



Algorithms for path optimizations: a short survey

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Received: 1 June 2021 / Accepted: 6 October 2022 / Published online: 7 November 2022

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Abstract

Path finding is used to solve the problem of finding a traversable path through an environment with obstacles. This problem can be seen in many different fields of study and these areas rely on fast and efficient path finding algorithms. This paper aims to describe and review state of the art optimization techniques that are used on optimized path finding and compare their performances. Moreover, a special attention is paid on the proposed approaches to identify how they are tested on different test cases; whether the test cases are automatically generated or benchmark instances. The review opens avenues about the importance of automatic test case generation to test the different path finding algorithms.

Keywords Path Optimization · Evolutionary Algorithms · Swarm Intelligence Algorithms · Machine Learning Algorithms · Robotic Path Planing · Vehicle Routing

Mathematics Subject Classification 68T07

1 Introduction

Route planning or path finding or simply routing is a technique of developing collision free routes between a pair of specified origin and destination in a 2D/3D environment

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that contains obstacles. Route planning plays an important role in many applications, including hose/pipe routing in machines, circuit board designing, electrical wiring, vehicle routing, robotic path planning, etc. [1–5]. Though the term appears to be a simple task, routing is a complex process. As wiring harnesses become increasingly complex in electrical wiring, engineers need to consider things like wire length, bending radius and routing [3]. In the same way, the main aim of robot navigation is to find a safe and efficient optimal route that is smooth and safe in the environment it navigates. [6]. Also, in hose routing, selecting pre-specified catalog of angles for bends, keep away from collisions, and have minimum total length of the hoses and total number of bends is considered [1]. These are some of the examples to explain the complexity of routing in many areas. Because of this extensive use of routing in many fields and the advantages such as reduction of the planning time, total distance and time, and overall resource usage in better route planning, finding ways of doing that in an optimized way has become a crucial task. Many algorithms were developed over the years to solve routing problems in efficient and in an efficient manner.

Routing problems were also used in the literature to test the algorithms which are to produce optimal paths. The most popular approach would be to apply the algorithm on benchmark routing problems which are properly defined. It would also be sufficient in many situations but automatic test case generations might be very useful in some situations. For an example, consider robot navigation. There might be several obstacles in the environment and around them there can be many free points. Identification of these free points will enable users to generate several test cases (with different numbers of free points) and further several optimum paths.

The paper aims to describe the modern route optimization techniques used in the different routing problems in the literature and review their capabilities along with the methods they have adopted to handle the test cases to prove the capability of those techniques.

The remainder of the paper is organized as follows. Section 2 discusses the latest path finding algorithms based on various routing problems and their features and limitations/weaknesses. Also we consider how they generate test cases; whether they have generated their own test cases using a particular technique or they have based on randomly generated/benchmark test problems. Finally, Sect. 3 discusses these findings and finally we conclude the paper with further improvements that can be made.

2 Modern algorithms for route optimization

Path finding is used to solve the problem of finding a traversable path through starting point and destination by avoiding obstacles. This is a problem seen in many different fields of study where all of these areas rely on fast and efficient path finding algorithms. Different developments through research result in improving the accuracy and efficiency of path finding techniques over the years; thus the problem is still interested among the field of research. Finding the optimal path for a particular route optimization problem is not easy and it is a very tedious and time consuming task for people if it is done manually. When studying the existing research, we can identify many

different approaches have been applied on finding new approaches to gear the optimized path finding. Here we will discuss and compare several modern optimization algorithms/methods that have been used on route optimization.

Nature has its own capabilities which seem to be optimized perhaps due to the evolutionary process. The continued existence of these successful natural processes alone proves their ability and the usefulness in optimizing. The robustness of these natural practices gears the scientists to think along the same line to solve difficult problems that cannot be solved otherwise. Nature-inspired algorithms are such algorithms which adopt these successful procedures in the natural world to solve difficult problems in many areas. They are capable of giving remarkably successful solutions where other methods fail. The swarm behavior of the natural world and Darwin's concept of the 'survival of the fittest' are the main inspirations for these nature-inspired algorithms. Swarm intelligence/evolutionary optimization algorithms have been widely used in the past decade for optimization tasks because of their remarkable performances [7–11]. Among the problems that they have dealt with, path optimization is one of the main problems.

Once an algorithm is applied on a path optimization problem, there are some other issues that has to be dealt by the researches. First thing is to find methods to evaluate the performances of the algorithm. Assessing the quality of an algorithm commonly implies experimental comparisons between the given algorithm and other suitable algorithms. Even if showing the superiority of some algorithm is not the main goal, parameter tuning for good performance still requires experimental work to compare different algorithm variants. Success rate, effectiveness (solution quality) and efficiency (speed) are some of the performance measures that can be used specially when it is about nature-inspired algorithms. The next issue is with the problem instances that are to be used to get the performances and compare the algorithms. Experimental comparisons between algorithms require a choice of benchmark problems and problem instances. By looking at the literature, they distinguish three different approaches.

- Use existing problem instances from benchmark repository (like a library).
- Use existing problem instances generated by a problem instance generator.
- Use real-life problem instances from real life problems.

From these, the most difficult measuring criteria is to use problems with problem instance generators. These problem instance generators can be very problem specific and can use different mechanisms to generate the problem instances.

In this study we reviewed the research articles from the year 2000 to date. The selected articles were categorized according to the routing problems such as Hose Pipe Routing, Traveling Salesman Problem, Wire Routing, Robotic Path Planning and Vehicle Routing. Under each routing problem we reviewed articles based on the routing algorithm and mentioned their features and limitations/weaknesses. Also, in this paper, we identify different mechanisms in problem generation. Specifically when it comes to route optimization, this can be stated as obstacle detection mechanisms used in different studies.

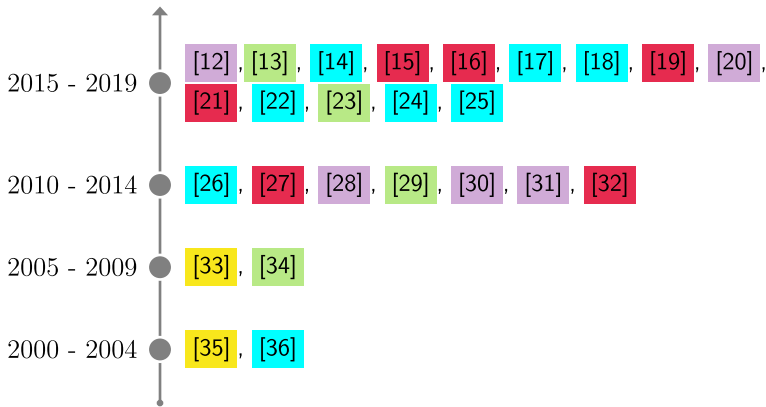


Fig. 1 Timeline of research where routing problems were used; Background colors represent different categories of problems: Hose/Pipe Routing, Traveling Salesman Problem, Wire Routing, Robotic Path Planning and Vehicle Routing

2.1 Summarized the literature according to the routing problems and routing algorithms

In Fig. 1 we summarize the studies according to the routing problems. The timeline of the literature summarized in this review is listed in Fig. 1.

According to Fig. 1, most of the recent research have been done based on vehicle routing problems. Also, there is an improvement of research studies in path optimization. Out of 25 research studies, 14 were done between 2015 to 2019.

Then we summarized the studies according to the routing algorithms. We consider three main nature-inspired meta-heuristic algorithms. Those are Evolutionary Algorithms, Swarm Intelligence Algorithms and Machine Learning algorithms. The timeline of the literature summarized in this review is listed in Fig. 2.

Figure 2 shows that machine learning algorithms are commonly used in recent studies. Out of 14 research studies 6 papers used machine learning algorithms to optimize their path planning.

In Sects. 2.2 to 2.6 we discuss the research studies done in various routing problems.

2.2 Hose/pipe routing

Hose routing is a technique of developing collision-free routes for hoses between starting and ending locations through an environment with obstacles. Hose routing needs to be done under multiple objectives and constraints. For example, in hose routing, selecting pre-specified catalog of angles for bends, keep away from collisions, and have minimum total length of the hoses and total number of bends is considered [1]. In this literature we found two research papers based on the Hose/Pipe Routing.

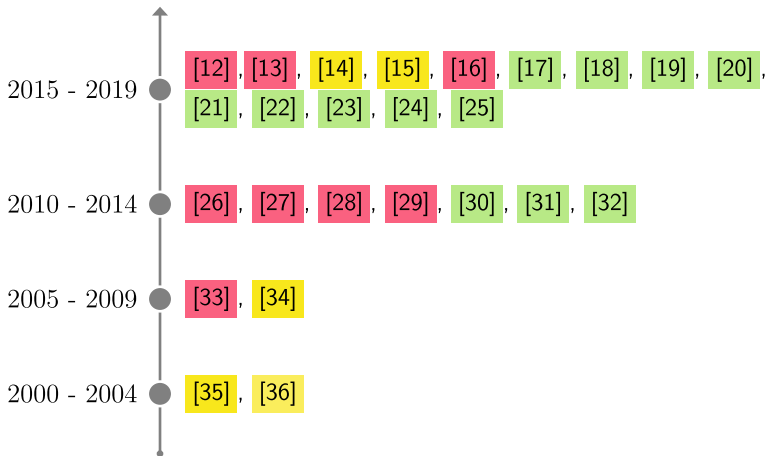


Fig. 2 Timeline of research where routing algorithms were used; Background colors represent different categories of algorithms: Evolutionary Algorithms, Swarm Intelligence Algorithms and Machine Learning Algorithms

Thantulage et al. [6] presented two ways of using the ant colony algorithm, called grid-based and random-based for automatic 3D hose routing which has some similarities to the TSP problem. To detect the obstacles this algorithm uses the tessellated format and to detect collision algorithm uses the RAPID library. According to this research, the accuracy of the collision detection depends on the number of triangles used to approximate the obstacles. The effectiveness of grid-based and random-based versions of the algorithm are demonstrated by simulation studies. Based on the simulation results shows that the proposed algorithm can handle complex environments and any shape that can be generated using any CAD software. The selection of the right resolution or the size of the grid plays an important role in the determination of the optimal path and affects the computational time. When the resolution increased, the algorithm requires higher amounts of memory and more time to compute the results. In the random-based version, the algorithm was able to find a reasonably good solution in a reasonable time for any of the tested models. At the starting stage, the researchers were implemented the algorithm only for optimizing the distance between the start and target points. The selection of pipe bends from a pre-specified catalogue of angles of bends, the minimizing of the cost of pipes, the avoidance of hot, sensitive and moving objects is going to consider in the next stage.

Genetic algorithm cannot be considered as a novice algorithm to solve pipe routing problems. The research carried out by Sunand Sandurkar and Wei Chen [35] proposed a nondeterministic optimization approach based on genetic algorithms to generate pipe routing solution sets with a good searching efficiency. According to their research, they found that representing the objects and pipes in the tessellated format gives huge benefits in the computation as well as in the usage. They demonstrated the versatility of the current approach and its ability to accommodate and efficiently solve problems involving 3D freeform obstacles. In this research they developed a versatile pipe route

Table 1 Summary of the literature, sorted according to the routing problem– Hose/pipe routing

Year	Title	Routing algorithm	Features	Weakness/limitations
2008	Grid based and random based ant colony algorithms for automatic hose routing in 3D space	Grid-based ant colony algorithm random based ant colony algorithm	Automatically detect obstacles using tessellated format use the RAPID library to detect collisions Used 3D models in grid-based version the resolution on the size of the grid plays an important role in the determination of the optimal path and affects the computational time. The advantage of using the random-based version is that it did not fail for any of the tested models and produced a reasonably good solution to the problem	In grid-based ant colony algorithm if resolution is increased, the algorithm requires higher amount of memory and more time to compute the results
2000	GAPRUS – Genetic algorithms based pipe routing using tessellated objects	Nondeterministic optimization approach based on genetic algorithms	Developed a versatile pipe route planning package called GAPRUS Automatically detect obstacles using Tessellated Format	

planning package called GAPRUS. By using GAPRUS package they generated the route of the optimal set of pipes between the specified points. When developing a pipe routing design system, researchers discussed two major issues. First one is they attempted to overcome the restrictions on representations of obstacles as free-form geometry. They made this effort because of the large computational overhead for checking the interference of obstacles. Using this method, any geometry that can be generated using commercial CAD modeling packages. Second issue is, they need to develop a method which has the same computational efficiency and sufficient accuracy at the same time. Currently this research considered simple cases of constraints and objectives but in future researchers were planned to focus on addressing more complex and realistic problems.

2.3 Traveling salesman problem

The Traveling Salesman Problem or TSP is an algorithmic problem tasked with finding the shortest route between a set of points and locations that must be visited. In the problem statement, the points are the cities a salesperson might visit. The salesman's goal is to keep both the travel costs and the distance traveled as low as possible. Following are the literature we found in our study based on the TSP.

The research done by Shoma Miki, Daisuke Yamamoto and Hiroyuki Ebara [20] focused on solving 2D Euclidean traveling salesman problem (TSP) using heuristics based on a convolutional neural network (CNN). The problem that is going to solve and the solution that the application gives are both in image format. The researchers applied reinforcement learning to the good-edge distribution. They evaluate the performances of their algorithms by conducting experiments. The suggested method get the suitable image of best tour as good-edge distribution using convolutional neural networks. According to the researchers, use of reinforcement learning to the solutions after applying the supervised learning will possibly improve the accuracy of the solution. The researchers claim the suitability of their method to solve problems with geometric spatial nature and encourage to use CNN for extracting features as images instead of 1-dimensional vectors.

Promising results have been obtained by a research carried out by Ariyasingha and Fernando [12] who proposed another extension to the ant colony algorithms to solve multi-objective optimization problems. They have proposed a random weight-based ant colony optimization (RWACO) for solving the traveling salesman problem. Two or more objective functions are optimized at the same time by this newly proposed algorithm. This new algorithm uses only one ant colony to optimize all objectives at the same time even though it is based on the ACS. Hence, this algorithm has the possibility of finding an outstanding set of pareto-optimal solutions. By using only one pheromone trail value in each construction step, all objectives can be emphasized differently as it aggregates randomly generated weights for each objective. According to the experimental results with other similar algorithms, RWACO algorithm performs well for the TSP in all objectives. According to the authors, the reasons for its better performance are that the RWACO algorithm aggregates heuristic information in the weighted sum approach and randomly generates weights for each iteration. Hence, it

covers most parts of the pareto-optimal front in each iteration. Apart from this research literature can be found on several multi-objective ant colony optimization (MOACO) algorithms which have been proposed to solve different optimization problems and particularly the traveling salesman problem [37–39].

Improving the cuckoo search (CS) through levy flights by applying an extension, Aziz Ouaraaba et al. [28] have reconstructed the population by introducing a new cuckoo category which is more intelligent. This is capable of solving symmetric traveling salesman problems. This discrete CS has been tested on forty one (41) benchmark TSP instances from the TSPLIB library which is publicly available. The comparisons were carried out with basic discrete CS and with some other recent modifications (GSA-ACS-PSOT) [40] and discrete particle swarm optimization (DPSO) [41]. The results indicate that the proposed discrete CS outperforms the other two methods in solving TSP. Levy flights were used to manage the intensification and diversification and the population structure was reconstructed with a variety of cuckoos. According to the authors, These major changes have improved the performances. As further experiments on the improved cuckoo algorithm, authors suggested testing it with combinatorial problems of routing and scheduling.

The aim of the study done by Maire and Mladenov [30] was to compare the quality of the solutions produced by the methods integer programming, Hopfield neural networks and Kohonen self-organizing maps and finding the exact parameters of these methods. They successfully implemented and tested these methods by using four traveling salesman problem (TSP) instances, containing 20, 40, 60, and 80 cities respectively. According to the results, the integer programming method is the best method. The integer programming method performs well because it finds the near optimal solution with a little effort using the mutual distances of the cities as an input. The performance of the Kohonen neural network was approximately closer to the performance of the integer programming method in terms of solution quality. The Kohonen neural network still needs some parameter tuning by the user. The performance of the Hopfield neural network is far behind compared to other two methods. This Hopfield neural network needs more work to tune the parameters. However, Hopfield neural network is implemented on hardware and that allows to solve the problem in much shorter time.

Ant system (Ant colony system (ACS) and neural network (Hopfield neural network) were compared and discussed by Abdel Moetty [31] for solving the traveling salesman problem (TSP). After studying the ant colony system (ACS) and Hopfield neural network, he designed an algorithm for solving the traveling salesman problem (TSP) using Hopfield neural network. He studied ACS by running experiments to understand its operation and also, he presented a proposed algorithm using a continuous hopfield neural network to solve the TSP problem. To enable the N neurons in the TSP network to compute a solution to the problem, the network must be described by an energy function in which the lowest energy state (the most stable state of the network) corresponds to the best path. By using the standard algorithm (ACS) with the proposed algorithm and applying both in a case study, which is showing that the approach of the Hopfield neural network is very fast compared to the standard algorithm and also archiving less or the same values of the shortest path. In Hopfield

network, he finds that it gives best solutions every time and show that as the number of cities increases the number of iteration-required increases.

2.4 Wire routing

In electronic design, wire routing, become increasingly complex in electrical wiring, engineers need to consider things like wire length, bending radius and routing [3]. Here we discussed four research studies based on wire routing.

Moving from TSPs to electrical wire routing, Pamarathne and Fernando [13] have presented a novel approach for electrical wire routes optimization using ant colony optimization algorithms. They considered start, intermediate and target points as points in a route. The study has forced on enhancing the multi-objective ant colony algorithms for electrical wire routing (MOACS-EWR) problem. When generating an optimized path to cover several points, they considered the length and the number of bends in a path. Avoiding obstacles and adhering to the wiring standards are the constraints considered when designing the algorithm. The two approaches were designed in this study. First approach is the multi-objective ant colony optimization algorithm (MCAS-MHR-1) and the second approach is multi-objective ant colony optimization algorithm with modified local pheromone updating rule (MCAS-MHR-2). These approaches were used to cover multiple points in electrical wire routing. When it is compared the performances, the two approaches worked successfully by giving good results, although the second method with the modified local pheromone updating rule performed better and faster than the first method. Extending the study, the researchers suggest to use the given algorithm to optimize electrical wire routes in an entire room. The simulations developed in this study direct the installation engineers to find the best layouts for electrical wiring.

Haiguang Liao et al. [23] used a deep reinforcement learning method to solve the global routing problem using a simulated environment. According to their study, the state space or the routing states and the action space or the routing decisions are considered as discrete and finite. Also, the researchers were saying that "The future routing state only depends on the current routing state and all state features are observable". By considering the above reason, the researchers modeled the problem as a markov decision process. To solve the global routing problem, the deep q-network (DQN) was chosen as the fundamental reinforcement learning algorithm. All the previous successful and unsuccessful net routing attempts was used to produce the 'Best' action for the dynamically evolving state of the routing. Another key contribution of this study is the development of a global routing problem sets generator. In this paper, researchers mentioned "The global routing problem sets generator have the capability to generate parameterized global routing problem sets with user-specified problem numbers, grid size, number of nets, number of pins in each net and capacity settings". The global routing problem sets generator allows to evaluate different routing algorithms. In addition to that it generates training datasets for future data-driven routing approaches. The generator follows the features of industrial global routing problems. This can be done by breaking the capacity settings. The researchers also stated that "The capacity settings were broken down into normal capacity and reduced capacity. The capacity of

Table 2 Summary of the literature, sorted according to the routing problem– Traveling salesman problem

Year	Title	Routing algorithm	Features	Weakness/limitations
2018	Applying deep learning and reinforcement learning to traveling salesman problem	Applying deep learning and reinforcement learning algorithm	Proposed algorithms use the CNN which approximates the image of optimal tour as good-edge distribution, and find a solution using good-edge values calculated from the distribution as an indication alternative to distances. Experiments with supervised learning confirmed that error ratios of solutions were improved in comparison with the conventional method	
2017	Random weight-based ant colony optimisation algorithm for the multi-objective optimisation problems	A Random weight-based ant colony optimization (RWACO)	By using this proposed a random weight-based ant colony optimization (RWACO) algorithm two or more objective functions optimizes at the same time.	Manually detect cities using TSPLIB
2014	Discrete cuckoo search algorithm for the traveling salesman problem	Discrete cuckoo search algorithm	The improved DCS algorithm is compared with some other recent methods (Genetic algorithm, Simulated annealing, Ant colony system with particle swarm optimisation techniques (GSA-ACS-PSOT) and Discrete Particle Swarm Optimisation (DPSO). The results of the tests show that DCS is superior to some other metaheuristics.	Manually detect cities using Electronic Library TSPLIB

Table 2 (continued)

Year	Title	Routing algorithm	Features	Weakness/limitations
2012	Comparison of neural networks for solving the traveling salesman problem	Integer programming method, Hopfield neural network and kohonen self organizing feature map neural network	According to the results, the integer programming method is the best method. The integer programming method performs well because it finds the near optimal solution with a little effort using the mutual distances of the cities as an input. The performance of the Kohonen neural network was approximately closer to the performance of the integer programming method in terms of solution quality. The performance of the Hopfield neural network is far behind compared to other two methods. This hopfield neural network need more work to tune the parameters.	Manually detect cities (Generated using MATLAB)
2010	Traveling salesman problem using neural network techniques	Hopfield neural network	By using the standard algorithm (ACS) with the proposed algorithm and applying both in a case study, which is showing that the approach of the Hopfield neural network is very fast compared to the standard algorithm and also archiving less or the same values of the shortest path	

edges on horizontal direction (x direction) for the first layer and vertical direction (y direction) on the second layer were determined by the normal capacity". According to the researchers, "The properties of global routing problems through capacity are set to be large enough in the simulated environment. Therefore, the overflow will not occur through direction (z direction)". Also, they described reduced capacity as "A set of specific edges in the problem to prescribe the capacity values". Reduced capacity are used in this study to generate the problem sets which are based on edge utilization conditions. They propose to train their model to generate a large number of problem sets automatically as their future works. Finally they emphasize that "This will help to scale the proposed system to larger grids with more complex net configurations and also it can increase the model's generalization ability to solve unseen problems".

Prior algorithm which has been implemented based on the particle swarm optimization (PSO) has been improved by Zulkifli Md Yusof et al. [29]. They have engaged with VLSI circuits to solve the routing problems. In this study they proposed a two-step binary particle swarm optimization (BPSO) approach. The attempt was to find a more suitable path to do a wire placement with buffer insertion from source to sink. The two steps were divided as from the first model the best wire placement plan was to identified and the second one was to give the best location of buffer insertion along the wire. The time delay formulated based on the iterative RLC delay model is used as the fitness function for the second BPSO. The performance of the proposed model is measured by doing a case study. The researchers compared the results of the case study with the previous PSO approaches for VLSI routing. Choosing the path and intelligently placing the buffers at the right location, are used to find minimum time delay. This is the objective of this study. The results of the case study express that the proposed approach has a potential for further extension. Extension can be done by considering more, including more objectives like power dissipation and noise.

The research done by Xuan Ma et al. [34] have proposed a two-level genetic algorithm (GA). They used this two-level chromosome coding to address the issues in cable route optimization. In this study, route search GA and a route combination GA are two types of genetic algorithms which combine hierarchically. The first-level GA finds several optimal solutions for each cable while the second-level GA searches for an optimal combination of the routes for all the cables. The cable routes represent the genes in the first level and the cable combinations represent the genes in the second level. In the first-level GA, an order list of the label for the node used for the route representation of the chromosomes. The list representation requires genetic manipulation of the chromosomes. To improve the efficiency of the route search, block crossover and block mutation are used as genetic operations. Routes are combined optimally in the second-level GA. The second-level GA may form, chromosomes which are not satisfying the constraints for the wiring tray. Those chromosomes are referred to as lethal genes. From the next generation, the algorithm is supposed to eliminate these lethal genes. But some good genes can also be in the lethal genes. To take the benefit of having good genes as in the lethal genes, authors use an evaluation method. In this study, authors were confirmed that for route searches the effective method is block crossover and block mutation. They used computer simulation for these experiments. Also, researchers confirmed the proposed GA functions can be used to address the problem of cable route optimization effectively.

Table 3 Summary of the literature, sorted according to the routing problem— Wire routing

Year	Title	Routing algorithm	Features	Weakness/limitations
2019	Optimizing the electrical wire routing through multiple points using multi-objective ant colony algorithms for electrical wire routing (MOACS-EWR)	Multi-objective ant colony algorithms	The two approaches were designed in this study. First approach is the multi-objective ant colony optimization algorithm (MCAS-MHR-1) and the second is multi-objective ant colony optimization algorithm with modified local pheromone updating rule (MCAS-MHR-2). Second method with the modified local pheromone updating rule performed better and faster than the first method	Manually detect obstacles
2019	A Deep reinforcement learning approach for global routing	A deep reinforcement learning	A properly trained q-network within the DQN formulation, researchers considered that the nets and the pins to be conjointly routed. Propose to train the model to generate large number of problems sets automatically as their future works	
2011	A two-step binary particle swarm optimization approach for routing in VLSI with iterative RLC delay model	A two-step binary particle swarm optimization approach	The performance of the proposed model measured by doing a case study. Researchers were compared the result of the case study with the previous PSO approach for VLSI routing. The results of the case study express that the proposed approach has a potential for further extension. Extension can be done by considering more including more objectives like power dissipation and noise	Manually detect obstacles

Table 3 (continued)

Year	Title	Routing algorithm	Features	Weakness/limitations
2006	A genetic algorithm for the optimization of cable routing	Genetic algorithm	<p>Route search GA and a route combination GA are two types of genetic algorithms used in this study. Authors confirmed that for route searches the effective method is block crossover and block mutation.</p> <p>Researchers confirmed the proposed GA functions can be used to address the problem of cable route optimization effectively.</p>	Manually detect obstacles using Tray graph models

2.5 Robotic path planing

Robotic Path planning is one of the most studied problems in the field of robotics. The main aim of robot navigation is to find a safe and efficient optimal route that is smooth and safe in the environment it navigates. [6]. In the literature, we studied six research papers based on robot path planing.

Hyansu Bae and others have been engaged in a research to figure out the possibility of using deep q learning to a multi-robot path planning algorithm. The proposed algorithm was combined with convolutional neural network (CNN) algorithm. Exact situation of the environment may analyze using image. This may be done using CNN. Then the robot navigation based on the situation may analyzed through deep q learning. In this study, they mentioned, existing path planning algorithms are highly depending on the environment. The proposed algorithm used an A* algorithm but this A* algorithm could not be used in a dynamic environment as a comparison algorithm. Regardless of the state of the environment; static or dynamic the proposed algorithm can be applied. The learning process was slow at the beginning as they said. The algorithm also used the popular A* algorithm for the real robots. A* gave the priority to the minimum distance than the searching time. The search area of each of those robots were similar to A* based learning under the given approach. Based on the simulation results, the proposed algorithm shows the flexible and efficient movement of the robots comparing with conventional methods under various environments [19].

Obstacle avoidance algorithm that takes the advantage of the genetic algorithm in path finding is presented in a research carried out by Kwaniewski and Gosiewski [15]. It is based on a 2D map which is built by a robot. and A 2nd degree B-spline is used for the path model. The performance of the method for most of the instances was high under one processor thread. The paper shows the results of the simulation tests. The 2D maps have various complexity levels. On every map, one hundred tests were carried out. According to the results, the algorithm was able to take the robot to the point in the majority of runs under the described termination conditions. The main disadvantage of the proposed method is its complexity. It makes the implementation quite difficult since there are two algorithms t; one is GA and the other one is the higher-level decision part. Implementation of the algorithm on mobile robots and testing of it in the real environment and finding paths in 3D maps are the further developments in this research as they stated in the paper.

Harshal S. Dewanga and others [16] used adaptive particle swarm optimization (APSO), to solve the mobile robot path planning problem. Real time path planning problems were easily solvable using the APSO than the canonical PSO algorithm.. The distances between robot to goal and robot to obstacles have been optimized to get a solution of the path planning of the robot. The capability of the proposed algorithm was examined by using different simulated experiments. The proposed APSO algorithm has been compared with the conventional PSO based on path length and time in static environments. The following conclusions were made on this research:

- The distance between robot to obstacle and robot to goal were used to construct the new objective function. Using adaptive PSO algorithm the researchers optimized the objective function to get the solution.

- The exploration and exploitation rates of the proposed APSO algorithm are more efficient than conventional PSO. Also, the proposed APSO algorithm handled the local minimal situations correctly.
- Using different environmental situations, the simulation experiment was carried out for the proposed APSO. The capability of the robot to avoid the obstacle and trails the target path were identified by the researchers.
- The duration and the length of the path traveled by the robot to reach the goal with different types of environmental simulations are used to compare the conventional PSO with proposed APSO. Using the proposed APSO algorithm, the robot can effectively perform the navigation process with a shorter path and a minimum time than conventional PSO.

The researchers were considered to find path planning algorithms for more complex environments and also deploy multiple robots than single mobile robots as future developments in the research.

Study of the navigation of humanoid robot called NAO, was done by Rahib H. Abiyev et al. [21] This research focused on a vision-based obstacle detection method to detect obstacles and path finding algorithms for a mobile robot. Support vector machines (SVM) were used to find a solution. They classify the image into areas with obstacles and without obstacles. To train the SVM, image histograms were used as inputs. The algorithm recognizes the images with obstacles from the other images. After recognizing areas with or without obstacles they create a binary matrix. A* search algorithm was employed to find the possible shortest path. The mobile robot is also capable of finding the new obstacles.. Finally, the robot follows the path that is found to be effective. As further enhancements, the study is focused on modifying the system to work on dynamic environments.

Three-dimensional vector field histogram (3DVFH+) algorithm is proposed by Simon Vanneste and others [32]. The algorithm is used to avoid real-time three-dimensional obstacles. This algorithm generates a robot motion to avoid obstacles in 3D. The 3DVFH+ algorithm is based on the two-dimensional vector field histogram (2DVFH+). The algorithm generates a 2D polar histogram using the octomap and it will be used to generate a robot motion. According to the results, robot is able to avoid 3D obstacles in real-time by taking obstacles that are closely located to the robot. The designed algorithm is capable of finding multiple paths, using this 2D binary polar histogram. The algorithm determines the path with the lowest path weight. To calculate the motion for the robot, the generated path will be used. A new robot motion is able to calculate by 3DVFH+ with an average time of 300 microseconds. The robot's size, robot's speed, octomap's resolution and multiple levels of thresholds are the factors used for the prior configurations. The researchers going to automate this process as future work.

The application of the ant colony optimization algorithms for robot path planning is studied by Michael Brand and others [27]. Researchers applied an ant colony optimization (ACO) algorithm to find the shortest and collision free route in a grid network for robot path planning. They considered obstacles with various shapes and sizes when simulating the dynamic environment. Two re-initialization schemes were

Table 4 Summary of the literature, sorted according to the routing problem– Robotic path planing

Year	Title	Routing algorithm	Features	Weakness/limitations
2019	Multi-robot path planning method using reinforcement learning	Deep reinforcement learning	Based on the simulation results, the proposed algorithm shows the flexible and efficient movement of the robots comparing with conventional methods under various environments	
2018	Genetic algorithm for mobile robot route planning with obstacle avoidance	Genetic algorithm	The performance of the method for most of the instances were high under one processor thread. Automatically detect obstacles using 2nd degree B-spline	The main disadvantage of the proposed method is its complexity
2018	A robust path planning for mobile robot using smart particle swarm optimization	Adaptive particle swarm optimization	The exploration and exploitation rate of the proposed APSO algorithm are more efficient than conventional PSO. Also, the proposed APSO algorithm handled the local minimal situations correctly Using proposed APSO robot can effectively perform navigation process with shortest path and time than conventional PSO. This may be justified by using simulated results	
2017	Robot pathfinding using vision based obstacle detection	Support vector machine and A*	Automatically detect obstacles using vision-based algorithms	

Table 4 (continued)

Year	Title	Routing algorithm	Features	Weakness/limitations
2014	3DVFH+: real-time three dimensional obstacle avoidance using an octomap	Three dimensional vector field histogram algorithm.	The algorithm will find multiple paths, using this 2D binary polar histogram. The algorithm will determine the path with the lowest path weight Automatically detect obstacles	
2010	Ant colony optimization algorithm for robot path planning	Ant colony optimization algorithm	Computer simulation results demonstrate that the ACO algorithm can successfully re-route the optimal path for the new network after obstacles are added	

discussed and compared for local and global pheromone initializations y . They considered investigation on different ACO algorithms with the proposed re-initializations, like the elitist ant system (EAS), the rank-based ant system, and the max-min ant system (MMAS) as their future works.

2.6 Vehicle routing

The vehicle routing problem (VRP) is a combinatorial optimization that involves finding an optimal design of routes traveled by a fleet of vehicles to serve a set of customers. In the traditional VRP, we try to detect routes for a homogeneous fleet of vehicles to satisfy the customers' demands. According to our study, most of the research studies done under vehicle routing.

Reinforcement learning solver addressing the vehicle routing problem (RL SolVeR Pro) was implemented by Arun Kumar Kalakanti and others [18] to get the optimal route using markov decision processes (MDP). Geometric clustering and route learning are the two phases in this RL SolVeR Pro model. Effectiveness and applicability of the proposed RL SolVeR Pro validate under various conditions and constraints. Different customer environments such as CType (Clustered Customers), R-type (Uniformly Distributed Customers) and RC-type (a mix of R and C types) and different problem sizes (200, 400, 600, 800 and 1000 customers) and stochastic elements (stochastic demand and stochastic travel time) are the conditions that were considered. The capacity of vehicles, operation time for each vehicle, single depot and single kind of vehicle

are the constraints considered. Clarke-wright savings and sweep heuristic models were used to compare the proposed model. The results indicate better performance of RL in deterministic and stochastic travel time settings respectively. The researchers plan to explore generalization of the solver to different stochastic travel time settings and evaluate the solver in dynamic environments as the future works.

Perception, Planning and Control are the key phases for the conception of an autonomous vehicle. Basically, environment modeling and localization used to compose perception. The aim of the planning is to generate an optimal route. This is based on the results of the perception step and used to set foot on a specified destination. At last, the control module is keen to follow the route that is generated. This is done by commanding the vehicle's actuators. Each component of the process discussed in a study done by Hind Laghmara and others [24] for obstacle avoidance. The main consideration was to combine the above tasks in a global architecture. A description of the environment assured by the perception module. The occupancy grid maps (OGM) is used for obstacle avoidance. This is also used to locate static and dynamic objects in the scene. The positions of the avoidable objects are used at the path planning level. A parameterized sigmoid function and a rolling horizon are used to generate a route and a speed profile. The reference path for the guidance control module is obtained from the curvature profile. A lateral guidance controller used to provide the appropriate steering angle to the vehicle. By using the center of percussion (CoP) as an alternative to the classic center of gravity. A feed-forward and a robust state-feedback actions are used to generate the proposed controller. The controller they proposed minimizes the effect of the disturbance on the lateral error and it is also used to reduce the guarantee of lateral stability. The outcome of the research is a successful obstacle avoidance.. The consideration of a positioning strategy is one of their future work and also, they consider the evaluation of the approach in more complex scenarios.

Obstacle detection and tracking is a vital component of autonomous vehicle environment perception. Also, it is considered as the base of the path planning and decision making of autonomous vehicles. The researchers, currently studying obstacle detection and tracking, mainly focus on computer vision and LiDAR. The computer vision-based approach is very sensitive to light but when the light is weak, poor detection and tracking may happen. The detection and tracking of autonomous vehicles may normally use LiDAR. The basic shape, distance measurement and position of the obstacle can be obtained by using the unusual ability of LiDAR. Based on these concepts, Desheng Xie et al. [25] proposed a new approach to improve static/moving obstacle detection and tracking. Initially, road point-cloud data are removed from the point-cloud data of one frame and the reuse of useful non-obstacle cells is carried out. In the process of obstacle detection, first they detect static obstacles by multi-frame and then it detects moving obstacles. The proposed dynamic tracking point model and the Kalman filter algorithm were applied to track the moving obstacles. The performances in the scenarios show that the proposed approach has high reliability.

Machine learning algorithms were also used and were successful in providing promising solutions to path optimization problems. Mohammadreza Nazari and others [17] generalized the work done by Bello et al. [42]. A framework presented by Bello et al. is used to handle combinatorial optimization problems using neural networks and reinforcement learning. This research work focused on the traveling salesman prob-

lem (TSP). Researchers trained a recurrent network by using a set of city coordinates and predicted a distribution over different city permutation. This approach assumes the system is static over time. This is a major issue and to overcome this Moham- madreza Nazari et al. proposed a new way. This approach is simpler than the pointer network approach and can efficiently handle both the static and dynamic elements of the system. The model proposed by them consists of a recurrent neural network (RNN) decoder. The input to the RNN decoder is the embeddings of the static elements. The output of the RNN and the dynamic element embeddings are fed into an attention mechanism used to form a distribution over the feasible destinations. This is chosen as the next decision point. The proposed framework can be applied as a self- driven learning procedure which requires the reward calculation. This has done using the generated outputs. Explicit distance matrix is not required in this proposed framework but one feed-forward pass of the network will update the routes based on the new data. According to the numerical experiments done by researchers, the performance of the proposed framework is considerably better than well-known classical heuristics. The method was compared with OR-tools and identified that VRP engine is one of the best open-source VRP solvers. With the proposed method, roughly 61% of the instances provide shorter tours. This was achieved by considering VRP instances with 50 and 100 customers. To supply the demand of a single node, multiple vehicles allowed by the RL-based framework is proposed in this study. They achieved this split delivery without any engineering and without any extra cost. This paper also explain how the proposed RL-based method can be applied to a more complicated stochastic version of the VRP.

In another study conducted by Mazin Abed Mohammed and others [14] attempted to find an optimal path for vehicle routing problem (VRP). They develop this solution using genetic algorithms to optimize the University Tenaga Nasional (UNITEN) shuttle service. In the way of finding the optimal solution, the researcher mainly considered factors such as reducing the time consumption, transportation cost and the distance of all paths. The study has been carried out in two phases. In the first phase, the shortest route for the VRP is found. This helps reduce the university students' transportation cost and a genetic algorithm has been applied to complete the first phase of the study. In the second phase, a CVRP model is identified to optimize the UNITEN shuttle bus services. They found that the proportion of reduction of distance of each route is relatively low, however the savings of the total distance traveled by buses become greater on a daily or monthly basis.

A vision-based obstacle avoidance approach was described in the research done by Joel O. Gaya and others [22]. They have conducted the study for autonomous underwater vehicles (AUVs) equipped with simple colored monocular cameras. They used a deep neural network for each input image to compute a transmission map that can be understood as a relative depth map. By using the underwater image, the depth of objects can identify the relation between medium effects and depth which helps to estimate a relative depth map.. The most appropriate region of interest (RoI) and the direction of escape can be identified using this map. The highest distance in an area can be determined by using this direction. The robot's dimensions and camera characteristics are also used for highest distance mean calculation. To estimate a transmission map on underwater images, the researchers proposed a new convolution

neural network (CNN). Two underwater video sequences were used for the evaluation of the study. According to the results of the evaluation, the approach presented in this study was able to find RoI successfully by avoiding coral reefs, fish, the sea-floor and any other object present in the scene. They plan to test their model in real-time with the underwater vehicle autonomously navigating as future work. Also, researchers are developing an end-to-end convolutional neural network to learn the whole process. The network will process an image and provide direct pulse-width modulation (PWM) controls to the vehicle without the requirement of the intermediate procedures.

Vehicle routing is also an optimization problem which is much similar to the TSPs but can be considered as a more generalized version of the TSP. It is a combinatorial optimization and integer programming problem which asks "What is the optimal set of routes for a fleet of vehicles to traverse in order to deliver to a given set of customers?". As a good solution with the base of the ant algorithms, The new pheromone deposition scheme is proposed by Srinjoy Ganguly and Swagatam Das [26]. According to them the pheromone concentration grows exponentially with time. Routes can be formed by integrating the global feature and the local feature and those formed routes may facilitate faster convergence. Another proposal in this research is a novel sequential constructive local search heuristic with greedy traits. To find better solutions, this new method set as the local search operator. A new two-way mutation scheme is formed by using Inter-route mutation and Intra-route mutation. This scheme may ensure that sufficient diversity is maintained throughout computation. This is another innovation in this research. Researchers tried to incorporate a pheromone deposition scheme, a local search scheme and a mutation scheme as new extensions to the standard ACO. The proposed ACO_PLM algorithm was compared with the improved ACO (IACO) as proposed by Bin et al. [43], the Improved Genetic Algorithm(IGA) for the VRP proposed by Honglin and Jijun [44] and the parallel tabu search algorithm (RR-PTS) by Rego and Roucairol [45]. This comparison tested on twelve benchmark instances and showed the ACO_PLM provides better results compared to other algorithms. Even though the proposed ACO_PLM is an efficient general combinatorial optimizer it cannot be used to solve the VRP efficiently.

To find paths and to have proper navigation, a vision-based method was presented by Muhammad Farooq Azam Khan and Sikander Hayat Khiyal [36]. By avoiding the use of exact camera calibration, this method is able to avoid obstacle and self-localization. In this system, two digital cameras were mounted. One was set on to the top of a vehicle which was operated remotely. The other one is mounted on an ordinary personal computer. This makes to implement and test the system. For navigation and obstacle detection, they have set one camera to face in front of the vehicle. Then for orientation and localization purpose, the other one is facing near the wall. According to this research, relative size and pixel intensity of the obstacles consider for detection process. The dimensions of the "obstacle-to-see" used to find the obstacles with greater pixel size. Then the obstacles with zero-pixel intensity and the dimensions of the group of adjacent pixels which are having the zero-pixel intensity were counted. This group of pixels are considered to be part of an obstacle if it is exceeding the pre-set obstacle dimension value. According to this method, regions within the critical area are classified as obstacles. Find out correct dimensions is considered as the first step, if an obstacle is detected in a frame of video stream. The correct dimensions of the

Table 5 Summary of the literature, sorted according to the routing problem–Vehicle routing

Year	Title	Routing algorithm	Features	Weakness/limitations
2019	RL SolVeR Pro: reinforcement learning for solving vehicle routing problem	Deep reinforcement learning	The results of this study show the better or equivalent performance of RL in deterministic and stochastic travel time setting respectively. The researchers in this study plan to explore generalization of the solver to different stochastic travel time setting and also the evaluation of the solver in dynamic environments for future work	Manually detect obstacles using “Extended SOLOMON” benchmarking dataset
2019	Obstacle avoidance, path planning and control for autonomous vehicles	Sigmoid function	Automatically detect obstacles using Occupancy Grid Maps (OGM)	
2019	Obstacle detection and tracking method for autonomous vehicle based on three-dimensional LiDAR	Deep learning	Automatically detect obstacles using computer vision and light detection and ranging	
2018	Reinforcement learning for solving the vehicle routing problem	Deep reinforcement learning	According to the numerical experiments done by researchers, the performance of the proposed framework considerably better than well-known classical heuristics which was design for the VRP	

Table 5 (continued)

Year	Title	Routing algorithm	Features	Weakness/limitations
2017	Solving vehicle routing problem by using improved genetic algorithm for optimal solution	Genetic algorithm	Researchers were found that the proportion of reduction of distance of each route is relatively low	
2016	Vision-based obstacle avoidance using deep learning	Deep neural network	According to the results of the evaluation, the approach presented in this study was able find RoI successfully by avoiding obstacles in the scene. They plan to test their model in real-time with the underwater vehicle autonomously navigating as future work	
2013	A novel ant colony optimization algorithm for the vehicle routing problem	A novel ant colony optimization algorithm abbreviated as ACO_PLM	The ACO_PLM provides better results compared to other heuristics. (Algorithm tested on the twelve benchmark instances.)	
2004	Obstacle avoidance and self-localization system for autonomous vehicles	Not mentioned	Automatically detect obstacles using Vision-based obstacle detection	

obstacle may go to find by this system in order to locate an obstacle. The dimensions of the obstacle are used to store the left and right pixel coordinates of the obstacle in each row of image frame. The system moves left and right one pixel at a time from left-most and right-most detected obstacle coordinates are used to select suitable intensity threshold. The intensity difference is calculated at each pixel. This is used to find whether the difference is greater than the threshold. The previous pixel coordinates

are stored as the extreme obstacle coordinates, when the intensity difference is greater than the threshold value. This task is carried out for each row containing the obstacle. For safe navigation around the obstacle, the correct obstacle dimensions are required. Once an obstacle has been detected, it is tracked from one frame to the next as long as it is visible. They have tested the proposed method using remotely operated toy cars where ordinary digital cameras were mounted on top of each. According to the results obtained, the system is successfully navigated around the different obstacles and identify the path correctly.

3 Discussion and conclusions

The literature discussed in this paper categorized path optimization problems into five categories as Hose/Pipe Routing, Travel Salesman Problem, Wire Routing, Robotic Path Planning and Vehicle Routing. Based on the Fig. 1, the literature summarizes that, most of the recent path optimization problems were discussed under Vehicle Routing. Also, most of the routing problems were trying to optimize the routes using Machine Learning algorithms showed in Fig. 2. Further we can state that most of the researchers moved on to automatically generate test cases to evaluate the performance of the algorithm.

According to the Figs. 1 and 2 there is an improvement in research studies done in the area of path optimization. Most of the recent studies based on vehicle routing problems and also, machine learning algorithms commonly used to solved the optimization problems.

Table 1 summarizes the studies done in the Hose/Pipe Routing. No recent studies done based on this routing problem. Two research studies were found in the year of 2006 and 2000. In these two studies researchers were automatically generated test cases to evaluate the performance.

Table 2 summarizes the studies done under the Traveling Salesman Problem. Five re- search articles found within the selected time period. In the recent studies deep learning algorithms were frequently used to solve the optimization problem. Many studies conducted in this routing problem area generate test cases manually. Studies done under wire routing problems were summarized in Table 3. We found four different methods used to solve the path optimization. Under this routing problem three research studies done test case generation manually and the other article considered this automatically generating test cases as their further works. Table 4 summarized the new routing problem area called Robotic Path Planning. Deep Reinforcement Learning, Genetic Algorithm, Adaptive Particle Swarm Optimization, Support Vector Machine and A* algorithms, Three Dimensional Vector Field Histogram algorithm and Ant Colony Optimization Algorithm are the algorithms which is used for path optimization were discussed. Out of five research articles three articles were automatically generate test cases. The research found under the Vehicle Routing problem summarized in Table 5. Deep Learning algorithms were commonly used by the researchers. Some of the researchers automatically generate their test cases and some have done it manually. In the context of optimization, the ant colony algorithms and deep learning algorithms have achieved a remarkable place in route optimization since it has

originally formed to solve path optimization problems. But in the recent literature the researches conducted on route optimization based on other natural algorithms are not less.

Because of the increasing complexity of the real world problems, optimal path finding is one of the most discussed topics in the context of optimization and hence significant amounts of research have been carried out in finding different mechanisms to achieve most promising paths to a given problem. This paper attempted to provide an overall picture of the state-of-the-art research on and with different optimization mechanisms used in solving different route optimization problems. Twenty five papers were selected and starting with a comprehensive introduction to the topic we discussed the modern algorithms that have been used on route optimization and then different problem generation mechanisms used in several research carried out on path optimization. The content of the paper indicates the fact that path optimization has been considered as one of the main optimization problems and many solutions were provided, but still there is enough room for more research on finding mechanisms on problem generation / free point generation which can be considered as a major contribution to the field of route optimization.

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