International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 13, No. 4, December 2022, pp. 2488~2497
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v13.i4.pp2488-2497

Expansion of high-voltage overhead transmission lines to remote areas

Ibrahim H. Al-Kharsan[1,4], Ameer Al-khaykan[2], Hassan Falah Fakhruldeen[3,4]
[1]Computer Technical Engineering Department, College of Technical Engineering, The Islamic University, Najaf, Iraq
[2]Biomedical Engineering Department, Al-Mustaqbal University College, Babil, Iraq
[3]Computer Techniques Engineering Department, Faculty of Information Technology, Imam Ja'afar Al-Sadiq University, Baghdad, Iraq
[4]Electrical Engineering Department, College of Engineering, University of Kufa, Kufa, Iraq

Article Info

Article history:

Received Mar 22, 2022
Revised Jul 28, 2022
Accepted Aug 12, 2022

Keywords:

Ant colony algorithm
Graphical search approaches
High voltage
Path planning
Potential field algorithm
Transmission lines

ABSTRACT

Delivering electrical energy to remote areas is one of the essential things in our modern world. Choosing the optimal route is one of the most critical factors contributing to reducing the power transmission system's cost. Other influencing factors such as the optimum alloy of the conductor wires are difficult to change, so only the aforementioned factor was adopted. In this paper, the optimized potential field algorithm is employed to determine the sub-optimum path that the transmission line should be installed. The best line for the towers is not necessarily the shortest or the cheapest one. Sometimes the best locations for the towers of the transmission lines coming according to the safety regards. It can be said that the best trajectory is a combination of several factors, including the length of the track in addition to other influencing factors depending on the work environment.

Corresponding Author:

Ibrahim Hasan Al-Kharsan
Computer Technical Engineering Department, College of Technical Engineering, The Islamic University Najaf, Iraq
Email: smrtg809@gmail.com

1. INTRODUCTION

The three dimensions (3D) path planning method is used to create a minimum path that ensures there is no collision with obstacles that are distributed in the environment. The importance of path planning in 3D comes from the increase in the applications of 3D environments. The electrical power engineers can use the potential field algorithm effectively as a one success technique of path planning to decide precisely the perfect path to establish the towers that carry the power in the far or not accessible areas. The best path does not always mean the shortest path but may mean the minimum cost according to the objective function. The autonomous robots use path planning to find their path in the 3D workspace [1].

In this work, the word (robot path) means the electrical power transmission lines' path. The word "robot" is used to better represent and understand during the work with the potential field algorithm. When we talk about a single robot's path planning, we should consider some essential aspects: the distance of the path, cost dependence parameters, and path smoothness. On the other side, when there are multiple robots in the environment, we should take into consideration additional aspects like internal collision avoidance, formation shape keeping, cooperation behavior, formation shape change, and total path distance [2]–[5]. The potential field describes as space and potential hills at all obstacles. The robot in the potential field moves toward the goal location while being repelled from the workspace's obstacles. According to the definition above, the mobile robot will move naturally to the goal point without collision [6]–[8]. The most critical weakness of the potential field algorithm is the local minimum solutions that may found it. The authors propose using the ant colony optimization algorithm to solve the drawbacks described above. Also, use it to improve the quality of the mobile robot's path or the path of the towers used in power transmission. A local minima problem occurs when the equivalent forces equal to zero [9]–[11]. The potential field algorithm is used to avoid Obstacle collision, as studied in the papers [12]–[20]. The algorithm has been modified to be suitable for use in the electrical power engineering field. It is a new attempt to utilize this algorithm out of the traditional usage in vehicles or quadcopter applications.

2. METHOD

In this section, we will study the theoretical aspects related to our work in this paper that may give a clearer understanding of the results obtained. The path planning complexity has been discussed beside the three main categories that lay under this approach. The road map from the first category and the potential field method has been studied. The ant colony was finally considered and explained because it can be used to improve the performance of the potential domain algorithm.

2.1. The complexity of path planning

In reality, the robot isn't just a dot in the space. The robot might be irregular, and the work space could have an unknown number of dimensions. The number of dimensions in a point representation of a robot is generally two or three, which makes it easier for algorithms to select the optimum path [21], [22]. Using sophisticated approaches like the start algorithm (A*) to steer the search to the suitable location is one of the most popular strategies for solving the problem of path planning. The appropriate location is where the best solution may be found. This strategy guarantees that searches aren't carried out in places that aren't connected. Precise procedures take time and can't be used in tiny spaces or with poor precision. The issue of path planning is stated to be polynomial in complexity.

2.2. Approaches of path planning

Path planning research began in the late 1960s and got popular in the 1980s [23]. An amount of scientific papers has arisen to resolve this concern in various environments, including static and dynamic cases. Many strategies have contributed and attempted to solve the path planning problem. Figure 1 indicates that these attempts or solutions may be classified into three categories: traditional techniques, guided approaches, and graph-based approaches. The classic approach combines conventional methods such as the roadmap and the potential field. This category includes optimization issues, including time complexity and precision. The second class can solve the challenges that the first category has been encountered effectively. The third one includes the Star algorithm (A*) and the Dijkstra algorithm, which uses a chart to draw out the pathways [24].

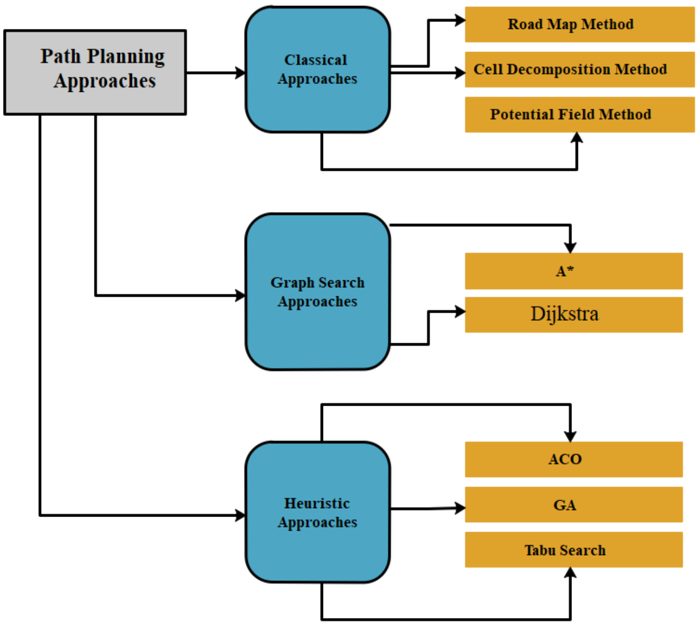

Figure 1. Path planning strategies [22], [24]

2.3. The roadmap approaches

The central concept is to make a roadmap out of a series of lines and each line in the map connecting two nodes. When the line does not cut any obstacles, it is constructed as a road linking the two nodes. As illustrated in Figure 2, a road map comprises a set of lines. The selected route is the continuous path inside the road map that links the start and destination places. If more than one path connects the start and aim locations on the roadmap, apply a Dijkstra algorithm to determine the shortest or optimal route, based on the problem's constraints [25]–[27].

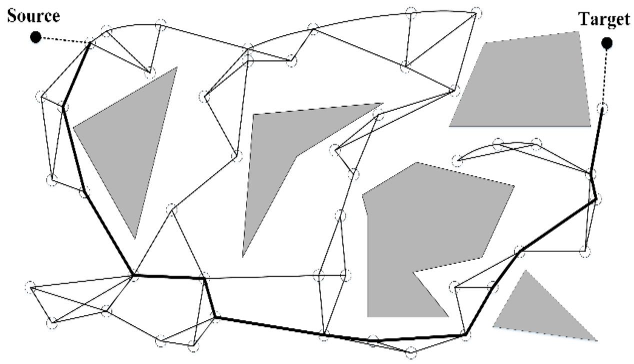

Figure 2. Roadmap approach of route planning

2.4. Graphical search approaches of path planning

The use of a graph to deal with the problem of path planning is well-known. Many strategies have been tested throughout the last years, and A-star [28] and depth-first search (DFS) [29] are two instances of this approach. DFS, as an example, is a search technique for tree data structures. This algorithm begins with the robot position because it is regarded as the source. The depth-first search may also be used to sort the vertices of a structure or tree linearly. There are four possible ways of doing this:

- A pre-order is a list of vertices in the order in which the depth-first search method examined them first. It is a concise and natural manner of expressing the search's progress. The expression in Polish notation is a pre-order of an expression tree.
- Post-order is a collection of vertices in the order in which the algorithm inspected them last. The expression in reverse Polish notation is a post-order of an expression tree.
- A reverse pre-order is the total opposite of a pre-order, i.e. a list of vertices in the reverse order of their initial evaluation. The terms "reverse pre-order" and "post ordering" are not interchangeable.
- The reverse of a post-order is a list of vertices in the opposite order of their previous visit. Pre-order and reverse post-order are not the same thing.

2.5. Artificial potential field approach

It is assumed in this algorithm that there is a field made up of two fundamental forces: attraction and repulsion [30], [31]. The robot is dragged towards the target at the target point via force, and the strength of repulsion is the other force. This force is stationed at the points where obstacles exist. The robot can navigate to the destination without striking any obstacles due to the forces of attraction and repulsion. This algorithm has undergone several revisions to face its flaws (local minima). Figure 3 show the potential field approach of path planning [32].

Despite their capacity to identify solutions and pathways free of collisions, traditional techniques have several restrictions and downsides. Long and sophisticated computations are critical of these restrictions, especially in big and complex domains. Another disadvantage of this algorithmic technique is its engagement in locally optimum solutions rather than the optimal global solution [33].

2.6. Potential field algorithm

In this work, we simulate the potential field algorithm in a 3D environment, where there are several obstacles in the 3D workspace. We suppose a spherical shape for obstacles. The obstacles are typically distributed around the straight-line path of the robot toward their target location. The path starts his motion in a straight line toward their goal and exhibit attraction to its target. On the other side, the robot exhibit repulsion from obstacles. The repulsion force was calculated according to Newton's law of universal gravitation after inverting the sign to negative in order to make it Newton's law of universal repulsion in the state of gravitation. In this case, the repulsion increases when the distance between the robot and obstacle decreases [34]. Figure 4 explain a hill for the obstacle's representation. Surface downiness represents attraction to the target, where Figure 5 represents the repulsion force with to distance between the transmission line and the obstacle.

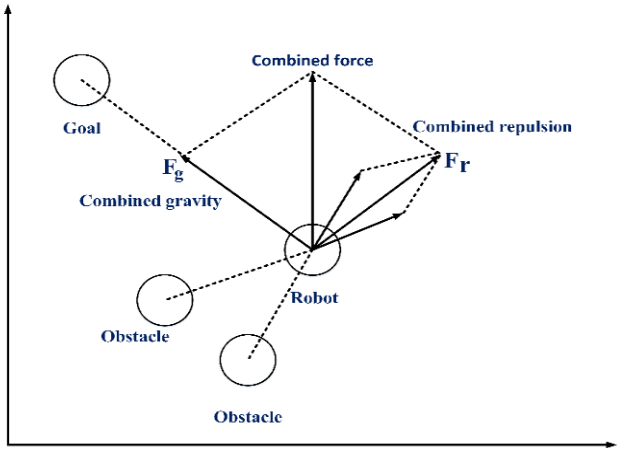

Figure 3. potential field approach of path planning

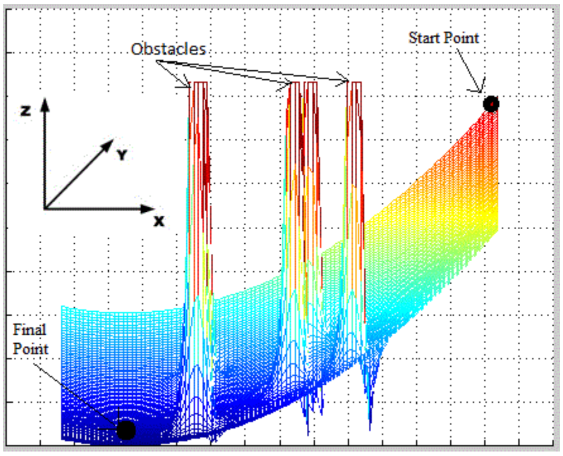

Figure 4. The basic idea of the potential field representation

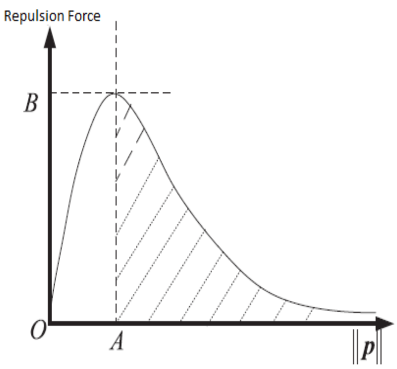

Figure 5. The repulsion force with respect to the distance between the transmission line and obstacle

Where B represents the maximum repulsion force at a distance A from the obstacle, P represents the Euclidean distance to the obstacle. According to the forces described above, we can calculate an equivalent force that affects the robot to move it naturally toward its goal without neither collisions nor a sharp edge in the path.

This algorithm work based on some assumptions which are:
- Obstacles have spherical shapes.
- The radius of obstacles is given or calculated.
- The mass of the robot and obstacles is given or it proportional to its radius.
- Source and goal 3D point of the robot are given.
- The speed of the robot is proportional to the equivalent force effect on the robot.

The procedure of potential field algorithm is:
- Compute a distance from the robot to each obstacle based on their current locations.
- Compute a repulsion force affected by each obstacle to the robot based on distance computed from the previous step.
- Compute an attraction force affected the robot based on the distance between the current location and its goal.
- Compute an equivalent force vector for the robot.
- Compute a speed (magnitude and direction) for the robot.

- If the new calculated speed opposite current speed in the direction exactly, then add a small random vector to it.
- Repeat all steps above until the robot's current location equals the goal location.

The above procedure is also described as and flowchart and pseudocode, as explained in Figure 6 and Figure 7, respectively.

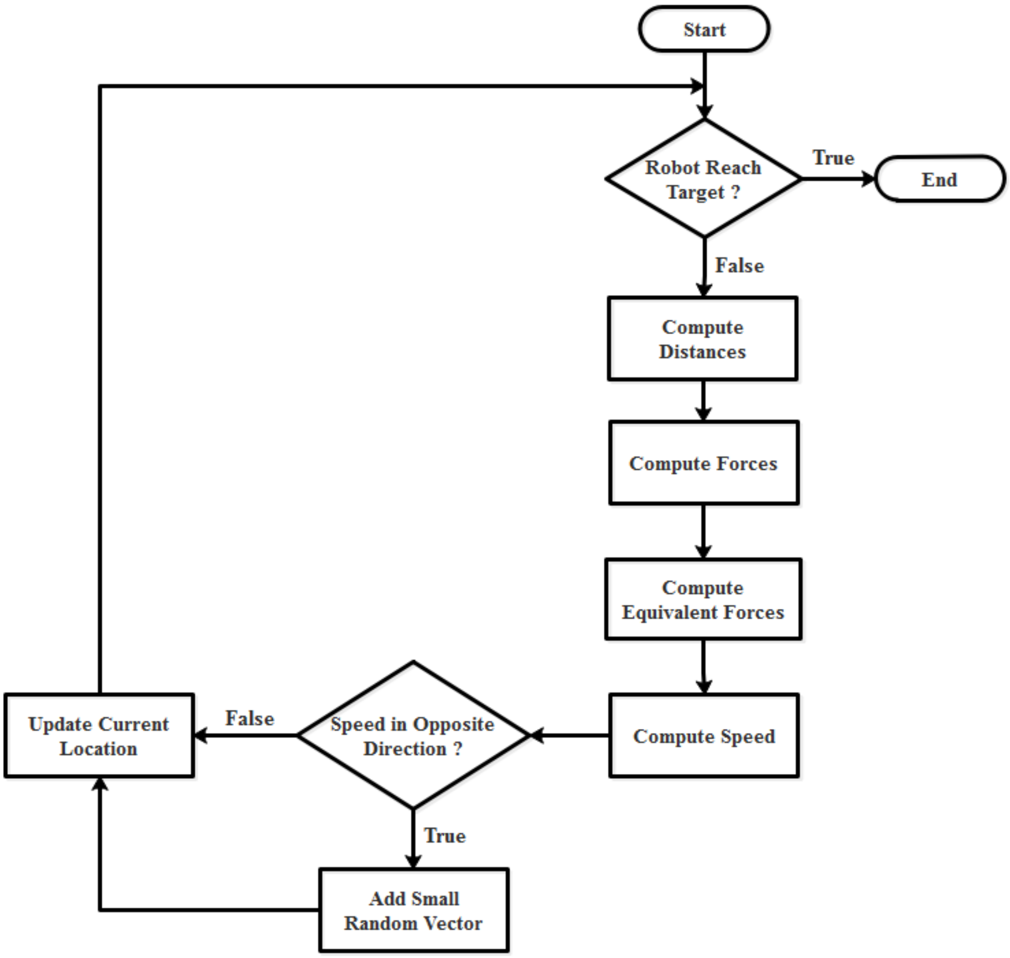

Figure 6. Flowchart of a potential field algorithm in the 3D environment

```
start;
while(!Robot reach target?)
{
  Computed distance;
  Computed forces;
  Computed equivalent force;
  Computed speed;

  if(speed in opposite direction?)
  {
    Add small randon vector;
  }
  Update current location;
}
End
```

Figure 7. Pseudocode of a potential field algorithm in the 3D environment

2.7. Ant colony optimization algorithm

This algorithm can be regarded as one of the essential algorithms used in many engineering fields besides their effectiveness in the path planning branch [35], [36]. The first section studied the ant`s behavior when there is an obstacle in the way between the nest and the destination (food place) in four different scenarios. The programming steps the ACO has followed to reach the optimal solution to improve the routine of the potential field algorithms are mentioned.

– Main idea

Naturally, ants can find the shortest path between their nest and food site. It can find the shortest path even though there are some possible paths. The process is carried out using pheromone. When ants pass from a specific pathway, they put pheromone. Pheromone attracts other ants to pass the same path. Ants tend to choose a path that has a higher pheromone concentration. After a while, pheromone concentration becomes high on the shorter path while decreasing from wrong paths. The presence of an obstacle in the ants' path makes him choose his way randomly at first. All ants then move gradually to the shorter path, as shown in Figure 8 [13]. The ants in case Figure 8(a) find a straight path between the food and the destination, and in this case, it is not trying to find the shortest or the optimal way because this way represents the optimum one. In case Figure 8(b), the ants encountered an obstacle on the way to the food place, so some ants return to the nest because it does not find the way to the food, but from another side, the others reach the destination. In case Figure 8(c) the ants learn the optimum path to the food, all the ants can reach the food without any hesitation. Case Figure 8(d) shows if for unexpected circumstances there was the shortest way has been available suddenly, and it represents the shortest return path. Here the ants will discover this route and pass through it to avoid the obstacle and reach the nest from the shortest path [37], [38].

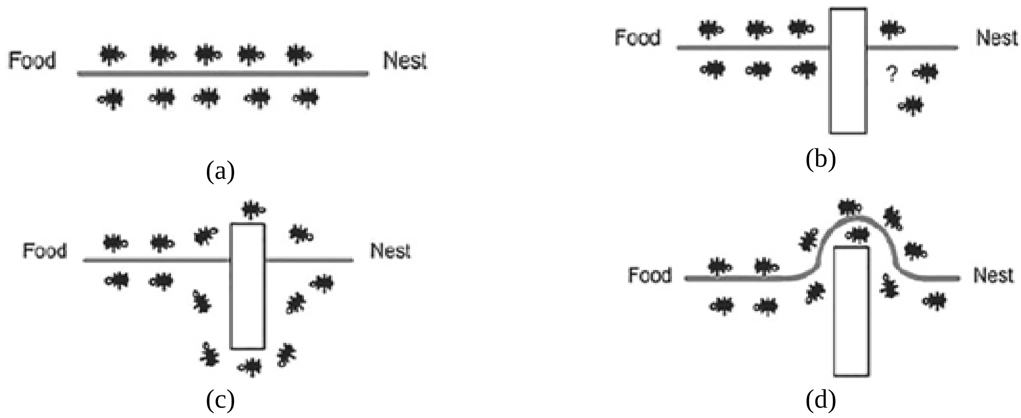

Figure 8. Ants approach to find the best path to the destination (food): (a) straight line between the nest and target and no need for the shortest path; (b) the ants do not know the optimal path when there is an obstacle; (c) the ant herd finds the optimal path in case of an obstacle and reaches the destination; and (d) the ants change the road to the food with the shortest path available because of certain circumstances

ACO follows the algorithm shown in Figure 9. Initially, configuration and configuration occur. During this step, the initial value of the pheromone is set. Then it enters a duplicate loop, ending when one of the stop conditions is reached. The amount of pheromone is continuously updated [13].

The purpose of using the ant algorithm is to improve the performance of the potential domain algorithm. The potential field algorithm contains some important factors such as the effect radius of each obstacle in addition to the repulsion force constant. This information is calculated using the ant algorithm. Thus, the potential field algorithm can work very efficiently.

```
1 Set Parameters, initialize pheromone;
2 While (termination condition not met) do
3 Construct Ant solutions;
4 Apply local search;
5 Optional update pheromones;
6 End
```

Figure 9. The programming steps to obtain the optimal path according to ACO

3. RESULTS AND DISCUSSION

The simulation results show the ability of the suggested algorithm to solve the problem of finding the optimal path effectively. Figure 10 represented the demanded path when one fixed obstacle in the studying field. The algorithm discovered the obstacle, avoided it successfully, and did not take a long turn but directly beside the obstacle. In the second scenario, we increased the difficulty of the environment by putting three fixed deterrents in the field between the starting of path and destination. The algorithm also finds the better path and reach the destination at a lower cost, as illustrated in Figure 11.

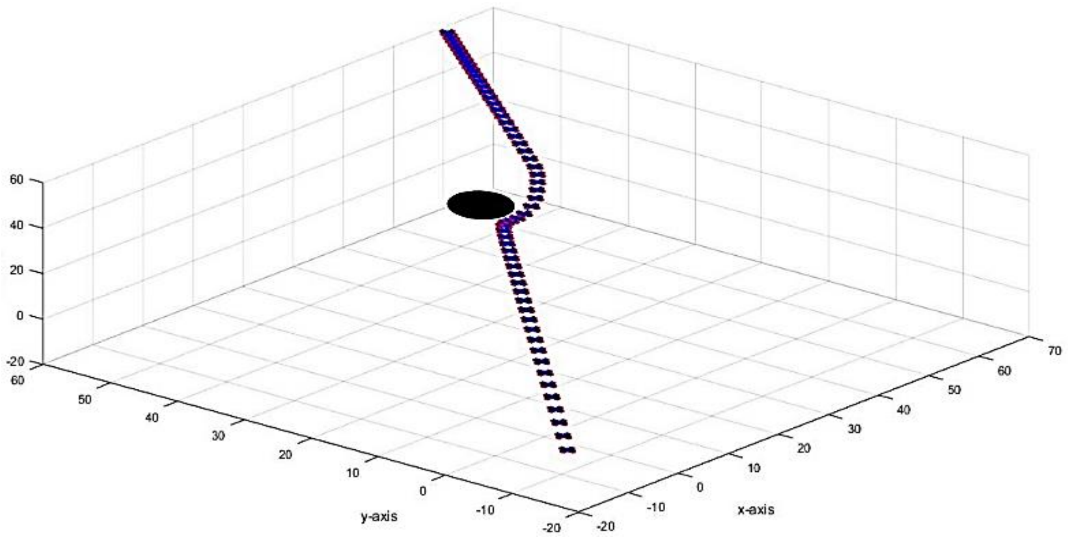

Figure 10. Collision-free path with existence of one fixed obstacle

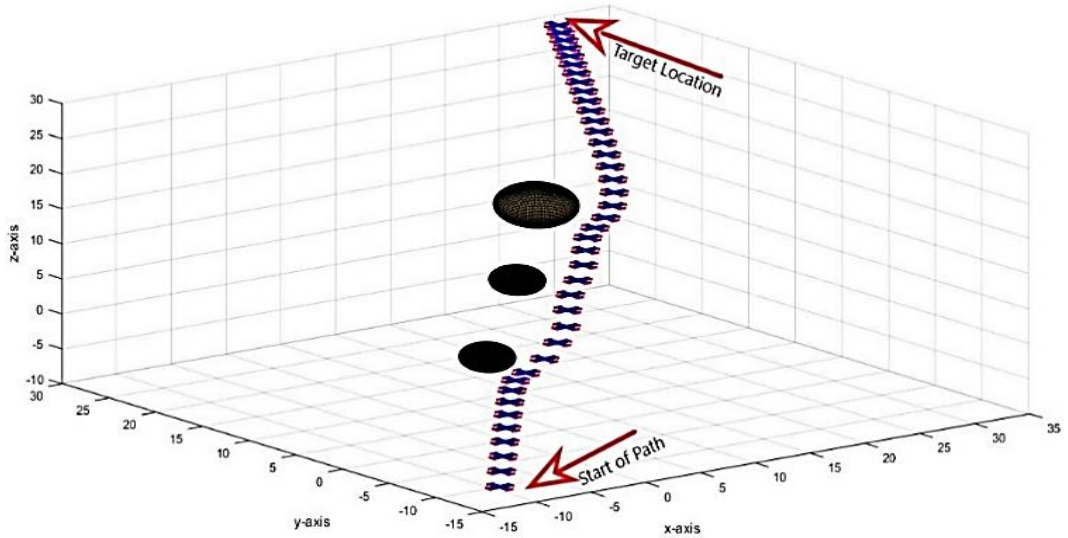

Figure 11. Collision free path with exist of three fixed obstacles

The starting and ending points can be any two points in space without any condition. It should be noted here that Figure 5 is to illustrate the force of attraction. In fact, the force of attraction used in the algorithm depends on the location of the target, no matter how high it is.

For more complexity, we added five complex preventive bodies to test the algorithm under severe conditions. However, the result was satisfactory to a great extent, as shown in Figure 12. The algorithm examined fifty different obstacles scattered randomly and varied for more insurance to make the problem harder with these constraints. Figure 13 depicts the algorithm drawing the best path between the start and destination point. The local minima problem is rare in the adopted case study. In some figures, it seems to exist but it doesn't. This conflict is just because of the 3D figures.

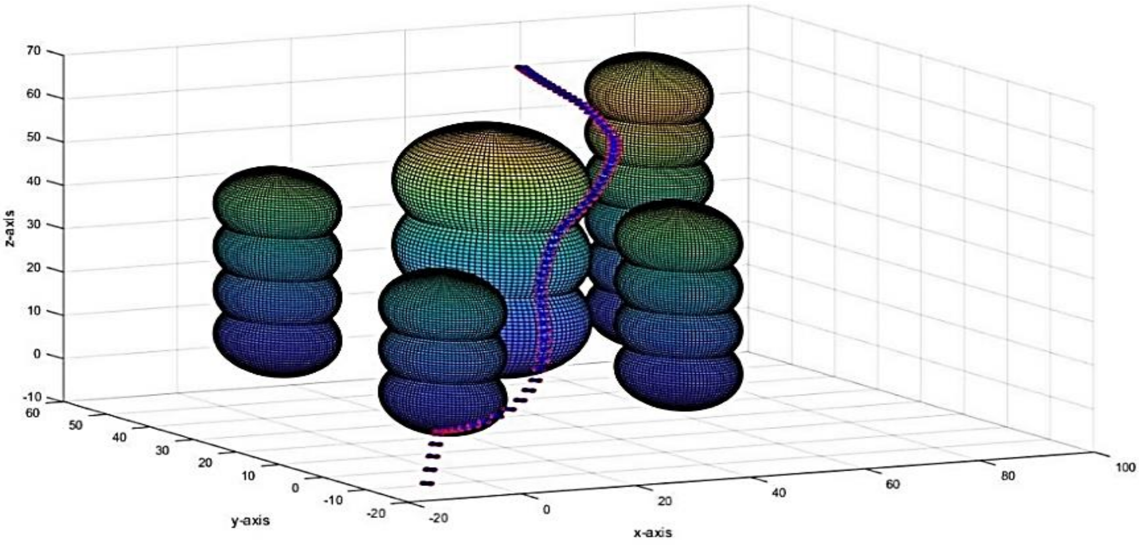

Figure 12. Collision-free path with existing of five complex obstacles

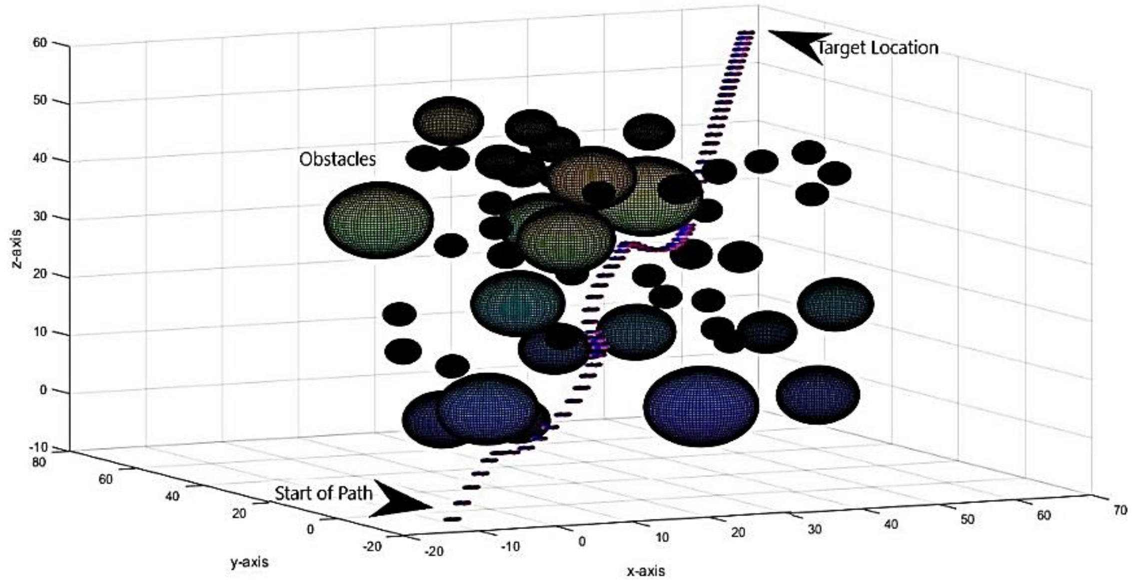

Figure 13. Collision-free path with exist of fifty fixed obstacles

4. CONCLUSION

The potential field technique is utilized in the 3D workspace to build a smooth collision-free path with no sharp edges, which reduces the time spent determining the best path for installing the electrical towers that carry the power to its destination. The optimal path means from another side the route that has less cost than the others, which is a critical point for the designers in the utility. The algorithm finds the better path in many situations, like having one fixed obstacle or in a more complicated environment when there are five and fifty obstacles. This paper can participate in delivers electrical energy to more areas at a lower cost and labor. The computational complexities of the algorithm are very simple. As it only needs information on the locations of obstacles as well as their sizes. In addition, the computational complexities can be neglected because each environment needs one computational execution process to get the best path.

REFERENCES

[1] A. Hameed, A. la Cour-Harbo, and O. L. Osen, "Side-to-side 3D coverage path planning approach for agricultural robots to minimize skip/overlap areas between swaths," *Robotics and Autonomous Systems*, vol. 76, pp. 36–45, Feb. 2016, doi: 10.1016/J.ROBOT.2015.11.009.

[2] I. H. Al-Kharsan, A. F. Marhoon, and J. R. Mahmood, "A new strategy for phase swapping load balancing relying on a meta-heuristic MOGWO algorithm," *Journal of Mechanics of Continua and Mathematical Sciences*, vol. 15, no. 2, pp. 84-102, 2020, doi: 10.26782/jmcms.2020.02.00008.

[3] Y. Wang and G. S. Chirikjian, "New potential field method for robot path planning," *Proceedings - IEEE International Conference on Robotics and Automation*, vol. 2, pp. 977–982, 2000, doi: 10.1109/ROBOT.2000.844727.

[4] E. N. Sabuddin *et al*., "Improved potential field methodfor robot path planning with path pruning," *Proceedings of the 11th National Technical Seminar on Unmanned System Technology*, 2019, pp. 113-127, doi: 10.1007/978-981-15-5281-6_9.

[5] J. Barraquand, B. Langlois and J. -C. Latombe, "Numerical potential field techniques for robot path planning," *Fifth International Conference on Advanced Robotics 'Robots in Unstructured Environments*, 1991, vol. 2, pp. 1012-1017, doi: 10.1109/ICAR.1991.240539.

[6] S. Choudhury, S. Scherer, and S. Singh, "RRT*-AR: sampling-based alternate routes planning with applications to autonomous emergency landing of a helicopter," *2013 IEEE International Conference on Robotics and Automation*, 2013, pp. 3947-3952, doi: 10.1109/ICRA.2013.6631133.

[7] S. M. Lavalle, "Rapidly-exploring random trees: a new tool for path planning," 1998, [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.35.1853. Accessed: Feb. 26, 2022.

[8] L. E. Kavraki, P. Svestka, J. -C. Latombe, and M. H. Overmars, "Probabilistic roadmaps for path planning in high-dimensional configuration spaces," in *IEEE Transactions on Robotics and Automation*, vol. 12, no. 4, pp. 566-580, Aug. 1996, doi: 10.1109/70.508439.

[9] H. A.-J. Al-Asady and H. F. Fakhruldeen, "Volts/Hz control of three phase induction machine: MATLAB Simulink," in *Journal of Physics: Conference Series*, 2021, vol. 1818, p. 012089, doi: 10.1088/1742-6596/1818/1/012089.

[10] M. J. Mohammed, M. T. Rashid, and A. A. Ali, "Design optimal PID controller for quad rotor system," *International Journal of Computer Applications*, vol. 106, no. 3, 2014. [Online]. Available: https://www.academia.edu/16391064/Design_Optimal_PID_Controller_for_Quad_rotor_System. [Accessed: Feb. 26, 2022].

[11] Y. K. Hwang and N. Ahuja, "A potential field approach to path planning," *IEEE Transactions on Robotics and Automation*, vol. 8, no. 1, pp. 23–32, 1992, doi: 10.1109/70.127236.

[12] J. Lagunas-Avila, R. Castro-Linares, and J. Alvarez-Gallegos, "Obstacle avoidance in leader-follower formation using artificial potential field algorithm," *2021 18th International Conference on Electrical Engineering, Computing Science and Automatic Control (CCE)*, 2021, pp. 1-6, doi: 10.1109/CCE53527.2021.9633083.

[13] D. S. Wais and W. S. Majeed, "The gravitational search algorithm for incorporating TCSC devices into the system for optimum power flow," *International Journal of Electrical & Computer Engineering*, vol. 11, no. 6, pp. 4678-4688, 2021. DOI: 10.11591/ijece.v11i6.pp4678-4688.

[14] I. Breido and V. Ivanov, "Prediction of the high voltage insulators service life based on the effective values of leakage currents," *Indonesian Journal of Electrical Engineering and Informatics (IJEEI)*, vol. 9, no. 2, pp. 289-301, 2021. DOI: 10.52549/ijeei.v9i2.3018.

[15] D. Wang, S. Chen, Y. Zhang, and L. Liu, "Path planning of mobile robot in dynamic environment: fuzzy artificial potential field and extensible neural network," *Artificial Life and Robotics*, vol. 26, pp. 129–139, 2021, doi: 10.1007/s10015-020-00630-6

[16] H. Zhang, Y. Zhu, X. Liu, X. Xu, "Analysis of obstacle avoidance strategy for dual-arm robot based on speed field with improved artificial potential field algorithm," *Electronics*, vol. 10, no. 15, p. 1850, 2021, doi: 10.3390/electronics10151850.

[17] A. Ma'Arif, W. Rahmaniar, M. A. M. Vera, A. A. Nuryono, R. Majdoubi, and A. Çakan, "Artificial potential field algorithm for obstacle avoidance in UAV quadrotor for dynamic environment," *2021 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT)*, 2021, pp. 184-189, doi: 10.1109/COMNETSAT53002.2021.9530803.

[18] A. Qamar, I. H. Al-Kharsan, Z. Uddin, and A. Alkhayyat, "Grounding grid fault diagnosis with emphasis on substation electromagnetic interference," in *IEEE Access*, vol. 10, pp. 15217-15226, 2022, doi: 10.1109/ACCESS.2022.3146722.

[19] P. K. Selvam, G. Raja, V. Rajagopal, K. Dev, and S. Knorr, "Collision-free path planning for UAVs using efficient artificial potential field algorithm," *2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring)*, 2021, pp. 1-5, doi: 10.1109/VTC2021-Spring51267.2021.9448937.

[20] S. Feng, Y. Qian, and Y. Wang, "Collision avoidance method of autonomous vehicle based on improved artificial potential field algorithm," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, Dec. 2021, vol. 235, no. 14, pp. 3416–3430, doi: 10.1177/09544070211014319.

[21] S. M. LaValle, *Planning algorithms*, Cambridge, UK: Cambridge University Press, 2006, doi: 10.1017/CBO9780511546877.

[22] J. H. Reif, "Complexity of the Generalized Mover's Problem.," *Defense Technical Information Center*, 1985. [Online]. Available: https://apps.dtic.mil/sti/citations/ADA161378. [Accessed: Feb. 26, 2022].

[23] J.-C. Latombe, *Robot motion planning*," New York, USA: Springer, 1991, doi: 10.1007/978-1-4615-4022-9.

[24] S. R. Salkuti and N. R. Battu, "An effective network reconfiguration approach of radial distribution system for loss minimization and voltage profile improvement," *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 4, pp. 1819-1827, 2021, doi: 10.11591/eei.v10i4.2867.

[25] A. N. Nazif, A. Davoodi, and P. Pasquier, "Multi-agent area coverage using a single query roadmap: a swarm intelligence approach," *Advances in Practical Multi-Agent Systems*, vol. 325, pp. 95–112, 2010, doi: 10.1007/978-3-642-16098-1_7.

[26] Z. Yan, N. Jouandeau, and A. A. Cherif, "ACS-PRM: adaptive cross sampling based probabilistic roadmap for multi-robot motion planning," *Advances in Intelligent Systems and Computing*, vol. 193, pp. 843–851, 2013, doi: 10.1007/978-3-642-33926-4_81.

[27] S. Milos, "Roadmap methods vs. cell decomposition in robot motion planning," *Proceedings of the 6th WSEAS International Conference on Signal Processing, Robotics and Automation*, 2007. [Online]. Available: https://www.researchgate.net/publication/262215647_Roadmap_methods_vs_cell_decomposition_in_robot_motion_planning. [Accessed: Feb. 26, 2022].

[28] G. Tang, C. Tang, C. Claramunt, X. Hu, and P. Zhou, "Geometric a-star algorithm: an improved a-star algorithm for AGV path planning in a port environment," in *IEEE Access*, vol. 9, pp. 59196-59210, 2021, doi: 10.1109/ACCESS.2021.3070054.

[29] J. Wang, Y. Xie, S. Xie, and X. Chen, "Cooperative particle swarm optimizer with depth first search strategy for global optimization of multimodal functions," *Applied Intelligence*, vol. 52, pp. 10161–10180, Jan. 2022, doi: 10.1007/S10489-021-03005-x.

[30] Z. Zhu, H. Lyu, J. Zhang, and Y. Yin, "An efficient ship automatic collision avoidance method based on modified artificial potential field," *Journal of Marine Science and Engineering*, vol. 10, no. 1, p. 3, Dec. 2021, doi: 10.3390/JMSE10010003.

[31] L. Li, D. Wu, Y. Huang, and Z. M. Yuan, "A path planning strategy unified with a COLREGS collision avoidance function based on deep reinforcement learning and artificial potential field," *Applied Ocean Research*, vol. 113, p. 102759, Aug. 2021, doi: 10.1016/J.APOR.2021.102759.

[32] F. Arambula Cosío and M. A. Padilla Castañeda, "Autonomous robot navigation using adaptive potential fields," *Mathematical and Computer Modelling*, vol. 40, no. 9–10, pp. 1141–1156, Nov. 2004, doi: 10.1016/J.MCM.2004.05.001.

[33] C. Miao, G. Chen, C. Yan, and Y. Wu, "Path planning optimization of indoor mobile robot based on adaptive ant colony algorithm," *Computers & Industrial Engineering*, vol. 156, p. 107230, Jun. 2021, doi: 10.1016/J.CIE.2021.107230.

[34] S. Karaman and E. Frazzoli, "Optimal kinodynamic motion planning using incremental sampling-based methods," *49th IEEE Conference on Decision and Control (CDC)*, 2010, pp. 7681-7687, doi: 10.1109/CDC.2010.5717430.

[35] Y. Ji, and B. Liu, "Research and implementation of robot path planning based on ant colony algorithm," *Journal of Physics: Conference Series*, Jan. 2022, vol. 2171, no. 1, p. 012074, doi: 10.1088/1742-6596/2171/1/012074.

[36] I. K. Saeed and K. Sheikhyounis, "Power quality improvement of distribution systems asymmetry caused by power disturbances based on particle swarm optimization-artificial neural network,' *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 25, no. 2, pp. 666-679, 2022, doi: 10.11591/ijeecs.v25.i2.pp666-679.

[37] X. Xiang, Y. Tian, X. Zhang, J. Xiao, and Y. Jin, "A pairwise proximity learning-based ant colony algorithm for dynamic vehicle routing problems," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 6, pp. 5275-5286, Jun. 2022, doi: 10.1109/TITS.2021.3052834.

[38] G. Rivera, C. A. Coello Coello, L. Cruz-Reyes, E. R. Fernandez, C. Gomez-Santillan, and N. Rangel-Valdez, "Preference incorporation into many-objective optimization: an ant colony algorithm based on interval outranking," *Swarm and Evolutionary Computation*, vol. 69, p. 101024, Mar. 2022, doi: 10.1016/J.SWEVO.2021.101024.

BIOGRAPHIES OF AUTHORS

Ibrahim H. Al-Kharsan received the B.Eng. degree in electrical engineering from the University of Kufa, Najaf, Iraq, in 2008, and the master's degree in engineering science from Jawaharlal Nehru Technological University Hyderabad, College of Engineering (India) 2013. The Ph.D. degree in electrical engineering from the College of Engineering, Electrical Engineering Department from Basrah University Iraq (2020). He is currently a lecturer in Islamic University, College of Technical Engineering, Computer Technique's Department. He worked previously as a lecturer in the College of Engineering in Kufa University, Computer Technique's Department in Al-Kadhum University College, and Electrical Department in Al-Najaf institute related to Al-Furat Al-Awsat Technical University. He can be contacted at email: smrtg809@gmail.com, or ibrahim.alkhersan@iunajaf.edu.iq.

Dr. Ameer Al-khaykan Doctorate in Electrical and Electronic Engineering, graduated from University of Chester in UK. Lecturer and researcher at Mustaqbal University College, also researcher and visitor lecturer at University of Chester. Research member in EPSRC. Many years of experiences in electrical engineering, energy system, renewable energy, sustainable energy system, DC system design and new control systems. Design many projects in smart gird and CCHPV and local energy system with intelligent control system design. IEEE student member, IET student member, IEEE conference reviewer, Iraqi Engineering Union (consultation level), editor and reviewer in international journal 'energy and building'. Expertise in supporting energy marketing. Strong ability to enhancing higher education through developments the interactive curriculum at Chester University. He can be contacted at email: avatar_iraq_1985@yahoo.com, or ameer.alkhaykan@mustaqbal-college.edu.iq.

Hassan Falah Fakhruldeen received the B.Eng. degree in communications engineering from Al-Furat Al-Awsat Technical University, Iraq, in 2010 and the M.S. and Ph.D. degrees in electronics and communications engineering from Baghdad University, Iraq, in 2013 and 2020, respectively. Currently, he is an Associate Professor at the Department of Electrical Engineering, University of Kufa. His research interests include photonics, optics, optical fiber communications, nano-photonic devices, plasmonic devices, optical communications, optical fiber networks, plasmonic sensors, all-optical signal processing, 5G communications, communications transmission lines, signal transmission planning, wireless networks, wireless communications, radio over fiber communications. He can be contacted at email: hassan.fakhruldeen@gmail.com.