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Hybrid D* Approach: A path planning for Biomedical Waste Robots

Dinesh Deshmukh[1*], Somnath Bhattacharya[1], S. Sanyal[1]

[1] Department of Mechanical Engineering, National Institute of Technology, Raipur, India

E-mail address: dbdeshmukh01@gmail.com

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Abstract: This paper presents a hybrid path planning design for autonomous robots tasked with collecting biomedical waste within healthcare facilities. Biomedical wastes are 74% more infectious as compared to normal wastes. There are great chances of getting infected if manually cleaned. If the biomedical wastes are cleaned with the help of autonomous robot then it will be helpful in avoiding infections from the same. We are designing the path planning required for the robot to perform the desired tasks. The proposed approach utilizes a hybrid D* (Dynamic A) algorithm, joining the strengths of both D* lite and D* extra lite to achieve efficient and adaptable navigation in complex, dynamic environments. The hybrid D* algorithm enables the robot to dynamically update its path in response to real-time changes in the environment, such as obstacles, restricted areas, and other moving agents. We recorded displacement ranges from 11.657 - 21.657 units, velocity ranges from 1.082 - 1.165 units/s & acceleration ranges from 0.054 - 0.116 units/s square for path planned through hybrid D*. The simulation was conduction under different configuration of layouts. Through simulations and experimental validation, we demonstrate the effectiveness of the proposed approach in optimizing waste collection routes, minimizing travel time, and improving overall operational efficiency.

Keywords: Biomedical Waste, Robotics, Path Planning, D* Algorithm, Dynamic Environments, Autonomous Navigation

1. Introduction

Cleanliness and hygiene are most important factors of life at majority of places in order to live the life healthy, without any disease & harms. Even the government of India is focusing on cleanliness everywhere through “Swachya Bharat Abhiyan”. Moreover cleaning of domestic offices, hotels and houses are little bit simple but when talking about cleanliness in industries and hospitals; it requires more attentions to cleaning methods & machines utilized for the same.

The importance of cleanliness and hygiene has been seen during COVID-19 period. During that Stability of virus on different surfaces under the test conditions is from 2 – 7 days. Biomedical wastes (BMW) are those wastes which are obtained in health care facilities. BMW robots have been developed to assist in the handling and disposal of BMW in healthcare facilities. However, the successful implementation of BMW robots depends on an efficient path-planning system.

Properly managing biomedical waste is paramount in healthcare settings to ensure public health safety and environmental protection. This literature review explores the current state of biomedical waste management, including regulations, conventions, and emerging treatment technologies. It emphasises minimising waste generation and adhering to country-specific norms [1]. We have seen the effect of infection from biomedical wastes or recent examples of corona virus infections [2]. Biomedical waste robots can potentially reduce the risk of exposure to hazardous waste and improve the efficiency of waste disposal in healthcare facilities.

The paper sheds light on managing medical waste generated during the Covid crisis. The study underscores the importance of implementing rigorous safety measures to protect healthcare workers and the general public from potential infections arising from the mishandling of medical waste [3]. In some communities and primary healthcare facilities, minimal attention is paid to biomedical wastes by the producers and handlers. These are due to some of them being unaware of practices for managing biomedical wastes [4].

Robots can collect and transport biomedical waste in healthcare facilities to achieve this. However, the path

dbdeshmukh01@gmail.com

planning of these robots is challenging and requires efficient algorithms to optimise their movements. Several literature reviews are conducted to examine the requirement for a more in-depth application of operations management tools and techniques used for biomedical waste management [5]. A unique combination of PRM, ant colony optimisation and third-order B-spline curve has been used for the static environment [6].

The PRM produces the path; ant colony optimisation optimises the path, and the B-spline curve smoothens the path produced. This combination is used for complex and very complex static environments [7]. The cuckoo search algorithm is applied for optimal path planning in a static environment. The algorithm is based on the behaviour of cuckoos, avoiding obstacles and achieving the shortest path for autonomous vehicles [8]. The used RRT and RRT* for finding initial solutions and then embedded into post-processing algorithms like the Informed RRT* [9]. In the PRM method, initial path planning is done under limited environments [10]. For path planning in a huge search space, an artificial endocrine system-based path planning (AES-PP) is used [11]. Application of two stages Half-Sweep Arithmetic Mean (HSAM) to obtain the Harmonic functions to solve path planning problem in a 2D indoor environment [12].Three samplers were used for sampling-based planning to promote samples inside corridors and towards narrow passages in the centre of corridors. This approach improved path planning in constrained spaces [13]. A probabilistic roadmap (PRM) method is utilised for path planning, particularly for manipulators navigating narrow passages in obstacle spaces [14]. An Elastic band (EB) & EB-RRT methods are used for path planning of mobile robots so that it is global planning and dynamic re-planning, respectively [15].

A*, RRT*, and CNN methods are used for path planning and optimisation [16]. A path-planning method called PRM-RL was introduced for long-range mobile robots with noisy sensors. They utilised PRM for outdoor planning and RL for indoor planning, conducting simulations for both kinematic differential drive and kinodynamic car-like robots [17]. A genetic algorithm is utilised to find optimal paths in a static grid environment [18]. The D* algorithm with particle swarm optimisation is used for path planning in dynamic environments. This approach combined defining the path with the D* algorithm and optimising it using particle swarm optimisation [19]. The CCD* algorithm [20] is used for floor-cleaning mobile robot path planning which was inspired by the path transform (PT) algorithm [21]. The path planning of the vehicle power train has been performed through an improved A-stat path-searching algorithm [22].

The survey consists of Coverage Path Planning (CPP) in robotics, showcasing recent advancements based on successful CPP methods. CPP involves determining paths that cover all points of an area or volume of interest while avoiding obstacles [23]. The improved PRM algorithm is used for path planning in narrow passages [24]. A multi-agent robot system consisting of two Turlebot2 robots with the ROS used to locate and navigate fire extinguishers [25] Mixed path planning is employed for multi-robots in structured hospital environments. Graph search algorithms were used for path planning in hospital corridors, and the artificial potential field method was utilised for planning paths in hospital rooms [26]. Exploited deep domain transfer learning in CNN used for biomedical classification (OASIS MRI data set). Image processing done to identify different positions of skull [27].

From above literature survey discussed, we have found that robots were not employed to cleaning of biomedical wastes in most of cases. Again the collection of BMW should be on category basis, we cannot treat them as general wastes. Different algorithms used for path planning of robots. There was not utilization of hybrid D* algorithm.

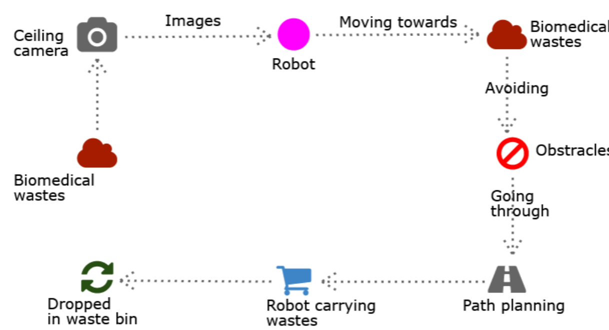


Figure 1: Representation of working of automatic cleaning robot

Our objective in this paper is to design the robot that will collect the particular BMW according to the categories mentioned in BMW policies and practices. An efficient path-planning system for biomedical waste robots is paramount as it plays a critical role in successfully implementing and operating these robots in healthcare facilities. Biomedical waste robots are designed to automate the collection and disposal of hazardous medical waste, reducing the risk of exposure to healthcare workers and the public. Again we are going to use hybrid D* algorithm which was not used earlier to plan the path required for robot to navigation.

Here is a brief introduction on how our biomedical waste robot will work. Suppose a biomedical waste is lying on a floor in the OPD area of a healthcare facility then ceiling camera will identify it as shown in figure 1. Then those images from selling will be communicated to robots. The robot will decide the waste as a goal point and it will move from its position to the west position to

collect it through a path planning algorithm. Again the robot will avoid hospitals coming in its path as per the path planning. Once the robot reaches the waste, it will collect and move towards the designated waste bin.
There are mainly five types of biomedical waste. We are focusing on designing a robot for infected plastic and sharp types of wastes. Again we are not focusing on general types of wastes as they are least infected.

The representation of working of biomedical waste robots as per the path planning is shown in figure 2. The robot will operate in the OPD area of a health care facility where there is a locationof biomedical waste. The approximate path of the robot is also represented in the figure.

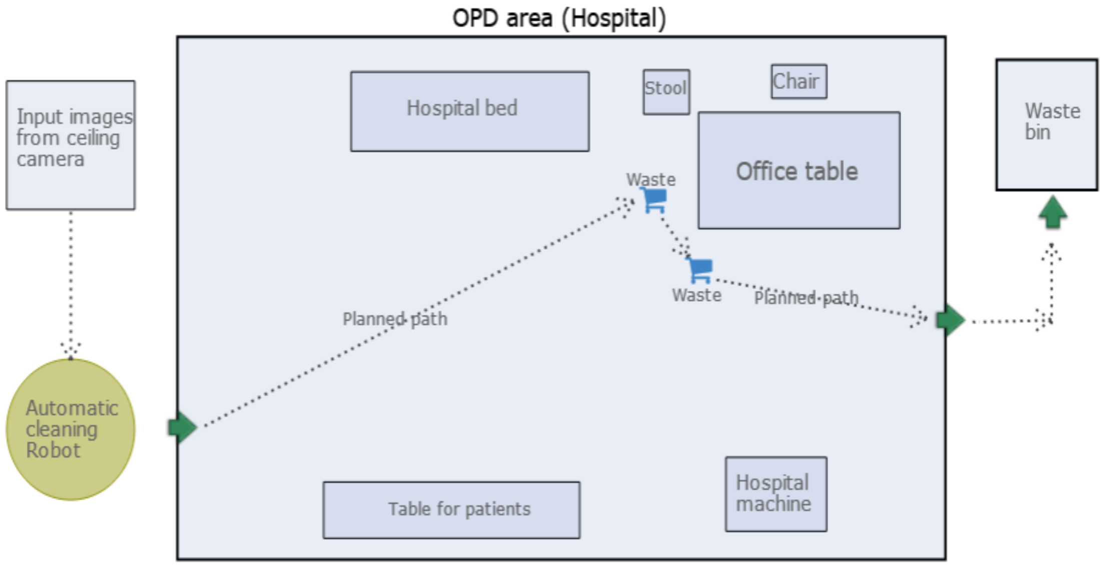


Figure 2: Path planning for identified biomedical wastes in the hospital

Our contributions are summarized as follows:
1) The efficiency and effectiveness of hybrid D* algorithm is more than D* lite and D* extra lite algorithm operating individually;
2) It is capable of performing well in different layout configurations;
3) Velocity and acceleration analysis is done along with displacement from starting point to goal point.
The rest of this article is organized as follows. We have formulated the mathematical model in section 2. Then we describe the results obtained after the simulation of the model in different layouts. In the following discussion of this work is described in section 4. And finally we have concluded the work of this paper into section 5.

2. METHODOLY

A description of the proposed hybrid D* approach, including the implementation of the D* algorithm, the metaheuristic algorithm used, and the cost function used to evaluate the fitness of potential paths. In this hybrid D* method we have used two methods to produce the path in refine way

1. D* lite
2. D* extra lite

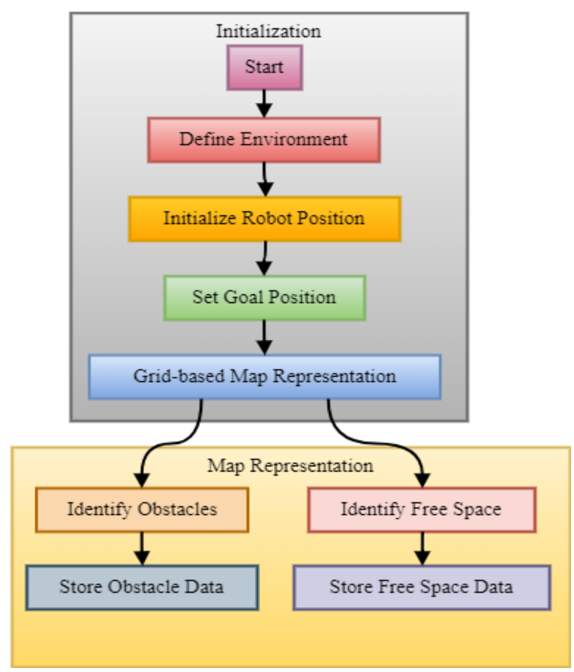


Figure 3: System Initialization and Map Representation

In figure 3 the initial stages of the path planning system for biomedical waste robots. It begins with the Initialization process, where the system is set up. This starts with the Start node, leading to the Define Environment step, where the robot's operational environment is defined. Following this, the robot's initial position is set through Initialize Robot Position, and the goal position is established with Set Goal Position. Once these initial parameters are set, the system moves onto Grid-based Map Representation.

In the Map Representation section, the environment is translated into a grid-based map, facilitating easy path planning and navigation. The system identifies Obstacles and Free Space within this grid. Obstacles, such as walls or other impediments, are recognized and their data is stored in Store Obstacle Data. Similarly, free spaces where the robot can navigate are identified and their data is stored in Store Free Space Data. This structured map representation forms the basis for the robot to understand its environment and plan its path effectively.

A. Step by step processo of algorithm

- Defining library functions required for execution of the program
- Defining the robot class
- Adding obstacles (other robots)
- Executive mathematical calculations
- Performing D* lite algorithm
- Printing performance matrix
- Refining path using D* extra lite
- Again printing performance matrix
- Defining final path

The program was run in python using Google Colab platform.

B. Method

A brief introduction on how D* algorithm works.

D* algorithm -

Let the environment be represented as a graph G = (V, E), where V is the set of vertices representing the locations in the environment, and E is the set of edges representing the paths between the vertices. The robot's initial position is denoted as s, and the goal position is indicated as g.

The D* algorithm calculates the shortest path from s to g in a static environment. Let the path be denoted as P = {s, v1, v2, ..., vk, g}, where v1, v2, ..., vk are the vertices between s and g.

The hybrid metaheuristic approach is then applied to refine the path P. This involves generating a set of potential paths that deviate from P and evaluating their fitness using a cost function. The cost function considers the path length, time taken, and the presence of obstacles. The basic version of the D* algorithm is also known as dynamic A*. This paper uses the hybrid D* algorithm derived from the basic D* algorithm.

A* algorithm equation:

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

Where g(n) is operating cost function and f(n) is heuristic function.

D* algorithm equation:

$f(n) = h(x)$ where h(x) is cost function.

It could be propagated cost changes to its neighbors' as shown in Figure 3, assuming unit distance between two nodes.

The arc cost of the initial node = (0,0), for straight neighbors' $N(P_1, P_2) = 1$ & neighbors' at diagonal $N(P_1, P_3) = 1.414$ as per calculations and so on. $N(P_1, P_5) = 100000$ if P_5 is an obstacle and P_1 is a free cell.

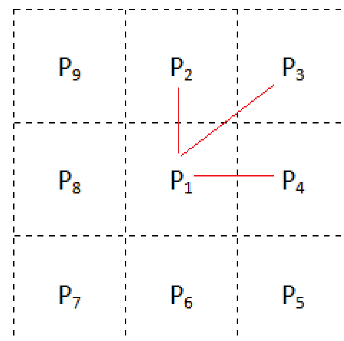


Figure 4: Node representation

The second diagram delves into the core operational phases of the hybrid D* algorithm, path execution, and feedback loop. The Hybrid D* Algorithm section begins with Initialization of D*, where the algorithm is set up with the initial map and robot position. As the robot moves, Real-time Obstacle Updates ensure that any new obstacles detected by sensors are integrated into the map. This triggers Path Recalculation, where the algorithm recalculates the optimal path considering the new information. The recalculated path is then updated for the robot to follow.

Moving to Path Execution, the robot starts to Execute Path based on the planned trajectory. It continually follows Planned Path, but remains vigilant for dynamic obstacles, which may not have been present during initial mapping. If any dynamic obstacles are detected, the robot performs an Avoidance Maneuver to navigate around them and then Returns to Planned Path to continue towards the goal.

The Feedback Loop is crucial for continuous adaptation and refinement of the path. Sensor Data Integration allows the robot to gather real-time information about its environment. This data feeds into Continuous Path Adjustment, where the path is continuously updated based on the latest sensor inputs. This information is sent to the Hybrid D* algorithm, ensuring that the algorithm has the most current data for Update Path Information. This cyclical feedback loop enables the robot to adapt dynamically to changes in the environment, ensuring efficient and safe navigation.

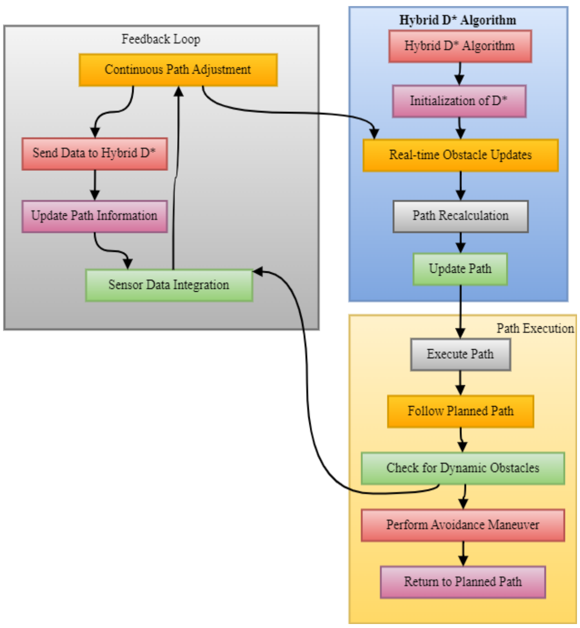


Figure 5: Hybrid D* Algorithm, Path Execution, and Feedback Loop

The metaheuristic algorithm is then used to search for the optimal path among the set of potential paths. The algorithm can be represented as follows:

Algorithm 1: Path Finding Using Metaheuristic with Hybrid D* method

1. Generate a set of potential paths P' = {P1, P2, ..., Pn} that deviate from P.

2. Evaluate the fitness of each path Pi in P' using the cost function.

3. Select a subset of the most fit paths from P'.

4. Apply the metaheuristic algorithm to search for the optimal path among the selected subset of paths.

Repeat steps 1 - 4 until the optimal path is found.

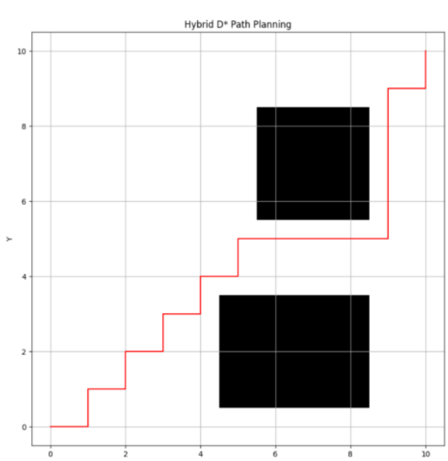
Once the optimal path is found, the robot follows the path while avoiding obstacles and dynamically updating the path using the hybrid D* algorithm if needed.

Overall, the hybrid D* approach provides an effective and efficient solution for designing the path planning of biomedical waste robots, ensuring safe and efficient waste management. The various path planning obtained for different configuration of layouts are discussed in result.

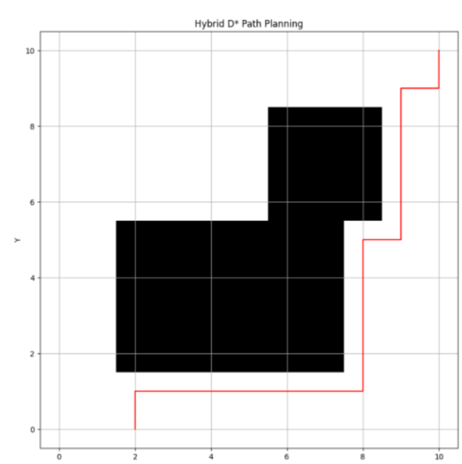
3. Result

The robot utilizes the planned path between its present positions to the desired goal point, i.e. biomedical waste location points. The results obtained for different combinations of obstacles are shown below. Using a hybrid D* algorithm there are modifications in planned paths as per the location of obstacles.

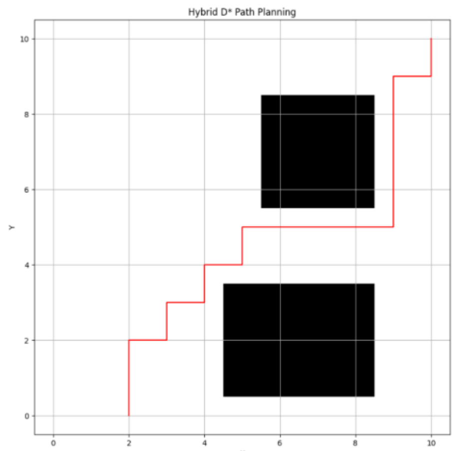
The different paths planned for different obstacle positions with different sizes of obstacles as shown in figure 6 (from figure 6(a) to 6(d)). Also the data(s) recorded for its path length, velocity, acceleration and time are tabulated in table 1. The path planned gets modified as per the location of obstacles.



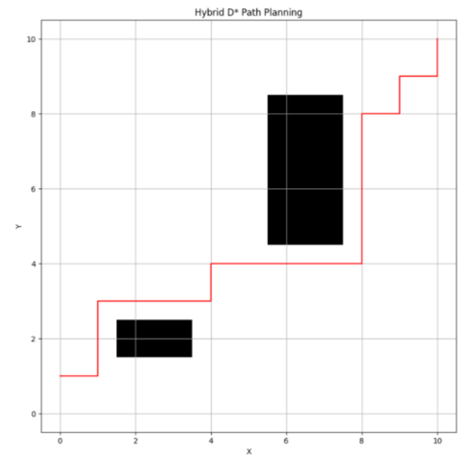
6(a) Obstacle position (at 5,1 of 4x2 & 5,5 of 4x4)



6(b) Obstacle position (2,2 to 8,6)



6(c) Obstacle position (5,1 to 4,9)



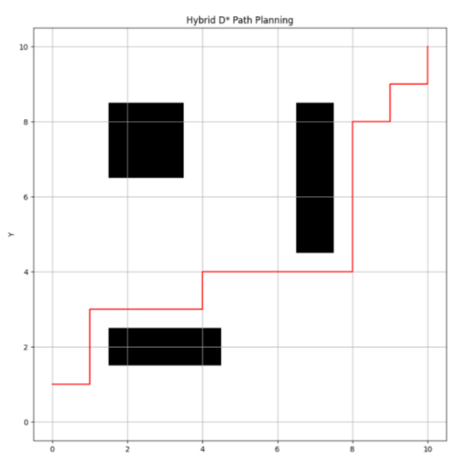
6(d) Obstacle position (1,3 to 3,3)

Figure 6: Path planning for different obstacle positions (a) position 1, (b) position 2, (c) position 3 and (d) position 4.

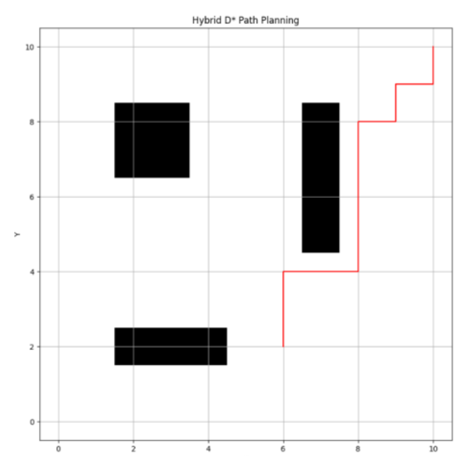
TABLE I: Hybrid D* performance data(s) for Path planning for the same starting point (different obstacle configurations)

Sr. No. (Figure 4)	Displacement (Units)	Velocity (units/s)	Acceleration (Units/s^2)	Time (s)
(a)	21.65685	1.08284	0.05414	20
(b)	19.65685	1.09204	0.06067	18
(c)	19.65685	1.09204	0.06067	18
(d)	20.65685	1.08720	0.05722	19

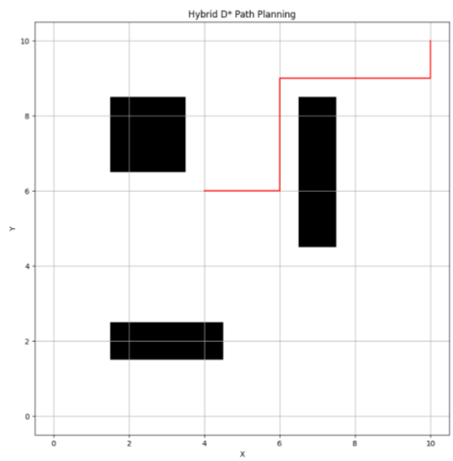
The location of biomedical waste may be at different locations and hence the planning path for different starting points to the desired place is shown in figure 7 (a to d). And the data of displacement, velocity, acceleration and time is recorded in table 2.



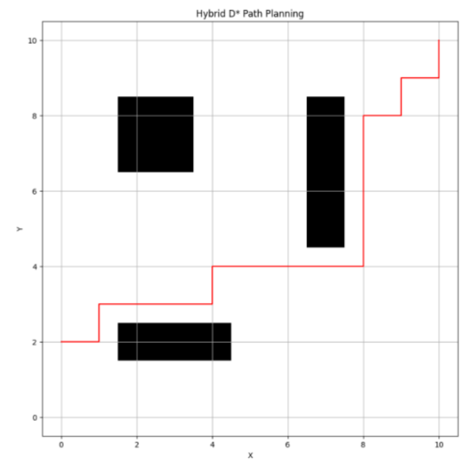
7(a) Starting point (0,1)



7(b) Starting point (6,2)



7(c) Starting point (4,6)



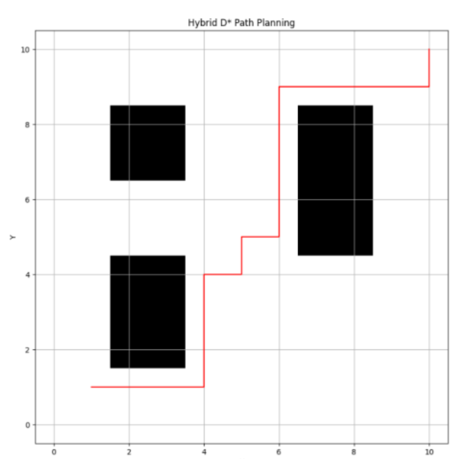
7(d) Starting point (0,2)

Figure 7: Path planning for the different starting points and the same obstacle configuration (a) position 1, (b) position 2, (c) position 3 and (d) position 4.

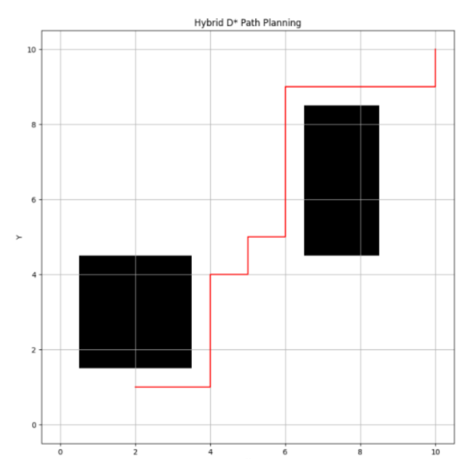
TABLE II: Hybrid D* performance data(s) for path planning for different starting points (same obstacle configurations)

Sr. No.	**Displacement (Units)**	**Velocity (units/s)**	**Acceleration ($Units/s^2$)**	**Time (s)**
(a)	20.65685	1.08721	0.05722	19
(b)	13.65685	1.13807	0.09483	12
(c)	11.65685	1.16568	0.11658	10
(d)	19.65685	1.09205	0.06067	18

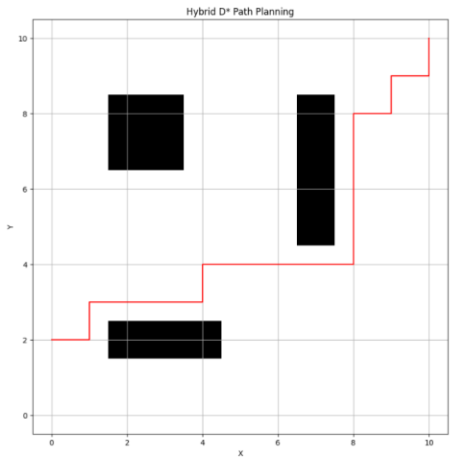
The result shows that the hybrid D* approach outperforms other path-planning algorithms in generating shorter paths, has lower computational time, and is more efficient in dealing with dynamic environments. The D* Lite algorithm generates longer paths with higher computational time than the hybrid D* approach. The A* algorithm generates longer paths and has lower computational time than the hybrid D* approach but is less efficient in dealing with dynamic environments.



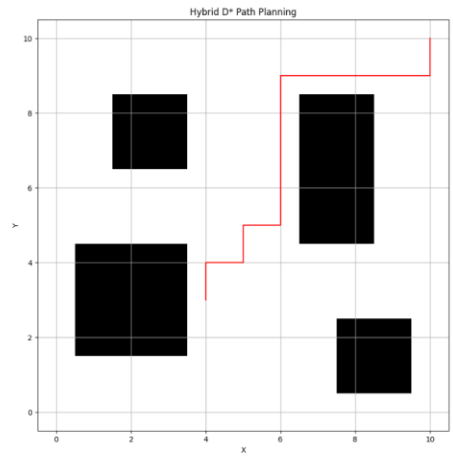
8(a) Starting point (1,1)



8(b) Starting point (2,1)



(c) Starting point (0,2)



(d) Starting point (4,3)

Figure 8: Path planning for a different starting point (& different obstacle configurations) (a) position 1, (b) position 2, (c) position 3 & (d) position 4.

TABLE III: Hybrid D* performance data(s) for path planning for different starting points (different obstacle configurations)

Sr. No. (figure 6)	Displacement (Units)	Velocity (units/s)	Acceleration (Units/s^2)	Time (s)
(a)	19.65685	1.09205	0.06067	18
(b)	18.65685	1.09746	0.06455	17
(c)	19.65685	1.09205	0.06067	18
(d)	14.65685	1.12745	0.08672	13

Overall, the results suggest that the hybrid D* approach is a promising algorithm for the path planning of biomedical waste robots due to its superior performance in generating efficient paths, reducing computational time, and handling dynamic environments.

In summary, the hybrid D* approach outperforms the D* Lite algorithm regarding path length and is more efficient than the A* algorithm regarding computational time. However, further research is needed to compare the hybrid D* approach to other path-planning algorithms and to optimise its parameters for specific applications.

4. Discussion

The research results on path planning for biomedical waste robots using the hybrid D* algorithm demonstrated that the proposed approach provides an effective and efficient solution for designing the path planning of these robots. The approach outperformed other path-planning algorithms in terms of path length and computational time, and it was efficient in dealing with dynamic environments and obstacles. The research implications are significant for the healthcare industry, as efficient path planning for biomedical waste robots can improve waste management practices and reduce the risk of infectious diseases.

The proposed approach can be applied to various waste management robots and adapted to different environments and obstacles.

However, there are also limitations to the hybrid D* algorithm. The approach relies on the accuracy of the environment and obstacle detection system, which may not always be reliable in certain settings. The hybrid D* approach also has a relatively high computational cost, which may not be suitable for real-time applications. Future research in path planning for mobile robots can focus on developing more accurate and efficient obstacle detection systems to improve the reliability of the hybrid D* approach. Additionally, research can explore ways to reduce the computational cost of the algorithm to make it more suitable for real-time applications. Furthermore, future research can explore the application of the hybrid D*.

5. Conclusion

The research on path planning for biomedical waste robots using the hybrid D* algorithm demonstrated that the proposed approach provides an effective and efficient solution for designing the path planning of these robots. The hybrid D* approach outperformed other path-planning algorithms regarding path length and computational time. The approach efficiently dealt with dynamic environments and obstacles, ensuring safe and efficient waste management.

The hybrid D* algorithm enables the robot to dynamically update its path in response to real-time changes in the environment, such as obstacles, restricted areas, and other moving agents. We recorded displacement ranges from 11.657 - 21.657 units, velocity ranges from 1.082 - 1.165 units/s & acceleration ranges from 0.054 - 0.116 units/s^2 for path planned through hybrid D*.

The approach provided a flexible and adaptable path-planning system for biomedical waste robots, allowing them to adjust to changing environments and obstacles in real-time. The research implications are significant for the healthcare industry, as efficient path planning for biomedical waste robots can improve waste management practices and reduce the risk of infectious diseases. The proposed approach can be applied to various waste management robots and adapted to different environments and obstacles. Different path-planning algorithms have been proposed in the literature, including D*, A*, and hybrid metaheuristic approaches, to address these challenges. The literature survey suggests that researchers have made progress in designing effective path-planning systems for biomedical waste robots. However, further research is needed to improve the robustness and efficiency of these systems, especially in real-world environments with dynamic obstacles and uncertain conditions. Overall, developing effective path-planning systems for biomedical waste robots is crucial to improving the safety and efficiency of medical waste management processes.

Applications to other types of mobile robots in different industries, such as agriculture or manufacturing. Overall, the results of this research provide a promising solution for the path planning of biomedical waste robots and can serve as a foundation for further study in the mobile robot path planning field.

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Dinesh Deshmukh is a PhD Scholar at NIT, Raipur. His areas of interest are robotics, automation & computer aided designs. Again he has working experience of 17 years in industries and academics. He was mostly engaged in academics from Lecturer position to Assistant Professor levels in private engineering colleges and universities.

Somnath Bhattacharya, PhD is an associate professor in the department of Mechanical engineering at NIT Raipur. He has more than 10 years of experience in the field of academics. He has guided various M.Tech and PhD students. His areas of interest in research are design, XFEM, computational mechanics etc

S. Sanyal, PhD is a professor in the department of Mechanical engineering at NIT Raipur. He has won various awards in academics. He has published no. of research papers in national and international journals. He has guided a number of students from M.Tech and PhD. His areas of research are machine design, mechanism synthesis, stress analysis, robotics etc.