Journal of Engineering Research and Reports

Volume 26, Issue 7, Page 57-63, 2024; Article no.JERR.118284
ISSN: 2582-2926

Research on Lifting Path Planning Algorithms for Intelligent Cranes

Guoxiang Yu [a] and Shoubo Wang [a*]

[a] *North China University of Water Resources and Electric Power, Zhengzhou, Henan, China.*

Authors' contributions

This work was carried out in between both all authors. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jerr/2024/v26i71193

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/118284

Method Article

Received: 04/04/2024
Accepted: 06/06/2024
Published: 11/06/2024

ABSTRACT

Path planning algorithm is one of the key technologies in the study of intelligent cranes, and a good path planning algorithm can quickly plan a safe and collision-free path. The current research status of path planning technology in the field of crane lifting path planning is reviewed. The implementation principles of various types of algorithms are analysed, and the current research status of mainstream path planning algorithms is summarized. According to the characteristics of crane path planning algorithms, crane path planning algorithms are classified into traditional path planning algorithms, intelligent path planning algorithms and deep reinforcement learning algorithms. For each type of algorithm is analysed and summarized, and the development of crane path planning algorithms is looked forward to, hoping to provide reference for related research.

Keywords: Intelligent crane; route planning; traditional algorithm; intelligent algorithm.

1. INTRODUCTION

As the most common lifting equipment in modern production, cranes are widely used in machinery and equipment manufacturing, port terminals, nuclear power construction and other fields. It can help people to greatly improve the efficiency of work, is the most widely used and the largest number of a lifting machine [1]. However, there are some problems in the process of its use, one

**Corresponding author: Email: 2483405836@qq.com;*

Cite as: *Yu, Guoxiang, and Shoubo Wang. 2024. "Research on Lifting Path Planning Algorithms for Intelligent Cranes". Journal of Engineering Research and Reports 26 (7):57-63. https://doi.org/10.9734/jerr/2024/v26i71193.*

is due to improper manual operation can easily lead to safety accidents; the second is in some unsuitable for people to enter the harsh environment affecting the health of personnel. Crane intelligence can effectively solve such problems, but also its future development direction [2]. Path planning technology is an important part of crane intelligence, through the path planning can make the crane effectively avoid obstacles, in order to ensure that no collision under the premise of finding the optimal path between the starting position and the target position [3]. In recent years, more and more researchers combined with the actual working conditions of the crane, using a variety of algorithms to study it. various algorithms to study it. Commonly used algorithms include traditional path planning algorithms, intelligent optimisation algorithms, and deep learning algorithms.

In this paper, firstly, the commonly used crane path planning algorithms are summarised and classified, secondly, the algorithm application methods in the path planning process are analysed, and finally, by comparing the advantages and disadvantages of various types of algorithms, the development of crane path planning algorithms is outlooked from the crane application scenarios.

2. TRADITIONAL PATH PLANNING ALGORITHMS

Traditional planning algorithms require an accurate modelled description of obstacles within a structured environment. This type of algorithm relies on a display representation of the environment.

2.1 A*Algorithmus

In 1968 the A* algorithm was co-published by Peter Hart et al. of the Stanford Research Institute and is a commonly used path finding and graph search algorithm. It guides the operation of the algorithm through heuristic functions, and the A* algorithm introduces the cost function on the basis of Dijkstra's algorithm and serves as an evaluation index. The cost function is as follows:

$$f(n) = g(n) + h(n)$$

where: f(n) represents the generation value of the current node n, which is the cost function;
g(n) denotes the current generation value from the start point to the current node n;
h(n) represents the estimated generation value from the current node n to the target point, which is a heuristic function.

A* algorithm is widely used in global path search, but in the face of complex environments often produce too many corners and long search time, low planning efficiency. Li et al. [4] for the anti-rocking crane operating characteristics of the A* algorithm to improve, proposed to find the path of the corner and judge whether it can be deleted, will be optimised for two paths into a section, after three times to improve the optimisation, can effectively reduce the number of corners, reduce the number of starts and stops of the bridge crane, and greatly improve the efficiency of the crane operation. Sun et al. [5] The grid method modeling based on two-layer security is proposed, and the dynamic trade-off coefficient is introduced to improve the heuristic function, as well as the path node optimization strategy. Not only does A* ensure the safety of the algorithm, but also improves the search efficiency, shortens the length of the path and the number of corners, for global path planning in practice does not have real-time obstacle avoidance ability, the DWA algorithm and the improved A* algorithm to integrate, to ensure that the bridge crane for real-time obstacle avoidance, enhance the bridge crane in the complex working environment of the adaptive capacity. Sun Lu et al. [6] The heuristic evaluation function of the A* algorithm is improved by adding a node steering cost function, which aims to enable the algorithm to plan fewer steering nodes at the appropriate expense of the selection of shorter paths, thus reducing the number of crane starts and stops. Geng et al. [7] The two-way A* algorithm can be used to improve the search efficiency, and the weight of the evaluation function can be adjusted by changing the obstacle occupancy rate, thus making the searched path more effective in avoiding obstacles.

The improvement of the A* algorithm mainly solves the problems of the algorithm in search speed and target accessibility in complex environments, and combines with the actual work of the crane to improve the practical application of the A* algorithm in path planning.

2.2 Artificial Potential field Algorithm

The artificial potential field method was proposed by Dr Khatib in 1986, which is a virtual force method, and its main idea is to imagine the control object as a force body, by constructing the gravitational field and repulsive field that play a common role around the target position and obstacles, so that the force body can move freely under the influence of the force field in the environment, and finally reach the target point. Its principle is simple and path smoothing is widely used in robot path planning.

The traditional artificial potential field algorithm is easy to fall into the local minima, has the target unreachable problem, and is prone to the phenomena such as path jitter in the narrow region. In response to the problem of intelligences falling into local minima, Li et al. [8], in order to solve the target unreachable defects and weaken the motion tendency of the hook deviating from the target point due to the distance between the obstacle and the target point is too close, in the obstacle repulsive force to add a direction by the hook pointing to the target point sub-repulsive force, overcoming the problem of the target unreachable defects. Li et al. [9] also for such problems, put forward the method of two-layer artificial potential field, in the construction of the repulsive potential field function to join the method about the distance between the weight and the target position, by analysing the repulsive force generated by the two-layer artificial potential field, and get the relationship equation of the relevant parameters, through the MATLAB simulation to verify the effectiveness of this method.

By optimising the repulsive field function and other methods, the artificial potential field algorithm effectively solves the problems of easily falling into local minima and target unreachability near obstacles, improves the robot's obstacle avoidance rate, and guarantees the algorithm's target reachability in path planning.

3. INTELLIGENT PATH PLANNING ALGORITHM

Intelligent algorithms are capable of learning and adapting to the environment, and are able to acquire new information to optimise paths during planning.

3.1 Ant Colony Algorithm

The Ant Colony algorithm is an algorithm inspired by the be haviour of ants foraging for food in nature, and relies on the fact that ants secrete something called pheromones as they forage for food. The ants will leave pheromone residues on the paths they have already travelled, and the more ants that have travelled, the more pheromone will be left behind. Such a positive feedback mechanism causes the ants to forage according to the paths with high pheromone, so that the optimal path is selected.

Qu et al [10] through the study of robotics and bridge cranes combined with their own motion characteristics, proposed bridge crane intelligent operation control system composition scheme and path planning algorithm. And the use of ant colony algorithm in the MATLAB simulation environment to establish the working environment of the crane lifting objects, in the obstacle irregularities and special requirements of the path planning, are able to ensure that the bridge crane to get the optimised path. Chen et al. [11] established the steel coil warehouse three environment model, the use of ant colony algorithm for lifting multi-programme path planning, through the effective evaluation of the path planning method proved the effective line and feasibility. Li et al. [12] By analysing the difference and connection between bridge crane lifting path planning and robot path, considering the operating characteristics of the crane and the swinging problem of the heavy load in the lifting process, they improved the heuristic function of the ant colony algorithm, the adaptive hair coefficient, and the cost function, etc. The number of inflection points of the path is integrated with the distance to the path. The number of inflection points of the path is integrated into the distance heuristic function to effectively reduce crane braking. Adaptive volatile coefficients are used so that the crane can still quickly find the optimal planning path when dealing with more obstacles. Zhou et al. [13] For the ant colony algorithm convergence speed is slow, easy to fall into the shortcomings of the local optimum. Drawing on the idea of A* algorithm, they constructed an adaptive heuristic function of the ant colony algorithm, and related to the "survival of the strongest" updating mechanism in the wolf pack algorithm, they improved the updating method of the ant colony, increased the amount of pheromone on the locally optimal paths, and reduced the amount of pheromone on the locally worst paths. The results show that the algorithm can effectively improve the convergence speed and avoid falling into the local optimum.

The ant colony algorithm improves the heuristic function, pheromone update mechanism. By combining with other algorithms, it better solves the locking phenomenon, slow convergence speed and local extreme value problems that exist when the algorithm is used for path planning in the real environment, which makes the algorithm much more trustworthy.

3.2 Genetic Algorithms

Genetic algorithm is a global optimisation algorithm that mimics the natural selection and genetic variation of organisms in the process of reproducing their offspring. In 1962, genetic algorithm was proposed by John Holland, which mainly consists of the process of path encoding and constructing fitness function. The algorithm has the characteristics of self-learning and self-adaptation. It is able to search different regions of the solution space in parallel, which makes the search converge to the optimal solution, but the reliability of its results is poor, and it cannot obtain the optimal solution stably.

Dan et al. [14] analysed the genetic algorithm process, using indefinite length path encoding, which makes the composition form of initial individuals in the path population has more flexibility and the population search space domain is more selective. The use of non-repeating initial populations ensures the diversity of individuals in the population. As a result, the global optimal or sub-optimal obstacle avoidance paths can be output in any environment, which has good generality. Deng et al. [15] designed a path point coding mechanism in three-dimensional space and a genetic operator with heuristics suitable for path planning, selected the appropriate direction and step size for multi-objective optimisation, and the experimental results showed the effectiveness of the changed algorithm. Wei et al. [16] improve the genetic representation of the objective function solution, change the set of replacement grids from 8 to 4, and introduce the evaluation function into the influence of the number of inflection points. Obtain the planning route that conforms to the crane operation with no slash, few inflection points and short length. Li et al. [17] added recovery operation, reconstruction operation and recording superiority operation on top of the traditional algorithm, designed the metric function and genetic operator, and verified the effectiveness of the algorithm according to the multiple lifting paths provided with specific routines.

For the genetic algorithm, the crossover probability and mutation probability in the genetic operation are changed by a new mechanism instead of the original selection operator or combined with an adaptive algorithm, which improves the defects of being prone to premature maturity and falling into local optimum, and further strengthens the robustness and scalability of the algorithm.

3.3 RRT Algorithm

RRT algorithm is a fast sampling-based extended random tree algorithm proposed by Lavalle in 1998, the algorithm runs without the need to build a model based on the surrounding environment, the algorithm has a simple structure, good applicability to problems in high-dimensional spaces and some complex environments, and a strong fast exploration of the unknown space, but the algorithm searches with blindness, a strong dependence on the distance of nearby obstacles, and a high degree of spatial complexity is high.

Sun et al. [18] used RRTConnect++, an improved algorithm of RRT, to perform path planning for multiple cranes, adding intelligent determination of the planning region between initialisation and random sampling. That is, after initialising the position space, a rectangular region for planning is determined, sampling and expanding in this rectangular region improves the planning efficiency, and the effectiveness of the algorithm is verified through cases. Zhang et al. [19] added a guidance function to impose guidance on the direction of the algorithm sampling to a certain extent to improve the search efficiency. The sampling points are traversed using the crystal spore method, and the forward expansion increases the dynamic step size. Through testing, the improved method is feasible and effective in both static and dynamic scenarios. Jun Peng et al. [20] segmented the environmental map and used the artificial potential field method with variable weights to sample random points and select a suitable random search tree to expand the nodes. Chen et al. [21] used a two-way RRT algorithm that generates two trees at the same time at the initial and termination positions, and combined the particle swarm algorithm in generating paths to obtain a more desirable path in a three-dimensional complex environment.

For the RRT algorithm, by optimising the sampling nodes and sampling step size, and adding the guide function to improve its search efficiency, the shortcomings such as blindness and slow search are effectively solved, making the algorithm more reliable.

3.4 Particle Swarm Algorithm

Particle swarm algorithm is a new type of swarm intelligence optimization algorithm proposed by simulating the survival be haviour of bird flocks, which has the characteristics of both evolutionary computation and swarm intelligence to achieve the search for optimal solutions in complex space, and it has the advantages of simple rules, easy to implement, and fast convergence speed.

Zhang et al. [22] generate fan-shaped path effective area according to the actual operating area of the tower crane and reorder the first generation particles, which can effectively improve the efficiency of the tower crane operation and verify the feasibility of the algorithm. Li et al. [23] sorted the particles according to the fitness value to improve the speed of the algorithm, and added the path length and path smoothness to the fitness function to make the generated path smoother. The feasibility of 3D environment was verified. Lu et al. [24] constructed the objective function with the shortest path, calculated the particle fitness value, and introduced the exponential change perturbation to transform the speed weight change factor, so that the algorithm can jump out of the local optimum thus carry out the static optimal planning of the crane running path with the whole domain specifying the departure point and arrival point.

The particle swarm algorithm combined with other strategies for the improvement of the position updating method greatly improves the global search ability and convergence speed of the algorithm. The algorithm has been adjusted by specific functions to the parameters, which has a stronger local search ability, and the robustness and flexibility have been significantly improved.

4. DEEP REINFORCEMENT LEARNING ALGORITHMS

Deep reinforcement learning algorithms are mainly classified into learning algorithms with and without models, and model-based ones are dynamic programming algorithms. The model-free ones are Q-learning algorithm and DQN algorithm based on value function, AC algorithm, A2C, algorithm, REINFORC algorithm, etc. based on policy.

Guo et al. [25] combined the advantages of Double DQN and Dueling DQN algorithms, deepened the network structure using the Resnet Block method, used the multi-process technology to separate the data classification, data sampling and network updating for computing, which improved the computational speed, and verified the validity of deep learning for real-time dynamic path planning for cranes through simulation. Yi et al. [26] proposed TD3-TCLPP, a tower crane lifting path planning algorithm based on TD3. Improvements are made to the reward function, ex post experience playback, and exploration strategy, and it is verified through experiments that it outperforms the traditional algorithms in terms of planning time.

5. COMPARISON OF CRANE PATH PLANNING ALGORITHMS

Based on the above analysis and research, three types of algorithms: traditional path planning algorithms, intelligent optimisation algorithms and deep reinforcement learning algorithms have their own advantages and disadvantages and applicable scenarios in path planning, as shown in Table 1.

Table 1. Crane path planning algorithm

Algorithm category	Algorithm name	Dominance	Inferior
Traditional path planning algorithms	A*Algorithm	Ability to quickly find the shortest path	The path is not smooth and does not guarantee an optimal solution
	Artificial potential field algorithm	Strong local path planning capability	Prone to local optimality, objective unreachability
Intelligent Path Planning Algorithm	Ant colony algorithm	Strong global search capability	Unstable, slow convergence
	Genetic Algorithm	Global search capability, easy to find the optimal solution	Parameter sensitive, slow convergence in some cases
	RRT algorithm	Fast and suitable for high dimensional spaces	Pathfinding effect is affected by the number of sampling points
	Particle Swarm Algorithm	Faster convergence, no gradient	Easily converged prematurely
Deep reinforcement learning algorithms	DQN algorithm	For discrete spaces	Slow convergence

6. CONCLUSION

With the development of science and technology, excellent path planning algorithms can make the crane more intelligent in completing the lifting task, through the improvement and innovation of traditional path planning algorithms, research based on intelligent bionic algorithms, and the integration of deep reinforcement learning algorithms can help to promote the development of the field of unmanned cranes, and better cope with the more complex environment.

Most of the research work on crane-related path planning algorithms is based on the improvement of the characteristics of the algorithm itself, and relatively little research on the fusion of algorithms, and future research on crane path planning algorithms should be focused on the fusion of algorithms to improve the performance and applicability of path planning algorithms, so as to achieve efficient path planning.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. SHAO Xuezhu, LI Yao, ZHANG Jinggang, et al. Research on the method of trajectory planning for bridge cranes [J]. Journal of System Simulation. 2019;31(5): 971-977.
2. Lin Chenggang. Development of Intelligent Unmanned Crane Equipment and Explanation of Related Issues [J]. Electronic Components and Information Technology. 2022;6(05):126-129.
3. Jiao Laiwen. Research on intelligent operation system and path planning of overhead travelling crane[J]. China Equipment Engineering. 2020;2:88-89.
4. Li Fan. Research on the path planning of overhead travelling crane based on anti-sway control [D]. Dalian University of Technology; 2021.
5. Sun Hanting. Research on automatic obstacle avoidance path planning algorithm based on intelligent bridge crane [D]. Taiyuan University of Science and Technology; 2022.
6. Sun Lu. Research on path planning and active obstacle avoidance of bridge crane spreader system [D]. Shanghai University of Applied Technology; 2021.
7. Geng MW. Research on intelligent crane path planning [D]. Taiyuan University of Science and Technology; 2023.
8. Li Zeliang. Research on autonomous safe operation system of intelligent crane [D]. Henan University of Technology,2023.
9. Li Zheren. Research on intelligent bridge crane path planning [D]. Taiyuan University of Science and Technology; 2019.
10. Qu Yunlan. Research on automatic spatial transport path planning for bridge crane lifts [D]. Dalian:Dalian University of Technology; 2018.
11. Chen Jingtao, Wendu LI, Rizheng WEN, et al. Research on path planning of overhead travelling crane in steel coil storage[J]. Lifting and Transportation Machinery. 2021;(S1):63-65.
12. LI Xiaojin,CHEN Zhimei. Research on crane lifting path planning method for bridge cranes[J]. Journal of Taiyuan University of Science and Technology. 2017;38(06):445-449.
13. ZHOU Hao, CAO Xuyang, WANG Denglong, et al. Research on path planning problem of bridge crane based on improved ant colony algorithm [J]. Mechanical Design and Manufacturing. 2021;4:133-136.
14. Tenzin Ozhu. Research on intelligent operation system of bridge crane and its path planning [D]. Dalian University of Technology; 2013.
15. Deng Qianwang, Gao Likun, Luo Zhengping, et al. Crane lifting path planning based on multi-objective genetic algorithm [J]. Journal of Hunan University (Natural Science Edition). 2014;41(1):63-69.
16. Wei Yunping, Qiang Baomin, Chao Suquan, et al. Application of improved path planning algorithm in bridge cranes [J]. Computer Measurement and Control. 2015;23(8):2844-2846+2850.
17. Li Liuqun. Research on Sensing and Path Planning of Webots-based Truck Crane Work Scene [D]. Northern Nationalities University; 2017.

18. Sun Jisheng,Wang Xin,Wang Danhong. Multi-crane path planning based on improved RRTConnect++ algorithm[J]. Petrochemical Construction. 2016;38(2): 35-38.
19. Zhang E-D. Research on Intelligent Planning Method of Mobile Crane Lifting Path under Virtual Construction Scenario [D]. Tsinghua University; 2018.
20. Jun Peng. Research on the application of improved RRT algorithm in mobile robot path planning [D]. Nanjing University of Posts and Telecommunications; 2022.
21. CHEN Zhimei, LI Min, SHAO Xuezhu, et al. Obstacle avoidance path planning for bridge cranes based on improved RRT algorithm[J]. Journal of System Simulation. 2021;33(08):1832-1838.
22. ZHANG Zhi, WEN Zhaohui, LI Wei. Research on scene modelling and operation path planning of self-driving tower crane [J]. Construction Mechanisation. 2024;45(1):11-18.
23. Li M. Research on obstacle avoidance path planning method for bridge crane hoisting [D]. Taiyuan University of Science and Technology; 2020.
24. Lu Yukun, Chen Fei. Crane operation path planning based on improved particle swarm optimization algorithm [J]. Equipment Machinery. 2023;2:61-65.
25. Guo Wanda. Research on real-time obstacle avoidance of crawler crane based on deep reinforcement learning [D]. Dalian University of Technology; 2021.
26. Yin Zhiyuan. Tower crane lifting path planning based on deep reinforcement learning [D]. Shandong University; 2022.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/118284