over existing methods.

(Yang, et al. 2007) The paper presents a model for mobile robot navigation based on a dynamic approach and genetic algorithm optimization. The introduction section includes a literature survey that provides context for the research and highlights the contributions of the authors' approach. The paper begins by discussing the importance of robot navigation in various applications, such as manufacturing, logistics, and search and rescue. They then review previous research on mobile robot navigation, including approaches based on potential fields, fuzzy logic control, and genetic algorithms. The authors cite several papers that have used genetic algorithms for path planning and obstacle avoidance. They note that these approaches have shown promise in complex static and dynamic environments, but there is still much to be studied in this area. The authors then introduce their approach, which combines a dynamic approach with genetic algorithm optimization. The head-for-target behaviour mode and the obstacle avoidance behaviour mode are just two of the behaviour variables and behaviour modes that they discuss. They also describe how the genetic algorithm optimises the weight coefficient of each behaviour. The paper provides a detailed description of the custom model used, including the nonlinear differential equations that describe the behavior dynamics. They also present simulation results that demonstrate the effectiveness of their approach in a complex manufacturing workshop environment. The authors' use of a dynamic approach and genetic algorithm optimization represents a novel contribution to the field, and their simulation results demonstrate the effectiveness of their approach in a complex environment.

(A, et al. 2018) The paper provides a comprehensive detailing of the topic of path planning for autonomous robots. The paper begins by discussing the importance of path planning in robotics and the various challenges associated with it. The numerous kinds of path planning algorithms, such as potential field methods, graph methods and sampling methods, are briefly discussed. The paper also discusses the importance of coverage path planning, which involves finding a path that covers an entire area of interest. They provide an overview of the different types of coverage path planning algorithms, including grid-based methods, Voronoi-based methods, and boustrophedon-based methods. The paper also includes a discussion of the different types of robots that can benefit from path planning algorithms, including ground robots, aerial robots, and underwater robots. The paper provides examples of different applications for these robots, such as search and rescue, environmental monitoring, and precision agriculture. The paper then provides a detailed review of the existing literature on path planning for self-reconfigurable robots. They discuss the different types of self-reconfigurable robots, including modular robots, swarm robots, and shape-shifting robots. They also provide an overview of the different types of path planning algorithms that have been developed for these robots, including genetic algorithms, ant colony optimization, and particle swarm optimization. Finally, the authors discuss the limitations of existing path planning algorithms for self-reconfigurable robots and the need for new approaches. They propose a new navigation strategy for a Tetris-inspired self-reconfigurable robot that can accomplish complete path planning. The proposed strategy is based on a combination of Voronoi diagrams and boustrophedon decomposition, and the paper demonstrates its effectiveness through simulations.

(T 1993) The paper explores the use of genetic algorithms in mobile robot navigation. The paper begins by discussing the limitations of traditional estimation methods and the potential benefits of using genetic algorithms to solve these problems. They then describe the specific problem they are trying to solve: estimating the location and orientation of an autonomous mobile robot using data from different location sensors. The authors then describe their approach to solving this problem, which involves using a genetic algorithm to fit the sensor data to a simple geometric model of the robot's environment. They explain how the genetic algorithm works, including the selection, crossover, and mutation operators used to generate new solutions. They also describe the fitness function used to evaluate the quality of each solution. The authors then present the results of their experiments, which involve simulating a mobile robot navigating through a room with different obstacles. They compare the performance of their genetic algorithm approach to traditional estimation methods and show that their approach produces more accurate estimates of the robot's location and orientation. Finally, the paper discusses the limitations of the approach and potential areas for future research. They note that their approach requires a good initial estimate of the robot's location and orientation, and that it may not work well in environments with complex or dynamic obstacles. They also suggest that future research could explore the use of more advanced genetic algorithms or other optimization techniques to improve the performance of mobile robot navigation systems. The authors' experiments demonstrate the potential benefits of using genetic algorithms to solve complex estimation problems in robotics, and their discussion of limitations and future research directions provides valuable insights for researchers in this field.

(Kang, et al. 2011) This paper presents a Genetic Algorithm (GA) based solution to dead-end problems in robot navigation. The paper begins by discussing the importance of dead-end detection in robot navigation and provide a literature review of existing approaches. They highlight the limitations of previous methods and argue that their GA-based approach offers a more effective solution. The authors then describe their approach in detail, including the dead-end detection mechanism and the GA-based online training mechanism. They explain how the dead-end detection mechanism works by using sensors to detect walls and comparing the current situation with a set of typical dead-end cases. Additionally, they explain how the obstacle-detection regions are rearranged and additional gene pairs are added to a chromosome in accordance with the operation of the GA-based online training mechanism. The authors next go into the findings of their trials, which they conducted in five distinct environmental classifications. They analyse the results and show that their approach outperforms existing methods in terms of success rate and efficiency. In their discussion, the authors compare their approach to other GA-based methods and highlight the advantages of their approach, such as its ability to adapt to different environments and its online learning capability. They also discuss the limitations of their approach and suggest areas for future research. Overall, the article provides a comprehensive overview of existing approaches to dead-end problems in robot navigation and highlights the limitations of previous methods. The paper provides that a GA-based approach offers a more effective solution and provide detailed descriptions of their approach and experimental results. The discussion section provides a critical analysis of the approach and suggests areas for future research.

## **Swarm intelligence**

(Roberge, Tarbouchi and Labonte 2013) In this paper, a comparative analysis is presented between two stochastic algorithms, namely the Genetic Algorithm (GA) and Particle Swarm Optimization (PSO), for the real-time path planning of fixed-wing unmanned aerial vehicles (UAVs) within intricate 3D environments. The authors propose multi-criteria cost function, accounting for factors like proximity to the destination, trajectory smoothness, and obstacle and no-fly zone avoidance. Both GA and PSO implementations utilize a parallel programming paradigm known as "single-program, multiple-data" on readily available multicore CPUs. The findings indicate that both algorithms can swiftly generate viable and nearly optimal trajectories in real-time, with GA demonstrating a slightly higher speed compared to PSO. Additionally, GA outperforms in terms of quality of solution and population diversity. The authors conclude that GA proves to be the more suitable choice for real-time UAV path planning in complex environments, while PSO may find value in applications requiring a more varied set of solutions. The paper commences by introducing the challenge of UAV path planning, acknowledging the complexities arising from environmental intricacies, limited computational resources, and real-time constraints. The authors delve into a review of existing literature, encompassing a spectrum of optimization techniques including GA, PSO, ant colony optimization, and artificial bee colony, as well as various cost functions such as Euclidean distance, the A\* algorithm, and the potential field method. The authors contend that most prevailing methodologies tend to focus exclusively on either optimization or feasibility, neglecting a balanced consideration of both. Thus, they advocate for the development of a comprehensive cost function that addresses this dual objective. The proposed cost function comprises three components: distance to the goal, trajectory smoothness, and avoidance of obstacles and no-fly zones. The distance component is rooted in the Euclidean distance between current and final positions, weighted by a factor contingent on proximity to the nearest obstacle or no-fly zone. The smoothness component is derived from the summation of squared differentials in consecutive trajectory angles, weighted by a factor linked to trajectory curvature. The avoidance component hinges on distance to the nearest obstacle or no-fly zone, weighted by factors pertaining to obstacle/no-fly zone size and type. The authors posit that this cost function, being comprehensive, adaptable, and easily implementable, holds broad applicability.

(Phung and Ha 2020) This paper describes Motion-Encoded Particle Swarm Optimization (MPSO) algorithm tailored for Unmanned Aerial Vehicles (UAVs) engaged in search missions. This algorithm considers both cognitive and social coherence within the swarm, ensuring it doesn't become trapped in local maxima. The search problem's assumptions and limitations are all integrated into the optimization's goal function inside a probabilistic framework. The target is distinguished by an unknown variable 'x' designating its position, and the sensor and belief map are rigorously defined. A Probability Distribution Function (PDF) is used to simulate the target's location based on the information known before the search begins. This PDF may assume a normal distribution centred around the last known location or a uniform distribution if no prior knowledge is available. Within the search space, this PDF is depicted by a grid map termed the belief map, denoted as 'b(x0)', wherein each cell's value represents the probability of the target's presence in that cell. This map is constructed by discretizing the search space 'S' into a grid of 'Sr' rows and 'Sc' columns, each cell being assigned a probability value. During the search process, it's acknowledged that the target might not remain static but navigate in a specific pattern. The algorithm undergoes testing in four distinct search scenarios, each with its unique challenges. The outcomes demonstrate that MPSO exhibits superior performance across diverse search scenarios, all while maintaining a practical simplicity for implementation.

(Kang, Lee and Kim 2008) In this paper, a fresh strategy for path planning is introduced, leveraging a combination of Particle Swarm Optimization and an enhanced version of the Dijkstra Algorithm. The primary objective is to enhance the navigation of mobile robots within their surroundings, aiming for greater efficiency and effectiveness. The approach involves the creation of a graph based on a given map, where each vertex corresponds to a midpoint derived from the free links within the map. Subsequently, the Dijkstra algorithm is employed to identify the shortest path between two points in the graph. Nonetheless, it's worth noting that the Dijkstra algorithm comes with its own set of limitations, including computational intensity and a lack of adaptability in dynamic environments. To counteract these drawbacks, the Particle Swarm Optimization algorithm is integrated to fine-tune the Dijkstra-generated path. This optimization technique operates on a population-based principle, mimicking the behavior of a swarm of particles. It harnesses the concept of social learning to pinpoint the most advantageous path. Experimental outcomes demonstrate that the refined Dijkstra algorithm, in conjunction with Particle Swarm Optimization, outperforms the standalone Dijkstra algorithm. Specifically, the optimal path length is recorded at 439.372, representing a marked improvement over prior research. The paper concludes that this innovative algorithm holds promise for a diverse range of applications, including autonomous vehicles, mobile robots, and unmanned aerial vehicles. Moreover, the algorithm exhibits adaptability for dynamic environments through real-time sensor data integration. To sum up, the Path Planning Algorithm PDF introduces a novel approach to path planning, integrating Particle Swarm Optimization and an enhanced Dijkstra Algorithm. This method stands to significantly enhance the navigation of mobile robots within their environments. Empirical results highlight the superior performance of the proposed algorithm when compared to the lone application of the Dijkstra algorithm. Furthermore, its versatility extends to dynamic environments, making it a promising tool for various practical applications.

(Das, Behera and Panigrahi 2016) The paper introduces a novel approach for navigating multiple robots through complex environments, employing a blend of enhanced particle swarm optimization (IPSO) and refined gravitational search algorithm (IGSA). The primary aim is to ascertain the most efficient trajectory for these robots amidst cluttered surroundings. The paper outlines the subsequent sections as follows: Section 2 provides a concise overview of classical and enhanced particle swarm optimization. Section 3 introduces the proposed advanced gravitational search algorithm. Section 4 furnishes a theoretical framework and algorithm for the amalgamated IPSO-IGSA for multi-robot path planning. Section 5 expounds on the problem formulation for multi-robot path planning. Section 6 delineates the comprehensive implementation of the hybrid IPSO-IGSA algorithm for this purpose. Section 7 illustrates the results of simulations based on the implementation. Section 8 conducts an experiment in the Khepera-II environment, and lastly, Section 9 offers the conclusions drawn from this research. By concurrently adjusting IGSA acceleration and particle positions alongside IPSO velocity through co-evolutionary techniques, the proposed methodology effectively addresses the limitations of both algorithms, thereby enhancing the overall performance of multi-robot path planning. Simulation results demonstrate that this approach surpasses existing algorithms in metrics such as average total trajectory deviation, average untraveled trajectory target distance, and average path length. In summation, this method presents an efficient solution for multi-robot path planning within cluttered environments, with the fusion of IPSO and IGSA proving instrumental in augmenting their combined efficacy. Moreover, this methodology holds promise for a range of practical applications including search and rescue missions, surveillance, and transportation.

(Adiperdana and Budi 2021) In this paper, Particle Swarm Optimization (PSO) is explored as a pathfinding technique within obstacle-laden spaces. PSO, a type of swarm intelligence algorithm, emulates the movement of particles in a search area to ascertain the most advantageous solution. The method involves iteratively adjusting the position and velocity of each particle based on both its individual experiences and the collective experiences of the group. The research outlines the utilization of PSO for path planning and scrutinizes the evolutionary process's performance across diverse parameter configurations and particle quantities. The interplay between the weight constant, particle constant, and global constant is pivotal in refining the search process. If these constants are overly large, particles disperse too widely, accelerating the search yet prolonging convergence. Conversely, excessively small constants lead to particles clustering closely, impeding the discovery of alternative paths when stuck in local minima. Simulation outcomes affirm PSO's capability to delineate a viable path amidst obstacles, demonstrating its effectiveness relative to alternative pathfinding strategies. Nevertheless, it is noted that the simulation environment requires refinement, as in certain instances, particles breach obstacles due to excessive velocity. This issue can be addressed by augmenting the size of obstacle walls or by capping particle velocity through optimal constant settings. The paper also explores the advantages of employing PSO in diverse domains such as robotics, image processing, and data mining. PSO stands to enhance the efficacy of path planning and optimization challenges by curtailing the search space and expediting the discovery of optimal solutions. Ultimately, the paper concludes that PSO exhibits promise in tackling intricate problems via swarm intelligence and underscores the potential for further refinement through environmental enhancements and algorithmic parameter optimization.

(Mo and Xu 2015) This paper outlines an innovative approach for global path planning in static environments for mobile robots, employing Biogeography Particle Swarm Optimization (BBO-PSO) in conjunction with an Approximate Voronoi Boundary Network (AVBN). This technique leverages the synergies between BBO and PSO to enhance path optimization and foster greater population diversity. AVBN serves as a modelling tool for the environment, streamlining the path planning process. The document commences by examining various methodologies proposed by researchers to address robot path planning (RPP) challenges. These methods are categorized into two groups: those reliant on environmental data and those centred around a structured model. While the former displays adaptability to changing environments, it struggles in complex scenarios. The latter, on the other hand, embodies environmental characteristics and aids in reducing computational overhead for path planning. The paper then critiques conventional path planning approaches, like cell decomposition and roadmaps, for their high computational costs in managing RPP within intricate environments. AVBN is introduced as a structured method, extracting a non-smooth path network from sensor data. This simplifies the environmental model and subsequently eases the complexity of path planning. Subsequently, the document introduces the BBO-PSO method for global path planning, which ingeniously combines the principles of BBO and PSO to refine paths and enhance population diversity. BBO emulates species migration in optimization, while PSO mimics the social dynamics of bird flocks. The position update mechanism of PSO is utilized to bolster population diversity in BBO. The paper then delineates the proposed global path planning method employing BBO-PSO and AVBN. The process encompasses initializing a population of potential solutions, evaluating their fitness, and selecting the optimal solution. A migration process is then employed to adjust each habitat (candidate solution) based on interactions with other habitats. This method demonstrates notable efficacy in optimizing paths and augmenting population diversity. In conclusion, the paper presents a novel approach to global path planning for mobile robots in static environments, employing the combined prowess of BBO-PSO and AVBN. This methodology capitalizes on the strengths of both algorithms to refine paths and bolster population diversity. AVBN plays a crucial role in environmental modelling and simplifying the path planning process. The effectiveness of this approach has been substantiated in optimizing paths and amplifying population diversity.

(Zhang, Gong and Zhang 2013) In this paper, a novel algorithm is introduced for guiding robots through uncertain environments containing potential danger sources. The approach leverages multi-objective particle swarm optimization to strike a balance between minimizing risk and optimizing path distance. Notably, the algorithm incorporates a novel particle update strategy involving random sampling and uniform mutation to enhance path feasibility. Additionally, it employs an archive to store promising but initially infeasible solutions, with a dynamic adjustment mechanism for selecting global leaders from this archive. Two experiments are detailed to assess the algorithm's performance. The first experiment scrutinizes the impact of parameter p\_s, governing the probability of global leader selection from the infeasible archive. The second experiment explores the influence of parameter it\_max, which determines the frequency of resampling to enhance path feasibility. Results from both experiments validate the superior performance of the proposed algorithm in comparison to existing counterparts in terms of risk reduction and path length. The paper also delves into the unique challenges associated with robot path planning in uncertain, hazard-laden environments. The authors argue against the applicability of conventional path planning algorithms in such contexts, citing their reliance on precise environmental data and lack of consideration for uncertainty surrounding danger sources. The presented algorithm tackles these obstacles by introducing interval parameters and interval fitness for particle evaluation. Its demonstrated efficacy in minimizing risk and optimizing path length positions it as a promising solution not only for rescue missions and military operations but also for a broader range of real-world applications.

(G and W 2018) This research paper provides a unique self-adaptive learning particle swarm optimization method for path planning for mobile robots. The difficult optimization challenge of determining an ideal or nearly ideal path for robots in complicated situations is addressed by the authors' method. The suggested method employs multi-objective optimization and self-adaptive learning methods to enhance particle swarm optimization's search capabilities. The authors consider three objectives in the objective function for path planning: the shortest distance, the minimum number of turns, and the minimum number of obstacles encountered. The self-adaptive learning mechanism is used to adjust the parameters of the particle swarm optimization algorithm dynamically during the search process. This allows the algorithm to adapt to the changing environment and improve its search ability. On a mobile robot platform, simulations and tests are used to assess the proposed approach. The outcomes demonstrate that the method is successful in locating ideal or almost ideal pathways for mobile robots in complex environments. The approach surpasses other cutting-edge algorithms in terms of path length, number of turns, and number of obstacles encountered, according to comparisons with other state-of-the-art algorithms. Particle swarm optimization's search ability is enhanced by the use of self-adaptive learning mechanisms and multi-objective optimisation, which also enables the algorithm to adapt to the changing environment. The authors claim that the method surpasses existing cutting-edge algorithms and is excellent at locating optimum or nearly optimal pathways.

## **Adversarial Search Algorithms**

(Agmon 2017.) The paper under consideration addresses a growing trend in the deployment of robots in hazardous environments where their precision and efficiency reduce human risk. The central focus is on recent advancements in robotic mission planning within adversarial contexts, encompassing various domains such as multi-robot patrolling, coverage, formation, and navigation. Importantly, it acknowledges the critical necessity of accounting for the presence of adversaries in these robotic environments, which introduces unique challenges and complexities into solving traditional robotic problems. The paper recognizes that in adversarial robotics, the critical aspect is modeling and addressing the knowledge and behaviour of adversaries. This viewpoint aligns with game theory, where robots and adversaries engage in a strategic interplay to maximize their respective utilities. The characterization of adversaries is two-fold, encompassing non-strategic adversaries with fixed threats and strategic adversaries that dynamically react to the robots' actions. The paper suggests an initial simulation approach involving non-reactive adversaries, followed by a more nuanced consideration of strategic behaviour. Within this framework, the paper dives into specific problems, such as multi-robot patrolling, coverage, formation, and navigation in adversarial settings. It grapples with the trade-offs between optimizing task-related criteria, like frequency, and the imperative of detecting and mitigating adversarial interference. This highlights the intricate balance required in adversarial robotics, where objectives must be achieved while simultaneously safeguarding against hostile actions. Furthermore, the paper explores the profound impact of an adversary's presence on multi-robot formation and navigation problems, underscoring the need for adaptive strategies in dynamic environments. It anticipates future research avenues in adversarial robotics, emphasizing the importance of developing more robust models and algorithms to address the evolving challenges in this field.

(Ivanová and Surynek, Adversarial Cooperative Path-Finding: Complexity and Algorithms 2014)This research paper focuses on the challenging problem of adversarial cooperative path-finding (ACPF), a critical issue in the fields of artificial intelligence and robotics. ACPF involves two teams of agents striving to reach their respective goals while avoiding collisions with each other, presenting intricate theoretical and practical challenges. The paper begins by outlining its key objectives: to investigate the theoretical properties and practical solving techniques for ACPF. One of the most significant contributions of this work is the revelation of the problem's computational complexity—PSPACE-hard—a result of paramount importance in computational complexity theory. This discovery underscores the inherent difficulty of ACPF and highlights its relevance in understanding the limits of algorithmic solutions. To tackle this complex problem, the paper introduces several solving approaches, including greedy algorithms, minimax methods, and the widely-used Monte Carlo Tree Search (MCTS). These techniques are crucial for addressing ACPF in real-world scenarios where multiple agents must make concurrent decisions to navigate shared environments efficiently. A notable aspect of the research is the conducted tournament, which serves to empirically compare the performance of the different solving approaches. This hands-on evaluation provides valuable insights into the practical applicability of each method, ultimately identifying MCTS as the most successful technique. This finding has practical implications for researchers and practitioners seeking effective strategies for ACPF in various applications, such as autonomous vehicles or multi-agent robotic systems. The paper also presents experimental results based on three instance scenarios: exchange, race, and mingled. These scenarios simulate agent interactions in 4-connected grid environments with strategically placed obstacles. The randomness in the initial agent locations and goals, coupled with variations in agent count and target locations, ensures a comprehensive exploration of ACPF dynamics. These experiments add depth to the paper's contributions, allowing readers to grasp the versatility and adaptability of the proposed solving techniques. In summary, the paper provides a comprehensive and well-rounded exploration of the adversarial cooperative path-finding problem and its solving techniques. Its theoretical insights into computational complexity, practical evaluations through tournaments, and experimental validations on diverse scenarios establish it as a valuable resource for both researchers and practitioners in the fields of artificial intelligence and robotics. This work not only contributes to advancing our understanding of ACPF but also offers practical guidance for addressing real-world challenges in multi-agent systems and autonomous navigation.

(Keidar and Agmon 2017)The article titled "Safety First: Strategic Navigation in Adversarial Environments" addresses a crucial issue in navigation within adversarial settings. The primary objective is to enable an agent to move through a graph while minimizing the risk of detection by a mobile adversary. This pursuit-evasion problem introduces a novel twist by incorporating adversarial modeling into the scenario. In this context, the evading agent is placed on a graph, with specific nodes designated as safehouses. The agent's task is to identify a path from its current position to a safehouse while minimizing the likelihood of encountering an adversary at any node along the way. The article explores various models of this problem, each with different assumptions regarding the agents' knowledge about their opponent. These models rely on a framework for computing node utility, which measures the desirability of each node as a potential location for the agent. This utility framework takes into account strategic considerations and game theory concepts, allowing the agent to plan its path based on its risk attitude. One key contribution of the article is the development of a framework for computing utilities associated with each node in the graph. This framework serves as the foundation for finding solutions to the StratNAV problem across the different examined variants. The article also provides theoretical guarantees, such as expected utility maximization and equilibrium analysis, to support the proposed approach. A noteworthy aspect of the research is the recognition that agents may acquire information about their adversary while enroute to their destination, be it a safehouse or an interception point. This information is then used to adapt the agent's strategy effectively, enhancing its chances of reaching the target safely. Theoretical analysis and extensive experimental results demonstrate the effectiveness of these strategy updates in achieving the desired outcome. In addition to theoretical analysis, the proposed framework for computing node utilities offers a versatile solution for addressing various challenges in this domain. Overall, the research contributes valuable insights into the field of navigation in the presence of mobile adversaries.

(Ivanová and Surynek, Adversarial Multi-Agent Path Finding is Intractable 2021)This research article delves into an intriguing variant of the Multi-Agent Path Finding (MAPF) problem known as Adversarial Multi-Agent Path Finding (AMAPF). In AMAPF, the complexity of MAPF is heightened as it involves two opposing teams of agents navigating a shared environment represented by an undirected graph. The primary objective of one team is to guide their agents to their respective goal locations, while the opposing team's aim is to obstruct this progress. A noteworthy finding of the article is the establishment that determining a winning strategy for the first team in AMAPF falls into the EXPTIME complexity class, illustrating the formidable computational challenges inherent in this problem. The article situates AMAPF within the broader context of MAPF, a well-studied problem in multi-agent systems. While MAPF has attracted considerable research attention with various solving algorithms available, the introduction of adversarial dynamics in AMAPF introduces a substantial escalation in computational complexity. To provide a comprehensive foundation, the article discusses the computational complexity of optimal solutions for standard MAPF, both in undirected and directed graph settings, as well as several MAPF variants characterized by different objectives and constraints. The authors undertake a meticulous exploration of the computational intricacies associated with AMAPF and present innovative algorithms tailored to address this challenging variant. They demonstrate the complexity by reducing AMAPF to a two-player game scenario where players compete to satisfy a propositional formula, establishing a critical link between the two problem domains. This reduction highlights that if a winning strategy exists in the game, it also exists in the corresponding AMAPF instance, thereby offering valuable insights into tackling AMAPF from a game-theoretical perspective. The article emphasizes the broad applicability of AMAPF in various multi-agent scenarios, including military command and control, security operations, and computer games. Furthermore, it suggests avenues for further exploration, such as extending AMAPF to consider the capacities of vertices and edges or investigating instances on specialized graphs like grid graphs or bi-connected graphs. These potential extensions indicate the rich landscape of research opportunities that AMAPF presents.

(Lisý, et al. 2009)The paper titled "Adversarial Search with Procedural Knowledge Heuristic" offers a novel approach to planning in large-scale multiplayer domains, focusing on the integration of procedural knowledge within a game tree search algorithm. This algorithm is designed to address scalability challenges and gain insights into how individual players pursue their objectives. The background knowledge necessary for this algorithm can be categorized into three key components. Firstly, the paper discusses the importance of algorithms that generate atomic actions that contribute to achieving specific goals. These actions form the basis for planning and decision-making within the multiplayer environment. Secondly, it emphasizes the significance of defining the conditions under which pursuing these goals becomes meaningful. Understanding the contextual aspects of the game world is crucial for effective planning. Thirdly, the paper introduces the concept of an evaluation function, which assigns a numeric value to each player and world state, representing the desirability of that state for the player. This evaluation function serves as a critical component in assessing the quality of different game states. The paper also delves into the learning aspect of the opponent's evaluation function, assuming that the opponent employs the minimax algorithm. It describes how the opponent's evaluation function is determined through a weighted sum of known world state characteristics, and how a hill-climbing approach is used to optimize these weights and depths based on a training set of opponent decisions. This insight into opponent modeling enhances the algorithm's effectiveness in anticipating adversary moves. The core contribution of the paper lies in the detailed explanation of the algorithm that integrates procedural knowledge into game-tree search. This algorithm forms the crux of the research and is thoroughly elucidated. Furthermore, the paper assesses the computational complexity of the algorithm and conducts experimental evaluations, examining factors such as search space reduction, precision loss, and scalability. These analyses provide empirical evidence of the algorithm's practical applicability. In summary, the paper offers a comprehensive framework for adversarial search with a procedural knowledge heuristic that can be adapted to diverse multiplayer domains. The algorithm it presents holds promise for enhancing scalability and capturing the strategic behaviors of individual players in these domains.

(Keidar, Agmon and Noa 2018)This paper discusses a comprehensive study on the challenging problem of safe navigation in adversarial environments. The authors of this research delve into various models and strategies aimed at achieving secure navigation and explore how risk attitudes can influence the construction of navigation strategies. They also examine different assumptions regarding the adversary's behavior and the impact of various types of information on an agent's ability to navigate safely. Additionally, the paragraph highlights the significance of on-the-fly strategy updates in addressing this problem. One key focus of this study is the exploration of different models and strategies for safe navigation. Adversarial environments often involve hostile entities or obstacles, making navigation a complex task. The authors investigate a range of approaches to tackle this challenge, considering both known and unknown adversary behaviors. By doing so, they offer a diverse set of tools and techniques that can be applied to enhance navigation in a variety of real-world scenarios. Another crucial aspect addressed in the study is the role of risk attitudes in shaping navigation strategies. Risk attitudes, such as risk-averse or risk-seeking behavior, can significantly impact decision-making in adversarial contexts. The authors provide theoretical and empirical analyses to demonstrate how different risk attitudes can lead to distinct navigation strategies. This insight can be instrumental in designing adaptive navigation systems tailored to an agent's risk preferences and the level of risk present in the environment. Furthermore, the study underscores the importance of on-the-fly strategy updates. In dynamic and unpredictable adversarial environments, static strategies may fall short. The authors propose a dynamic approach where agents continuously gather information during their movement and use this data to update their strategies in real-time. This adaptive strategy can lead to better performance compared to rigid, pre-defined plans. Additionally, the authors emphasize the significance of information in navigation. Different types of information, such as data about the adversary's location or environmental conditions, can impact an agent's ability to make informed decisions. The study evaluates the usefulness of various types of information, providing insights into which sources of data are most valuable for enhancing navigation strategies.

(Bakshi and Schneider 2023)This research paper introduces the Stealthy Terrain-Aware Multi-Agent Active Search (STAR) algorithm, which addresses the challenging problem of efficient target search in complex natural terrains while minimizing the risk of detection. STAR is a multi-objective parallelized Thompson sampling-based algorithm designed for reconnaissance tasks where search agents may face adversarial targets, emphasizing both target recovery and minimizing detection risk. One of STAR's distinguishing features is its optimization of two competing objectives: maximizing target recovery rate and minimizing a stealth penalty that quantifies the detectability of search agents by the targets. This dual-objective approach strikes a balance between achieving mission goals and ensuring the safety of the agents. Crucially, STAR leverages topographical information to reason about changing visibility risks during the search, enhancing its adaptability to varying terrains and environmental conditions. This terrain-awareness sets STAR apart from existing multi-agent active search methods. The algorithm employs a single Thompson Sample from the current belief to optimize the reward function, allowing for calculated randomness in agent decisions, even in the face of communication or hardware failures. Over time, as more observations are collected, agents learn to make more informed decisions, improving their search efficiency. In simulated scenarios, STAR consistently outperforms existing methods across different variables, including map type, communication reliability, the number of search agents, and the presence of adversarial targets. This robust performance highlights STAR's potential in various applications, such as search and rescue, environmental monitoring, and military operations. Furthermore, the algorithm's adaptability to changing visibility risks over the course of a search mission enhances its practicality in real-world scenarios. STAR's deployment on ground-based robotic platforms in sizable search regions demonstrates its scalability and applicability. Looking forward, the algorithm's performance can be further enhanced by incorporating additional environmental information, such as terrain roughness and vegetation density. Overall, STAR presents a promising approach for stealthy multi-agent active search tasks, addressing critical challenges in a range of domains.

(Benjamin 2002)The paper titled "Multi-objective Autonomous Vehicle Navigation using Interval Programming" authored by Michael R. Benjamin, discusses the challenges associated with controlling autonomous marine vehicles in complex environments featuring moving vehicles. The author contends that conventional arbitration schemes, which either suppress most behaviors or average them into a single action, result in unsatisfactory vehicle behavior. Instead, the author proposes a novel approach based on Interval Programming to solve multi-objective optimization problems, which arise in the context of autonomous vehicle control. The key premise is that in complex environments, each behavior of an autonomous vehicle should not only produce the best action to serve its specific goals but also generate alternative actions that can lead to an optimal compromise between different behaviors. This approach reframes action selection as a multi-objective optimization problem, akin to "multiple criteria decision making" (MCDM) or "multi-objective optimization." Interval Programming is presented as a suitable technique for this purpose, capable of handling uncertainty and imprecision in constraints and objectives. An illustrative real-world example is provided, where Interval Programming was employed to control an autonomous underwater vehicle (AUV) navigating a minefield while avoiding collisions with other vehicles. The method successfully found solutions that satisfied all constraints and optimized objectives, enabling the AUV to navigate through the complex environment effectively. Overall, through this work the author offers a valuable contribution to the domain of autonomous marine vehicle navigation and multi-objective optimization.

**Conclusion**

Our report provides a comprehensive analysis of **dynamic path finding for robot navigation** using heuristic algorithms, genetic algorithms, particle swarm algorithms, and adversarial search algorithms. We have discussed the importance of this problem in various domains, including autonomous vehicles, UAVs, and mobile robotics. Through a literature survey of 32 research articles, we have categorized the different algorithm types employed in this field and highlighted their strengths and weaknesses. Our analysis shows that each algorithm has its own advantages and limitations, and the choice of algorithm depends on the specific application and environment. Heuristic algorithms, such as A\* and D\* algorithms, are widely used in robotics and artificial intelligence for path discovery and leverage heuristics or domain-specific knowledge to guide the search process. Genetic algorithms, on the other hand, are inspired by natural selection and evolution and can be used to optimize complex objective functions. Particle swarm algorithms are based on the behaviour of social organisms, such as birds and fish, and can be used to find optimal solutions in dynamic environments. Adversarial search algorithms, such as minimax and alpha-beta pruning, are used in game theory and can be applied to path planning problems with multiple agents.

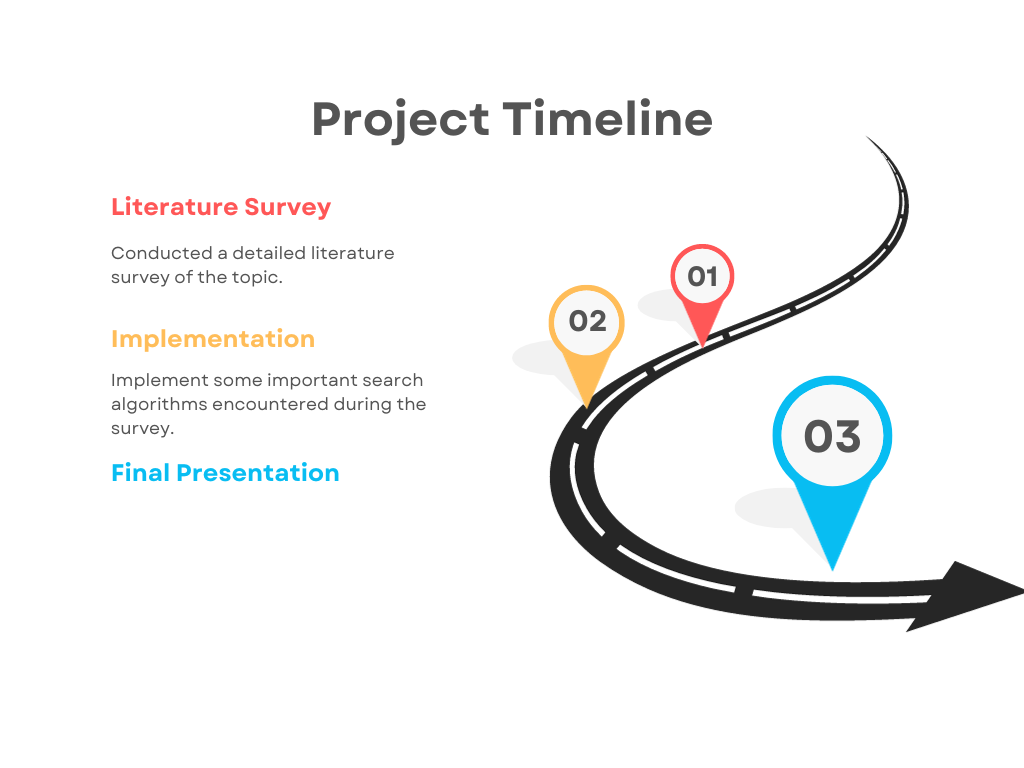
On the contrary we have also presented several case studies and experimental results demonstrating the effectiveness of different approaches in real-world scenarios. For example, in the domain of autonomous vehicles, dynamic path finding is essential for safe and efficient navigation in complex traffic environments. Our analysis shows that a hybrid approach that combines multiple algorithms, such as A\* and particle swarm algorithms, can achieve better performance and adaptability in such environments. Similarly, in the domain of UAVs, dynamic path finding is crucial for mission planning and obstacle avoidance. The study we conducted on genetic algorithms demonstrates their potential for optimising path planning and enhancing UAV performance. Furthermore, we have discussed some of the challenges involved in dynamic path finding, such as uncertainty, scalability, and real-time constraints. As we know that in dynamic environments, the environment can change rapidly, and the robot must be able to adapt to these changes quickly and efficiently. Scalability is another challenge, as the search space can become very large in complex environments, and the algorithm must be able to handle this efficiently. Real-time constraints are also important, as the robot must be able to make decisions quickly and avoid collisions with obstacles.

We have also identified some future research directions, such as incorporating machine learning techniques, developing more efficient algorithms, and addressing ethical and safety concerns in autonomous systems. Machine learning techniques can be used to improve the performance and adaptability of dynamic path finding algorithms by learning from experience and data. Developing more efficient algorithms, such as parallel algorithms and distributed algorithms, can also improve the scalability and real-time performance of dynamic path finding.

Addressing ethical and safety concerns in autonomous systems is also crucial, as these systems can have a significant impact on society and the environment. Ensuring that these systems are safe, reliable, and transparent is essential for their widespread adoption and acceptance. Overall, this report would potentially act as a valuable resource for researchers and practitioners in the field of robotics and artificial intelligence. By understanding the different algorithmic approaches and their applications, we can develop more intelligent and adaptive systems that can navigate complex environments and perform various tasks autonomously. The challenges involved in dynamic path finding are significant, but the potential benefits are enormous, and continued research and development in this field will be essential for realizing the full potential of autonomous systems.

In Phase-2 of the project, we intend to put several AI search techniques such as various evolutionary algorithms, simulated annealing algorithms, and heuristic algorithms into practice. In addition, we want to demonstrate how these algorithms operate and evaluate how well they perform when compared to one another. The major goal is to enhance our grasp of the ideas underlying the AI searching algorithms while also gaining practical experience with them. The benefits and drawbacks of these algorithms may also be understood by comparing them side by side in a real-world scenario.

A detailed graphical timeline of our plan of work is shown below.



# **References**

A, Le, Arunmozhi M, Veerajagadheswar P, Ku P-C, Minh TH, Sivanantham V, and Mohan. 2018. “Complete Path Planning for a Tetris-Inspired Self-Reconfigurable Robot by the Genetic Algorithm of the Traveling Salesman Problem.” *Electronics.*

Adiperdana, and Budi. 2021. *Using Particle Swarm Optimization as Pathfinding Strategy in a Space with Obstacles.* arXiv.

Agmon, Noa. 2017. “Robotic strategic behavior in adversarial environments.” *Proceedings of the 26th International Joint Conference on Artificial Intelligence.* 5106–5110.

Bakshi, Nikhil Angad, and Jeff Schneider. 2023. “Stealthy Terrain-Aware Multi-Agent Active Search.” *7th Annual Conference on Robot Learning.*

Benjamin, M R. 2002. “Multi-objective autonomous vehicle navigation in the presence of cooperative and adversarial moving contacts.” *OCEANS '02 MTS/IEEE.* Biloxi. 1878-1885.

Das, P K, H S Behera, and B K Panigrahi. 2016. “A hybridization of an improved particle swarm optimization and gravitational search algorithm for multi-robot path planning.” 14-28.

E, Koref R. 1990. “Real-Time heuristic search.” 189-211.

G, Li, and Chou W. 2018. “Path planning for mobile robot using self-adaptive learning particle swarm optimization.”

Geisler, T, and T W Manikas. 2002. “Autonomous robot navigation system using a novel value encoded genetic algorithm.” *45th Midwest Symposium on Circuits and Systems.*

Guruji, Akshay Agarwal, Himansh Parsediya, and Deep. 2016. “Time-efficient A\* Algorithm for Robot Path Planning.” Procedia Technology, 144-149.

Hart, P E, N J Nilsson, and B Raphael. 1968. *A Formal Basis for the Heuristic Determination of Minimum Cost Paths.* IEEE Transactions on Systems Science and Cybernetics, 100-107.

Ivanová, M, and P Surynek. 2014. “Adversarial Cooperative Path-Finding: Complexity and Algorithms.” *IEEE 26th International Conference on Tools with Artificial Intelligence.* Limassol. 75-82.

Ivanová, M, and P Surynek. 2021. “Adversarial Multi-Agent Path Finding is Intractable.” *IEEE 33rd International Conference on Tools with Artificial Intelligence* 481-486.

Kang, H I, B Lee, and K Kim. 2008. *Path Planning Algorithm Using the Particle Swarm Optimization and the Improved Dijkstra Algorithm.* Wuhan: IEEE Pacific-Asia Workshop on Computational Intelligence and Industrial Application, 1002-1004.

Kang, Xiaoming, Yong Yue, Dayou Li, and Carsten Maple. 2011. “Genetic algorithm based solution to dead-end problems in robot navigation.” *inderscience.*

Keidar, Ofri Agmon, and Noa. 2018. “Safe navigation in adversarial environments.” *Annals of Mathematics and Artificial Intelligence.*

Keidar, Ofri, and Noa Agmon. 2017. “Strategic Navigation in Adversarial Environments.” *16th Conference on Autonomous Agents and MultiAgent Systems .* Richland. 1581–1583.

Kokash, and Natallia. 2005. “An introduction to heuristic algorithms.” Department of Informatics and Telecommunications, 1-8.

Kumar, N, Z Vámossy, and Z M Szabó-Resch. 2016. *Heuristic approaches in robot navigation.* Budapest: IEEE 20th Jubilee International Conference on Intelligent Engineering Systems, 219-222.

Lisý, Viliam, Branislav Bošanský, Michal Jakob, and Michal Pěchouček. 2009. “Adversarial search with procedural knowledge heuristic.” *The 8th International Conference on Autonomous Agents and Multiagent Systems.* Richland. 899–906.

Manikas, T W, K Ashenayi, and R L Wainwright. 2007. *Genetic algorithms for autonomous robot navigation.* IEEE Instrumentation & Measurement Magazine, 26-31.

Miao, H, and Y C Tian. 2008. *Robot path planning in dynamic environments using a simulated annealing based approach.* Vietnam: 1253-1258.

Mo, Hongwei, and Lifang Xu. 2015. “Research of biogeography particle swarm optimization for robot path planning.” 91-99.

Moreno, L Armingol, J M Garrido, and S et al. 2002. “A Genetic Algorithm for Mobile Robot Localization Using Ultrasonic Sensors.” *Journal of Intelligent and Robotic Systems* 135–154.

Phung, Manh Duong, and Quang Phuc Ha. 2020. “Motion-encoded particle swarm optimization for moving target search using UAVs.”

Pooja, S, S Chethan, and C V Arjun. 2016. *Analyzing uninformed search strategy algorithms in state space search.* Jalgaon: International Conference on Global Trends in Signal Processing, Information Computing and Communication, 97-102.

Ramirez, D R, D Limon, J Gomez-Ortega, and E F Camacho. 1999. “Nonlinear MBPC for mobile robot navigation using genetic algorithms.” (IEEE International Conference on Robotics and Automation) 3: 2452-2457.

Roberge, V, M Tarbouchi, and G Labonte. 2013. *Comparison of Parallel Genetic Algorithm and Particle Swarm Optimization for Real-Time UAV Path Planning.* IEEE Transactions on Industrial Informatics.

T, Alander J. 1993. “ On Robot Navigation Using a Genetic Algorithm.” *Springer.*

Yang, S, W Fu, D Li, and W Wang. 2007. “Research on Application of Genetic Algorithm for Intelligent Mobile Robot Navigation Based on Dynamic Approach.” *IEEE International Conference on Automation and Logistics* 898-902.

Yun, S C, V Ganapathy, and T W Chien. 2010. *Enhanced D∗ Lite Algorithm for mobile robot navigation.* Penang: IEEE Symposium on Industrial Electronics and Applications, 545-550.

Zhang, Yong, Dun wei Gong, and Jian hua Zhang. 2013. “Robot path planning in uncertain environment using multi-objective particle swarm optimization.” 103: 172-185.