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A Systematic Literature Review of Path-Planning Strategies for Robot Navigation in Unknown Environment

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Abstract

The Many industries, including ports, space, surveillance, military, medicine and agriculture have benefited greatly from mobile robot technology. An autonomous mobile robot navigates in situations that are both static and dynamic. As a result, robotics experts have proposed a range of strategies. Perception, localization, path planning, and motion control are all required for mobile robot navigation. However, Path planning is a critical component of a quick and secure navigation. Over the previous few decades, many path-planning algorithms have been developed. Despite the fact that the majority of mobile robot applications take place in static environments, there is a scarcity of algorithms capable of guiding robots in dynamic contexts. This review compares qualitatively mobile robot path-planning systems capable of navigating robots in static and dynamic situations. Artificial potential fields, fuzzy logic, genetic algorithms, neural networks, particle swarm optimization, artificial bee colonies, bacterial foraging optimization, and ant-colony are all discussed in the paper. Each method's application domain, navigation technique and validation context are discussed and commonly utilized cutting-edge methods are analyzed. This research will help researchers choose appropriate path-planning approaches for various applications including robotic cranes at the sea ports as well as discover gaps for optimization.

Keywords: Mobile Robot; Path Planning; Perception; Motion Control; Heuristic Methods; Classical Methods.

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1. Introduction

Initially, mobile robots were exclusively used in the manufacturing industry. However, it is now widely employed in the mining industry [1], surveillance [2], space [3], military [4], hospital [5] and agriculture [6]. The robot is outfitted with sensors that are necessary to model the environment and localize its position, control the movements, identify obstructions, and avoid obstacles while executing navigational tasks [7]. Safe course planning from the beginning point to the destination position is the most crucial aspect of any navigational system. Because of this, the right choice of a navigational strategy is the most important part of a robot's path planning, regardless of whether it is operating in a simple or complicated environment. The basic purpose of navigation is to either accomplish a predefined target or to follow a predetermined path without colliding with anything [8].

Autonomous navigation is subdivided into four main subtasks as in fig.1 [9] . The sensing system records the robot's surroundings (Perception). Identification of the location of the robot in the environment (localization). The robot decides how to maneuver to avoid colliding with the goal (path-planning). Motion control is used to direct the robot's movements along the intended path.

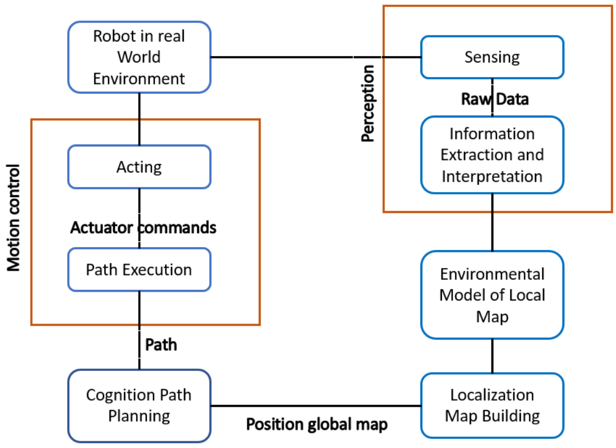

Figure 1: Flow diagram for mobile robot navigation [10].

Personal navigation is the handling of multiple aspects of the environment in relation to one another while taking their position into account. Fig.1 depicts the basic steps involved in the robot's operation. Path-planning is one of the most critical activities aforementioned, and it is the topic of this review [3]. As illustrated in fig.2, path-planning strategies are divided into two categories: classical approaches and heuristic approaches. As commonly utilized classical path-planning methods the literature also contains references to the Artificial Potential Field (APF) approach, cell decomposition, mathematical programming, and roadmap methodology. However, with the exception of the APF approach, most conventional methods failed to handle significant uncertainty in dynamic contexts.

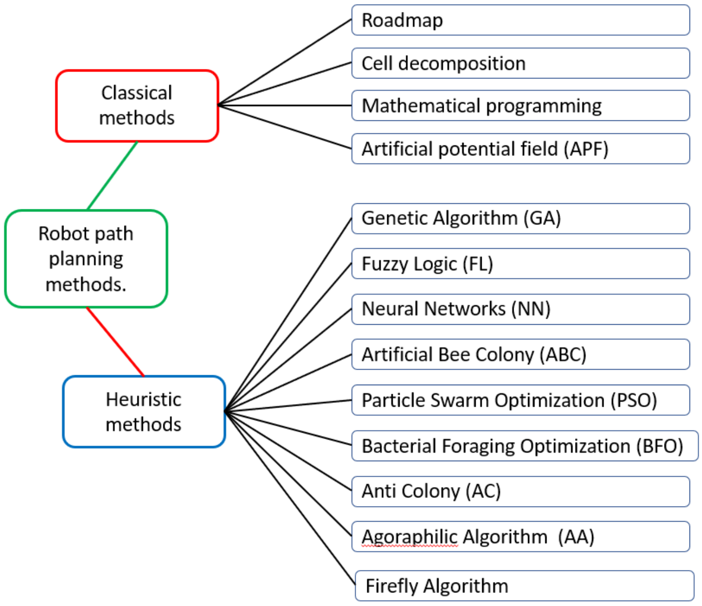

Figure 2: classification of mobile robot navigational approaches.

Numerous researchers have produced survey studies on the navigation of mobile robots; however, these surveys are not comprehensive enough to analyze each navigational technique [11]. This survey report on mobile robot navigation's recommended research gaps and the range of innovation in a particular field. Individual methods are thoroughly examined for static environments, dynamic environments with changing obstacles and goals, simulation analysis, experimental analysis, and numerous mobile robot navigation strategies. The survey also distinguishes between traditional and heuristic approaches in terms of effectiveness and application in specific situations such as aviation, land, underwater, industrial, and hazardous environments. Furthermore, hybridization approaches that have recently been applied to produce better results in path planning challenges for mobile robots are also discussed. To get an overview of what has been done on autonomous robot navigation, A systematic literature review (SLR) is carried out to provide answers to research questions. SLR identifies potential gaps in research on a specific problem area and advises practitioners and scholars who intend to do additional research on that problem area. SLR collects relevant studies from electronic databases, summarizes them, and presents them in order to answer preset research questions. An SLR study assists new researchers in the subject in understanding the state of the art and provides new views.

2. Background study

Despite the fact that robotics and autonomous navigation are widely debated topics in the literature, there are few surveys and studies that compare the most frequent methodologies. SLR requires more time and effort to complete than a traditional review, locating one is substantially more difficult.

In review by Rafai and colleagues [12] the most common classical and heuristic path planning approaches for mobile autonomous robots were reviewed. The Dijkstra algorithm, artificial potential field, probabilistic roadmap, and cell decomposition were among the conventional methods described. Fuzzy logic, neural networks, particle swarm optimization, genetic algorithms, cuckoo search algorithms, and artificial bee colonies were among the heuristic methods used. The prior literature lacked in-depth study. The research focused on both static and dynamic barriers. Inadequate research has been conducted on a variety of barriers to appropriately analyze the issue. Earlier works were expanded by focusing on the kind, shape, or placement of impediments and employing appropriate strategies. Most systems failed to function properly under certain settings, such as big or dynamic environments.

Study by Patle and colleagues [10] on mobile robot navigation classifies the various methods into classical and reactive approaches. It was determined that reactive approaches outperform classical procedures because they are better able to deal with uncertainty in the environment. For real-time navigation challenges, reactive techniques are preferred. Fewer research papers are published in dynamic environments than in static environments. There are much less works on robot navigation in a dynamic environment for a moving target problem than for a moving obstacle problem. Most articles to date have only demonstrated a simulation analysis; papers on real-time applications are far fewer. There are less papers on hybrid algorithms than on standalone algorithms, and hybridizing with reactive approaches can increase the performance of classical approaches.

This review paper by Mohanty and colleagueset [13] has outlined the many path planning approaches utilized for mobile robot navigation. The paper investigates both global and local path planning classifications, as well as traditional and heuristic techniques. Each method's pros and disadvantages were explored. Roadmaps, PF, and CD are among the traditional strategies described. These strategies will either seek a solution or demonstrate that one cannot be found. Because of their high computing requirements and incapacity to perform in dynamic conditions, they may not be trustworthy in real-world applications. Among the heuristic-based methods mentioned are ANNs, FLs, GAs, and PSOs. These are some of the most frequent strategies for mobile robot navigation. These algorithms, in contrast to the traditional approaches, do not promise to find a solution, but if they do, they will do so with significantly less effort and processing. Due to this, heuristic methods are significantly better suited for use in practical applications, particularly in dynamic contexts. They did not, however, offer any tests or assessments. Comparison of the investigated algorithms was limited to the use of global optimization, loop closure, map density, and core algorithms.

In this literature study Loganathan & Ahmad, [14], shows that the last ten years' worth of almost 200 articles on AMR navigation techniques were examined. The main difficulties and cutting-edge solutions to the numerous path planning issues in the AMR navigation were methodically determined. The following are the study's primary conclusions: Since the previous ten years, there has been a sharp rise in the use of heuristic methods, demonstrating their superiority to conventional methods. Heuristic approaches can be used to address many goals at once, such as lowering path length and energy consumption, which has become the main focus of many studies. Navigation in dynamic situations is essential since it simulates the scenario in the actual world. Nevertheless, compared to navigation in static situations, it has received less attention. The findings of this survey, particularly the evaluation of each technique's advantages and disadvantages as well as the popularity of particular approaches in addressing the identified major challenges, can be helpful in directing future research into the creation of fresh tactics that can raise the autonomy level of AMRs. Nevertheless, focusing just on path planning might not ensure success in actual execution. The following should be on the future research agenda in order to integrate robustness into the navigation techniques against unforeseen conditions when deployed to the real environment: Destination planning: Trajectory planning is required to maximize the robot's dynamic capabilities and mobility constraints, which can improve the navigation approach. This process takes a specified geometric path and gives it time information. It is frequently oversimplified in most current methodologies in an effort to reduce the complexity of the path planning. Sensory or perception of a robot: Sensing is frequently detached from planning in most path planning techniques. Incorporating sensors such as cameras and LiDARS can assist users in overcoming environmental uncertainties; nevertheless, this requires skilled utilization of sensor feedback. When planning the robot's path, keep in mind the sensor system's limits as well as methods that can improve sensor feedback.

The fundamental problem with the surveys listed above is that they don't provide any methodology or standards for carrying out the study, nor for choosing and contrasting the approaches. In the majority of these papers, the topics of path planning and control were not explored required for a robot to navigate autonomously, efficiently, and safely and methods used for path planning in robot autonomous navigation are not explicitly discussed. How to quality and compare navigation methods also open challenges in path planning are not clearly explained. However, we were unable to locate any research that looked at a whole navigation system that relied only on sensors. In addition to resolving these particular issues, there are several crucial factors pertaining to their compatibility and integration.

3. Methodology

3.1. Research protocol

We used Kitchenham's [15, 16] method for a systematic review of the literature, which was later adapted by Torres [17] that divides the process into three main phases: planning, conducting the review, and reporting the review. The research questions are established first. Following the development of research questions, databases are used to locate relevant studies. The database for the study was Google Scholar. Relevant research was discovered and then filtered and assessed according to a set of exclusion and quality criteria. To answer the study questions, all relevant information from the selected papers was retrieved and synthesized. Research question

3.2. Research questions

The research questions addressed by this study are:

1. What is necessary for a robot to carry out autonomous navigation, efficiently, and safely?
2. What methods are used for path planning in robot autonomous navigation?
3. How is navigation quality measured and compared to other methods?
4. What are the open challenges in path planning?

The goals of the research questions are respectively as follows:

1. To determine the bare minimum for a robot to travel autonomously in obstacle-filled situations.
2. Recognizing the research methods used in the literature or in papers cited as relevant and related.
3. To determine methods and criteria for assessing the effectiveness of autonomous navigation systems in order to compare and determine whether a system meets requirements.
4. To identify the gaps in the study for further research.

3.2. Search strategy

The search strategy utilized for this study includes the development of research questions, the search technique, the criteria for including and rejecting papers, the evaluation of paper quality, data extraction and analysis, and the distribution of the results. Pilot searches were undertaken to better understand the most frequently used terms while the methodology was being created and usual outcomes in the field of autonomous robot navigation. These results will be utilized to improve the protocol, study topics, and search strings. We will be able to define the four aforementioned research questions, with explanations of their major goals, by combining the learned knowledge with the requirements of the review. Google scholar was used to automate the search procedure. The search terms were created using queries and a few tries to get the optimal combination and variation of terms that allowed the most relevant research to be included in the results. The starting input of the search is “Autonomous robot” AND “navigation”. To locate synonyms for the keywords, articles were retrieved and abstracts were examined. The search terms "autonomous robot" AND "navigation" are used to obtain a broad overview of the investigations. To avoid missing important studies, a more sophisticated search string was developed after applying the exclusion criteria and analyzing all of the results. The following is the final search string.

“((autonomous AND (navigation OR mapping OR localization)) OR SLAM) AND (mobile OR robot*) AND (Obstacle avoidance OR path planning* OR sensors * OR transducers)”

The protocol also includes information on the extraction of useful data, such as the publishing, methodologies and implementation techniques that were employed, the testing process, and the findings validation. Both the quality evaluation of the chosen articles and the data extraction are done manually. To screen out irrelevant research and set the parameters for the systematic review, studies were examined and rated using exclusion criteria. The following are the exclusion criteria:

1. Publications not related to Path-Planning Strategies for Robot Navigation.

2. Publication not written in English

3. Publication that is a duplicate or already retrieved.

4. Full text of publication not available

5. Publication published before 2021.

Data extraction results from reading the complete document. This data includes methods and their descriptions, causes, sensors, cameras, robotics, implementation approaches, application area, validation procedure, validation context, errors, and claimed failures.The techniques highlight the primary issue that the writers addressed, including the action taken and the process used. The major steps of the approach are described, along with enough details to distinguish between studies that employ it and to comprehend its structure and characteristics. The specifics of the implementation are covered in the approaches, which also include the authors' usage of extracted algorithms, procedures, and other development decisions. We wish to understand the reasons for the techniques that were chosen. When we discuss methods in articles, we use this part to explain why they were chosen, as well as to define the main goals and driving forces behind the works. The application domain, which defines the method's purpose and context, as well as conditions in the environment, is related to these causes and objectives. The hardware field covers the robotic platform and modalities of movement used in the investigation. Furthermore, the number and type of cameras and sensors utilized, such as odometers, omnidirectional lenses, distance sensors, and inertial measurement sensors, depth cameras, webcams, and depth cameras, among others.

Finally, data is retrieved regarding the methods' testing and validation. The field for research validation contains the measurements and evaluation techniques that were used, including data collection. The validation context field contains further information on the tests' methods, environmental factors, whether they involve physical experiments or simulations, the activities that are carried out, whether benchmarks or datasets are used, and pertinent details about the testing setting. The final field contains mistakes made during the studies and anticipated procedure failures that impair usage.This review contained 47 papers, which are given in table 1, three of which are literature reviews. [73, 93, 94], 2 are models [59, 63], and the remaining 42 are methods.

Table 1: Reviewed papers.

Title	Country Author & Year	Targeted robot	Application domain	Method	Validation methods	Validation context
PSO Based Path Planning Strategy in Manufacturing Plants with Unknown Environmental Criteria	India [18] Ramakrishna & Subbaiah, 2023	Terrestrial with wheels	Control	PSO	Measurements	Experiments
Autonomous robot navigation based on a hierarchical cognitive model	China [19] Cai and colleagues 2023	Not specified	Obstacle detection	NN	Ability	Simulation
Optimal Path Planning for Mobile Robot Navigation Using FA-TPM in Cluttered Dynamic Environments	India [20] Herojit and colleagues 2023	Terrestrial With wheeled	Path planning	FA	Comparison with others	Experiments

Robot path planning using deep reinforcement learning	Mexico [21] Quinones-Ramirez and colleagues 2023	Terrestrial With wheeled	Localization	NN	Comparison with others	Localization
Neuro-fuzzy Control of a Mobile Robot	Tunisia [22] Reguii and colleagues 2023			Hybrid		
Multilayer Decision-Based Fuzzy Logic Model to Navigate Mobile Robot in Unknown Dynamic Environments	Iraq [23] Kamil & Moghrabiah, 2022	Terrestrial With wheeled	Path planning	FL	Difference to ground truth	Simulation
Path planning and collision avoidance methods for distributed multirobot systems in complex dynamic environments	China [24] Z. Yang and colleagues 2023	Terrestrial With tracks	Obstacle detection	Hybrid	Ability	Path planning
An Improved Algorithm for Complete Coverage Path Planning Based on Biologically Inspired Neural Network	China [25] Han and colleagues 2023	Aerial	Path planning	NN	Comparison with others	Mapping
Navigation for multi-humanoid using MFO-aided reinforcement learning approach	India [26] Kashyap and colleagues 2023	humanoid	Obstacle detection	NN	Qualitative	Simulation
Design and Experiments of a Two-Stage Fuzzy Controller for the Off-Center Steer-by-Wire System of an Agricultural Mobile Robot	China [27] Qu and colleagues 2023	Terrestrial With wheeled	Mapping	FL	Measurements	Experimentation
Design of a Saving-Energy Fuzzy Logic Controller for a Differential Drive Robot Based on an Optimization	Czech [28] Pham and colleagues 2023	Terrestrial With wheeled	Predefined navigation	FL	Qualitative	Simulation

A Bionic Dynamic Path Planning Algorithm of the Micro UAV Based on the Fusion of Deep Neural Network Optimization/Filtering and Hawk-Eye Vision	China [29] Z. Zhang and colleagues 2023	Unmanned Aerial Vehicle	Path planning .	NN	Difference to ground truth	Mapping
Cooperative collision avoidance in multirobot systems using fuzzy rules and velocity obstacles	China [30] Tang and colleagues 2023	Terrestrial With wheeled	Control	FL	Comparison with other	Localization
Adaptive Path Planning for Fusing Rapidly Exploring Random Trees and Deep Reinforcement Learning in an Agriculture Dynamic Environment UAVs	Portugal [31] Castro and colleagues 2023	Unmanned aerial vehicles	Localization	NN	Ability	Path planning
Path Planning Using Fuzzy Logic Control of a 2-DOF Robotic Arm	Italy [32] Bikova and colleagues 2022	Not specified	Path planning	FL	Measurements	Localization
A systematic review on recent advances in autonomous mobile robot navigation	Malaysia [14] Loganathan & Ahmad, 2023	Not specified	Control	Review	Review	Simulation
Obstacle avoidance and path planning of humanoid robot using fuzzy logic controller aided owl search algorithm in complicated workspaces	India [33] Kashyap & Parhi, 2022	Humanoid	Mapping	FL	Comparison with others	Simulation
Energy Efficient Local Path Planning Algorithm Based on Predictive Artificial Potential Field	Poland [34] Li, Tian, and colleagues 2022	Terrestrial With tracks	Path planning	APF	Qualitative	Mapping
A Genetic	Croatia [35]	Aerial	Path	GA	Ability	Simulation

Algorithm enhanced with Fuzzy-Logic for multi-objective Unmanned Aircraft Vehicle path planning missions*	Ntakolia and colleagues 2022		planning			
An Efficient Path Planning Algorithm Using a Potential Field for Ground Forces	Republic of Korea [36] Rasekhipour and colleagues 2021	Terrestrial With wheeled	Control	APF	Measurements	Locomotion
Fuzzy Adaptive Control for Vehicular Platoons With Constraints and Unknown Dead-Zone Input	China [37] Wei and colleagues 2023	Terrestrial With wheeled	Predefined navigation	FL	Ability	Locomotion
Fuzzy logic, neural-fuzzy network and honey bees algorithm to develop the swarm motion of aerial robots	German [38] Shafieenejad and colleagues 2022	Aerial	Competition	Neural fuzzy	Measurements	Simulation
Intelligent Optimization of Adaptive Dynamic Window Approach for Mobile Robot Motion Control Using Fuzzy Logic	UAE [39] Abubakr and colleagues 2022	Terrestrial With wheeled	Control	FL	Comparison with others	Mapping
Mobile Robot Path Planning based on Fuzzy Logic Algorithm in Dynamic Environment	China [8] S. Wang, 2022	Terrestrial With wheeled	Path planning	FL	Qualitative	Path planning
Enhancement of Cell Decomposition Path-Planning Algorithm for Autonomous Mobile Robot Based on an Intelligent Hybrid Optimization Method	Iraq [40] Kanoon and colleagues 2022	Humanoid	Competition	Hybrid	Comparison with others	Simulation
Radial Cell Decomposition	Egypt [41] Salama and	Aerial	Path planning	CD	Qualitative	Experimentation

Algorithm for Mobile Robot Path Planning	colleagues 2021					
On the Use of a Genetic Algorithm for Determining Ho–Cook Coefficients in Continuous Path Planning of Industrial Robotic Manipulators	Croatia [42] Grenko and colleagues 2023	Not specified	Control	GA	Ability	Mapping
Non-Parametric Calibration of the Inverse Kinematic Matrix of a Three-Wheeled Omnidirectional Mobile Robot Based on Genetic Algorithms	Spain [43] Palacín and colleagues 2023	Terrestrial With wheeled	Obstacle detection	GA	Mathematical demonstration	Simulation
Optimal scheduling for palletizing task using robotic arm and artificial bee colony algorithm	Poland [44] Szczepanski and colleagues 2022	Not specified	Predefined navigation	ABC	Measurements	Mapping
Research on Artificial Bee Colony Method Based Complete Coverage Path Planning Algorithm for Search and Rescue Robot	China [45] L. Yang, Xing, and colleagues 2022	Terrestrial With wheeled	Mapping	ABC	Ability	Simulation
Energy-Efficient Robot Configuration and Motion Planning Using Genetic Algorithm and Particle Swarm Optimization	Japan [46] Nonoyama and colleagues 2022	Terrestrial With wheeled	Localization	PSO	Ability	Experimentation
Obstacle Avoidance Path Planning of Space Robot Based on Improved Particle Swarm Optimization	China [3] J. Zhang and colleagues 2022	Terrestrial With wheeled	Path planning	PSO	Comparison with others	Simulation
Mobile robot navigation in	India [47]		Control	PSO	Ability	Localization

known manufacturing plant environment using particle swarm optimization						
Local Path Planning with Multiple Constraints for USV Based on Improved Bacterial Foraging Optimization Algorithm	China [48] Long and colleagues 2023	Not specified	Localizatio n	BFO	Ability	Simulation
A Bio-inspired trajectory planning method for robotic manipulators based on improved bacteria foraging optimization algorithm and tau theory	China [49] Z. Wang and colleagues 2022	Not specified	Control	BFO	Compariso n with others	Simulation
Wave Environment Decomposition with Adaptive Tri-Objective Particle Swarm Optimization for Mobile Robot Path Planning	Vietnam [50] Thi and colleagues 2022	Terrestrial With wheeled	Path planning	PSO	Difference to ground truth	Experimentation
An Effective Dynamic Path Planning Approach for Mobile Robots Based on Ant Colony Fusion Dynamic Windows	China [51] L. Yang, Fu, and colleagues 2022	Terrestrial With tracks	Path planning	AC	Compariso n with others	Mapping
Autonomous Obstacle Avoidance Path Planning for Grasping Manipulator Based on Elite Smoothing Ant Colony Algorithm	China [52] Meng & Zhu, 2022	Terrestrial With wheeled	Path planning	AC	Compariso n with others	Localization
Optimal Path Planning for Mobile Robot Navigation	India [20] Herojit and colleagues 2023	Terrestrial With wheeled	Obstacle detection	FA	Compariso n with others	Simulation

Using FA-TPM in Cluttered Dynamic Environments						
Hybrid FA-GA Controller for Path Planning of Mobile Robot	India [53] Patle and colleagues 2022	Terrestrial With wheeled	Obstacle detection	Hybrid	Ability	Simulation
Review of wheeled mobile robot collision avoidance under unknown environment	China [54] Y. Wang and colleagues 2021)	Terrestrial With wheeled	Obstacle detection	Revie w	Compariso n with others	Experimentation
A Review on Path Planning and Obstacle Avoidance Algorithms for Autonomous Mobile Robots	Malasya [12] Rafai and colleagues 2022	Not specified	Obstacle detection	Revie w	Ability	Simulation

Based on the requirements, we were unable to locate any systematic literature review, only one of the three reviews we found [93] provided the process used to choose the algorithms for analysis and comparison. The other two reviews' comparisons were brief and mostly dependent on the authors' judgments, and they omitted to disclose their methodologies. This information, along with the outcomes of the quality assessment, can be used to identify specific poorly defined procedures and methods used in the selection, testing, and evaluation of studies.

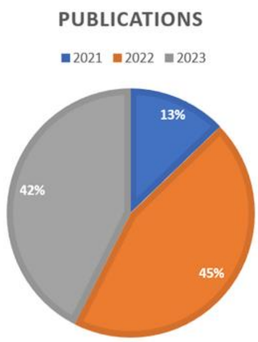

Figure 12

Looking at the retrieved data, we can observe that the area has had more articles this year than in the previous year with the fact that it is mid-year making it a trending topic (see Figure 1). They also offer a wealth of information, enabling breakthroughs in science.

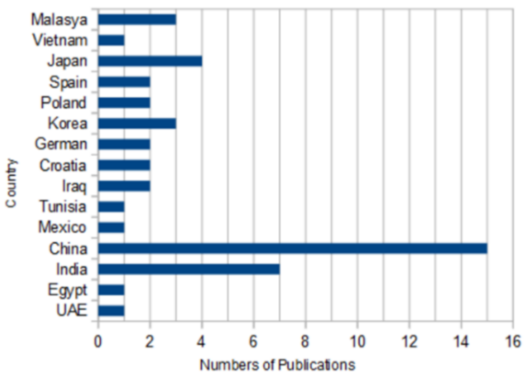

Figure 13

Figure 2 depicts the number of publications per country, with China leading the way, followed by India, both of which are major players in scientific research and robotic automation. As seen in Figure 3, the majority of robots use wheels for mobility, with a few additionally using tracks and human-like legs. Mobile Robots' Pioneer products are among the wheeled ones. As long as the navigation technique can be used to terrestrial robots for indoor navigation without significant adjustments, aerial robot research was also considered. There was no paper considered for underwater robots.In the below fig. 1 shows the experimental flowchart of our SET data analysis. Data is collected from X University, which contains 27,622 SET records of 701 sections for 35 different courses. Then we do preprocessing in order to apply the data mining algorithm. After that, opinions are analyzed. Lastly, all the findings are gathered for discussion.

The SET dataset has the numeric values for five different factors. Here, we are using Weka where k-means clustering will be used for grouping the data of class level and, lastly, a decision tree (J48) will be generated to identify the prominent factors that have significant impacts on SET. There are also qualitative opinions that are difficult to summarize in SET dataset. That's why Sentimental Analysis, a type of natural language processing, will be utilized to determine the polarity and subjectivity of the opinions. This will assist in identifying whether the opinion is positive.

4. Results

4.1 Autonomous Navigation Requirements (RQ1)

Although autonomous navigation can be utilized for a wide range of jobs, it is typically employed to accomplish other tasks with a variety of needs, such as search and rescue, transportation of people and loads, inspection and direction. The robot's movement and behavior, perception of and interaction with its surroundings, and ability to handle issues other than navigational ones are all governed by requirements. For instance, if a robot is being used for transportation, the system must be aware of how the robot will be loaded and unloaded, how precisely the robot must be parked, and speed limits, acceleration, deceleration, and turning angles are all factors to consider. are in order to prevent damage to the load or the robotIn the case of a guide robot, the system must walk along paths that are wide enough for them and change its locomotion speed to match the rhythm of the accompanying agents. Four navigational tasks are present. A complete navigation system should be possible by resolving the four navigational problems of locomotion, path planning, mapping, and location. Any of them would render autonomous navigation useless. Furthermore, despite the fact that these four actions can be stated, solved, and carried out independently, they are inextricably linked to one another. Localization and mapping are commonly solved concurrently using SLAM-based approaches. For the robot to navigate, it needs maps that depict how the world is organized and how recent observations relate to earlier ones. This suggests that prior to localization, mapping is required. To create an independent map of the environment, the robot must travel about and investigate new areas while collecting data. Based on its present attitude, it will compute the relationship between the observations. This means that the robot needs to locate itself in order to build and update the map. Because the outcomes of both tasks are reliant on each other, some strategies attempt to solve them concurrently, which, according to the research, yields better results than attempting to do them individually. [44, 56]. These two objectives are used in path planning to determine a feasible route between the robot's current pose and its destination position. Locomotion establishes how the robot should move to approach the objective while scanning for barriers and rerouting to prevent collisions using the computed path. Although several of the included publications show testing done outdoors or in a range of environments, the main focus of this evaluation is on indoor approaches. We decided to include them since, with little tweaks, they should operate indoors. We omitted any approaches or works that are only suitable for outdoor use, such as self-driving cars that rely on sensors that are not suitable for inside use or systems based on assumptions that are not necessarily valid in dynamic interior contexts.

4.2 Methods for Mobile Robot Autonomous Navigation (RQ2)

The process of autonomous navigation is divided into four main tasks: locomotion (control and obstacle detection), localization, mapping, path planning, and. Aside from these four categories, we discovered research that targets specific obstacles, such as competition-related tasks or planned navigation. In predetermined navigation, the system adheres to a specified and previously established course, indicating that it is not completely autonomous. Figure 4 shows the number of articles that address each of these critical goals.

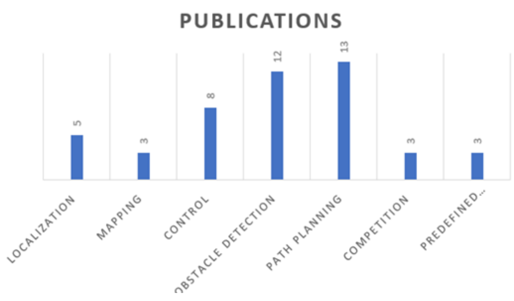

Figure 4: Number of articles chosen as per application domain.

The majority of studies concentrate on the path planning and obstacle detection issues, which are typically resolved concurrently via SLAM. This further demonstrates the vacuum in the literature caused by the absence of publications on comprehensive navigation systems. The solutions that are highlighted in the reports are represented by some of the key techniques we discovered in Figure 5. The majority of them address localization and mapping, but we were unable to identify any approaches that address all four tasks simultaneously and solely through sensors. The methodologies depicted in this figure are not mutually exclusive, it should be emphasized that the same study could have been counted in many categories at the same time. Furthermore, as we will see later, it is rarely examined if combining these multiple approaches is practical. Figure 6 depicts the relationship between these critical techniques and the field in which they were applied. Please keep in mind that the approaches in this figure, like those in the preceding one, are not mutually exclusive, thus the same study could have been classified in more than one way.

4.3 Navigation Verification and Evaluation (RQ3)

After the navigation methods have been proposed and developed, they must be tested and validated to ensure correct operation and, even more important, that they function in the real world. We present some of the tests and metrics used to assess the quality of the techniques, as well as benchmarks for comparing implementations, in this section. Figure 10 depicts the most prevalent validation methods discovered in our analysis. The majority of qualitative validation is based on the judgements of the writers. The authors used metrics such as distances to calculate the inaccuracy or precision of a method based on an ideal expected result. Whether or not the hypothesis is proven by experimentation, mathematical demonstration provides theoretical proof. When compared to previous studies, it is clear that the findings were evaluated against existing, comparable procedures. Measurements are articles that present quantitative experiments without validation or comparison to other experiments. The localization step of the navigation process was the most frequently employed. Estimating the robot attitude in relation to the surroundings or a reference is required for accurate localization. Approaches to assessing the localization process can be topology-based (positions in relation to areas or references), metric-based (coordinates and orientations in space), or a hybrid method (combining the two). The difference to the ground truth coordinates was the most commonly used method for assessing the correctness of the estimated localization. The most common validation techniques we found in our analysis are shown in Figure 10.

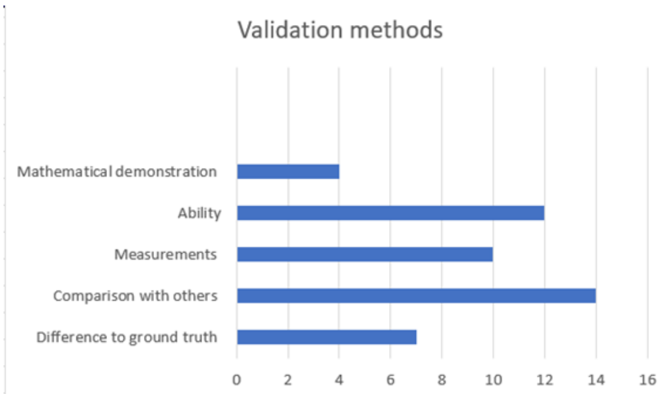

Figure 10: Number of articles chosen per validation method.

Figure 11 illustrates some of the most prevalent traits we found during the validation processes, including the use of simulations, experiments, tests for each navigation task, and dataset or benchmark usage. The localization step of the navigation process was the most frequently employed. Estimating the robot attitude in relation to the surroundings or a reference is required for accurate localization. Topology-based (positions in relation to regions or references), metric-based (coordinates and orientations in space), or hybrid (a combination of both) evaluations of the localization process are all possible. The most popular way to gauge the accuracy of the estimated localization was the difference from the ground truth coordinates.

We found that a widespread problem in the literature is insufficient validation and testing of proposed approaches and implementations. Even though the majority of the publications used in this analysis use simple measures to quantify navigation task errors, other reports simply provide qualitative analyses and judgments on their findings. Using their method, some authors claim that the robot could locate itself accurately in 5–10 seconds on average. They don't specify what constitutes a "good" localization, offer any evidence to support their claim that it was "good," or even describe what the average time means. Other studies assert that precise navigation and path planning outcomes were attained based on a few arbitrary trials, where they only recorded robot pose and error without defining the required accuracy and measurement requirements.

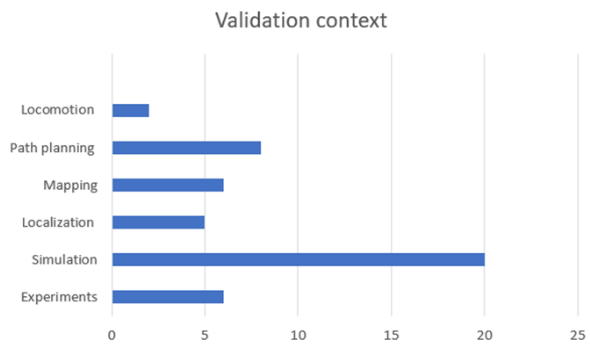

Figure 11: Number of articles chosen and categorized by validation context.

4.4 Open challenges in path planning (RQ4)

4.4.1 Requirements that are not well specified

One significant issue with this review is how badly, or not at all, the authors articulate the difficulties they intend to address with their techniques.

The defining of requirements is a key stage in building a high-quality, well-researched solution. The authors of the studies presented in this review, on the other hand, moved ahead to the creation of what the readers would consider as an arbitrarily chosen strategy. Even in these cases, the grounds for the original research are usually overlooked because some studies simply extend or improve upon established methodology. Developing an autonomous navigation system without a well-thought-out requirements specification may give positive results, but it is not guaranteed that the system will perform as predicted in the real world. Furthermore, problems caused by weak specifications are typically more difficult to resolve, especially when discovered later in the development process.

4.4.2 Poor Testing and Validation

There are clearly not enough publications on test methodologies, assessments, and outcome verification for autonomous navigation systems. The absence of extensive tests and validation results, whether conducted by the authors or by other academics, diminishes the possibility that the work will obtain credibility and be utilized as a reference in future initiatives. It is crucial to acknowledge this result so that it can be in-depthly examined, even if the purpose of this review was not to create and specify new test procedures for navigation systems. The evaluation of suggested methods and their implementations requires the development of more efficient testing and validation techniques. This advances the development of robots and robotic systems while also enhancing current quality, performance, and safety standards.

4.4.3 Popular Methods' Strengths and Weaknesses

We also recognized the strengths and shortcomings of previously discovered and discussed methods. The following remarks should assist readers in understanding the best uses of well-known autonomous navigation systems. The most well-known techniques were SLAM, which addressed both localization and mapping simultaneously. Several techniques, including but not limited to Kalman filters, particle filters, direct odometry, and neural networks, can be used to build SLAM solutions. Managing extremely large and dynamic environments, optimizing algorithms for mobile computers while maintaining acceptable accuracy, and interpreting the environment semantically for the performance of more challenging tasks are some of the outstanding challenges we found. Particle filtration and picture comparison with well-known instances are two additional strategies for robot localization that we discovered. These methods call for the map to be built up in advance and the acquisition of these references so that the robot can access them as it moves around the area. These approaches also have difficulty dealing with dynamic maps. As previously stated, algorithms that address localization and mapping separately have obstacles and give inferior results when compared to those that address both concurrently. The research in this study that employ boundary detection for robot control and obstacle identification provided the most promising outcomes. This is mostly owing to their capacity to deal with dynamic situations, as well as real-time image processing for collision avoidance and free path recognition. They can also adjust to various environments and robotics. Control can also be attained by looking for lines and other visual characteristics, comparing real-time images to references, and other methods. The main drawback of these strategies is that they only work well in well-known situations because they depend on the references obtained during the mapping process. We identified few studies that included path planning alongside the other navigation tasks. These pathfinding algorithms can be tweaked to deal with changing environments, allowing them to recognize changes in present paths and avoid impediments.

5. Conclusion

After performing a thorough literature review, we explored approaches and techniques used in autonomous navigation systems and appropriate for dynamic interior conditions, and we described our findings in this work. We also looked into the validation processes, tests, and implementations to uncover answers. Google Scholar was used to choose 47 studies. We were able to discover that there are now some concerns with the design and reporting of autonomous navigation systems as a consequence of our assessment of the research that comprised this study and our analysis of the data we had acquired. The two main strategies used in this work on mobile robot navigation are the classical and reactive approaches. The following are the study's principal conclusions: Reactive techniques outperform classical approaches because they are better able to deal with environmental uncertainty. There are much less works on robot navigation in a dynamic environment for a moving goal problem than for a moving obstacle problem. For real-time navigation challenges, reactive techniques are preferred. In a dynamic setting, fewer research articles are published than in a static environment. Most articles to date have only demonstrated a simulation analysis; there are far fewer papers on real-time applications. Compared to independent algorithms, there are less papers on hybrid algorithms. Fuzzy logic controller is the most commonly used however Sensor deprivation, selecting the right rules and tunning of membership functions still causes dead end making navigation hard There is a lot of potential in using newly developed algorithms like SFLA, CS, IWO, BA, HS, DE, BFO, ABC, and FA for navigation in an unknown complicated environment with maximum uncertainty, and they can be used to construct new sorts of hybrid techniques. By combining reactive approaches with classical approaches, performance of the former can be enhanced.

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