Challenging of Path Planning Algorithms for Autonomous Robot in Unknown Environment

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***Abstract*—When we do not have information of the environment, we called it unknown path planning. This paper shows the differentiable path planning methods and approaches of the algorithms in unknown environment and to understand on how the algorithms implemented in the unknown environment with some kinds of obstacles. The suitable implementation of methods and algorithms for the path planning are important for the autonomous robot to complete the path smoothly. We had done some reviews of individual paper to find the best method and algorithm in the path planning for the autonomous robot. From the reviews between the individual papers, we obtained that some algorithms are suitable for some cases in unknown environment. The evolution of D* algorithms give interesting and challenging methods in unknown environment especially in terms of speed up find the shortest path and when discover the new obstacle.**

***Index Terms*—path planning, obstacle avoidance, algorithms, unknown environment, autonomous robot, on-line path planning.**

I. Introduction

A lot of advanced equipment had introduced in everyday life for the world that is rapidly developing. There have been use an autonomous vehicle or robot in many of situation to facilitate a job such as unmanned vehicle which is a vehicle without a human on board. In others words unmanned vehicles can be autonomous vehicles which are capable sensing their environment on their own or can either be remote controlled or remote guided vehicles.

All types of the unmanned vehicles have their own specialty in different types of human desired and situation. For example types of unmanned vehicle, such as unmanned ground vehicle (UGV), unmanned aerial vehicle (UAV) for in the air. In the operation of underwater, namely (UUV) which is unmanned underwater vehicle and unmanned sea-based vehicle for include surface craft (USV).In this paper we focus on UGV only. We devote more in UGV application in unknown environment which is frequently used in surveillance or purposed to perform military tasks in place of soldiers with minimizing the human oversight. The unmanned vehicle also commonly contributes as military robot that capable to work outdoor or indoor in any types of ground. The UGV are normally combine with the artificial intelligence, computer technology and advanced processor developments which have various sensors, cameras or arms mounted on them. However for the successfully application on the autonomous vehicle or UGV, the routing or path planning is the most important part to consider [1].

In this paper we focus on finding the path planning method or technique to run the UGV or mobile robot with unknown environment or on-line path planning which is the complete information about the environment is not available to robot. There had two types of path planning, namely static path planning and dynamic path planning which is static path planning refers to the environment with no moving objects or obstacle and dynamic is refers to environment containing moving objects such as moving obstacle. The unknown environment always refers to the dynamic path planning. Moreover the algorithms for the path planning used on different kinds of situation in the obstacle occur, collision avoidance and the optimal path to search. Several of reviews on individual papers are discussed and search the problem to indicate the approach of algorithms or method are used successfully in the path planning.

The organization of this paper which is in section II some of concepts path planning problem are given based on the review of the individual paper. In section III, the surveys of current research and existing systems. Some of short reviews of individual papers are presented in section IV. Finally we conclude this paper in section V.

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II. THE ORETICAL BACKGROUND

In unknown environment, the UGV and mobile robot need to learn how it works in order to make best decisions or planning such as in the path planning. A suitable method are used to find the information of the unknown environment which is we do not know the obstacles in advanced. Moreover, path planning is dynamic when the path is continually recalculated as more information are available and contains changing object such as moving objects, whereas static planning refers to environment which do not have moving obstacles other than a navigating robot [2].

In addition, the path planning are local and global depend on the algorithms where the information about the environment is priori or not to the algorithms. A global path planning is when the information about the environment already known based on maps, cells or grid. Path planning local when the robot has no information about the environment and need to sense the environment before deciding to move towards target for obstacle avoidance and generates trajectory planning [2].

There are two types of path planners which is off-line and on-line path planning. The off-line path planning is when the complete information about the environment such as trajectory of obstacle is known in advance. Some of the techniques used for off-line path planning such as grid, meadow map, voronoi diagram or visibility graph. On-line path planning is not complete information about the environment in advance and the robots gets the information by using sensors as it moves through the environment [2].

A different approach is needed for unknown environment where have the obstacle movement that cannot predicted in advance. In this part we can conclude that unknown environments are same condition with online path planning and local path planning.

III. SURVEY OF CURRENT RESEARCH AND EXISTING SYSTEM

In the Unmanned Ground Vehicles (UGV) whether it is autonomous or be controlled by human, the systems have evolved into highly capable vehicle. It is used by the armed forces worldwide or the security forces and mostly for surveillance or data acquisition purposes.

The UGV or autonomous robot is widely use in military and industry purpose to facilitate a human task. Furthermore the military are used in the surveillance purposed which is fully equipped with several of sensors, camera and arm mounted on them for avoiding an intruder. Military UGV are more complicated because of multiple cohesive systems are needs for a UGV to be an effective and relevant system. For example talon bomb disposal vehicle by foster-Miller which is the robot arm includes a gripper, night vision cameras, microphone to monitor ambient sound and a claw for digging as in Fig. 1 [2].

Besides that UGV or autonomous robot are able to detect the objects of interest such as people and vehicle, collect about the information of the environment, work for extended hour without control by human, avoiding the harmful situation by disarm or remove explosive.

IV. SHORT REVIEWS ON INDIVIDUAL PAPERS

In this section, we focus on the review of the individual paper for UGV or autonomous robot in the unknown environment. Each of the paper has their own purpose and variations methods in overcoming the problems encountered.

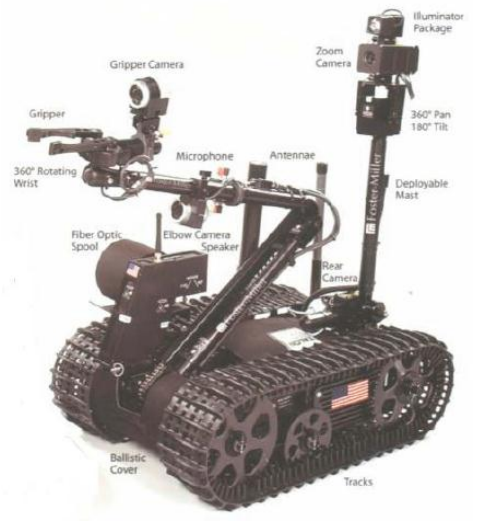

Figure 1. Example of UGV: Talon bomb disposal vehicle by foster-miller equipped with various weapon.

A. *Full-Sized Path Planning of Wheeled Mobile Robot with Simultaneous Free Space Locating Capability, by Ya-Chun Chang and Yoshio Yamamoto [3]*

Problem statement: The mobile robot hard to perform well in the path planning because of no reliable map to solve in a navigation algorithm problem for dynamic environment.

Proposed solution / Methodology: Implement a hybrid path planning algorithm for the design of autonomous vehicles such as mobile robot. The hybrid model of path planner is designed to help the robot in repeated transversals in unknown and obstacles environment.

The hybrid path planning is based on Potential Field method and Voronoi Diagram approach and is represented with the ability of concurrent navigation and map building. The motion equation of the mobile robot is derived. The feedback linearization technique is use as a control method which linearization is achieved between the control inputs and appropriate output.

The Potential Field method is use for obstacle avoidance during navigation. Its use the closest sensory measurement from the obstacle surface and define a smallish particle obstacle at the closest location which generates a small repulsive potential as well. Hough transformation is use to a preliminary requirement which is obstacle recognition ability for dead lock avoidance. The Voronoi diagram approach has been taken into account for complete path planning in helping the mobile robot to avoid being trapped by concave environment.

Result: The hybrid planner takes the superiority from low construction cost of environment by Voronoi diagram and lower searching cost by adding appealing potentials on selected edges on the graph compared to A* and Dijkstra algorithms. Moreover, by retracing on the generated graph (free path), the local minimum problem which is often occur in a dead-end and concave environment can be solved. Finally, the mobile robot can save the time in exploration for autonomous navigation and perform in unknown environment.

Pros & Cons: The collision avoidance algorithm constructed map information in helping the mobile robot travel the predefined position from start and goal in the path planning and between any targets on the existing map. The new Voronoi structure can be naturally merged and the map information can be increase if the robot starts a new exploration to an unvisited area.

B. *Study of Improvement of D* Algorithms for Mobile Robot Path Planning in Partial Unknown Environments, by Jianming Guo and Liang Liu [4]*

Problem Statement: To find a better quality of D* algorithm in terms of reduce the cost for the unknown environment.

Proposed solution / Methodology: D* algorithm are used in path planning in dynamic environment. D* improved for searching the optimal path and total angle changes in achieving a better path planning. The regularity grid method is use as represented the work environment of the robots. It uses serial number to represent every grid and the number of grid is depended to the size of robots and workspace for ensures the robot can move in the space. The improvement of the algorithm may search in the neighbor grid cells in 16 directions instead of eight directions by using D* algorithm for path planning.

Result: The improved of D* algorithm spend less in length and total angle of path. Hence find the neighbor grid cells in 16 directions instead of eight direction by using D* algorithms for path planning.

Pros & Cons: The improvement of D* algorithm had made the robot path planning smoother even there are not using the multiple of mobile robot. The advantage of algorithm based on conventional D* algorithm, it is a good foreground to research the path plan algorithm and make the direction continually changed and at the same time solve the calculation problem.

C. *Real-time Motion Planning for Mobile Robots by Means of Artificial Potential Field Method in Unknown Environment, by Tao Zhang, Yi Zhu and Jingyan Song [5].*

Problem statement: The mobile robot cannot reach the global minimum because it is trapped at the local minimum. Most of the current methods for solving local minima issue of APF method on-line in the unknown environment have their individual disadvantages.

Proposed solution / Methodology: Currently, the algorithms to solve the local minima issue of the APF method can be categorized into three types such as LMR (local minima removal, local minima escape (LME) and local minima avoid (LMA). Among the whole APF methods, most of LME methods and part of LMA methods can be employed for real time applications such as virtual target, random walking(RW),multiple potential, virtual obstacle (VO) and wall following methods. However there exist the issues of limit serviceability, and low reliability. Then new switching conditions among various behaviors are reasonably designed in order to guarantee the reliability and the generality of the method. Comparing with the previous methods which are normally considering specific obstacles, the effectiveness of this proposed method for the environment with convex polygon shaped obstacle has been theoretical proved.

The new method greatly weakens the blindness of decision making of robot and it is very helpful to select appropriate behaviors facing to the changeable situation. APF-based obstacle avoidance behaviors (when robots do not trap into the local minimum, it normally adopts the APF method for obstacle avoidance and access to the target). Approaching goal behavior (Only neglects the repulsive force of obstacle and considers superposition force equal to the attractive force of target).

Wall-following behavior (through the movement along the edge of obstacle, robot can bypass obstacle and escape local minimum trap).

Result: With comparing other traditional APF methods, the proposed method is more applicable for actual environment. It can realize effectively real-time motion planning with high reliability and generality. The cognitive capability of mobile robot to the environment can be improved in order to adapt to the changeable situation. The proposed method shows that it can be suitable to more complex unknown environment.

Pros & Cons: The algorithm solves the local minima issue and performs well in unknown environment because it can solve the problem such as in complex environment. This method can assist robot escape the current trap when it traps into the local minimum and also efficiency in the convex polygon obstacle environment.

D. *A Simple Local Path Planning Algorithm for autonomous Mobile Robot [6].*

Problem statement: The search of the path planning which is a mobile robot with a specified geometry and has to determine the correct direction to reach destination.

Proposed solution / Methodology: Approach the bug algorithm family and introduces the new algorithm namely PointBug in local path planning. The PointBug are used to try reduce the usage of outer parameter of obstacle. The robot is assumed equipped with an infinite range sensor, odometer and digital compass with ideal positioning. It determines where the next point to move toward target from a starting point and next point is determined by output of range sensor which detects the changes in distance from sensor to the nearest obstacle. The robot can scan the environment using range sensor by rotating from 00 up to 3600 at a constant speed. Meanwhile the robot ignores the sensor reading at rotation 1800 to avoid detection of previous sudden point. If there is no sudden point, within a single 3600 rotation, the target is assumed unavailable and then the robot stops.

Result: The information about the environment can be obtained immediately from the range sensor and the less use of outer parameter of obstacle area can shorter the total path length for mobile robot.

Pros & Cons: The new implement of bug algorithm for local path planning showed the better performance in range sensor detecting and scanning the obstacles. It is suitable to implement in unknown environment path planning. New approach of path planning, the point to point Sensor Based Path Planning Algorithm needs minimal amount of prior information compared to other bug algorithms which is need global information to update.

E. On-line Path Planning for Mobile Robots in Dynamic Environment, by P. Raja and S. Pugazhenthi [7]

Problem Statement: There is no complete information about the environment in advance. The autonomous robot are hard to fine the best on-line path planning where the obstacles are static and moving.

Proposed solution/ Methodology: The authors proposed algorithm using mathematical model and Particle swarm optimization (PSO) technique. The obstacle may in any shapes static or dynamic which can move without rotation on the own axis. The relative velocity should lie outside the collision cone for mobile robot to avoid collision with obstacle. For the environment with multiple obstacles the most imminent collision is avoided first. To arrive at the shortest collision free trajectory and satisfying dynamic constraints the PSO technique is use to optimize the velocity parameters of the robot.

Result: The mathematical model using PSO technique as proposed algorithm are effective and efficient in reaching the target along the shortest possible path and applicable to the environments which have static and dynamic obstacle.

Pros & Cons: The proposed algorithm presents the advanced evolutionary technique which is easier to implement and there are fewer parameters such as velocity, acceleration constraints of mobile robot, the mass of the robot including its payload and the coefficient of friction between the wheels of the robot and the floor to be adjusted. The advantage of the proposed technique is applicable in environment that has moving target.

F. Space D A Path-planning Algorithm for Multiple Robots in Unknown Environments, by Luan Silveira, Renan Q Maffei, Silvia S. C Botelho, Paulo L. Drews Jr. Alessandro de L. Bicho and Nelson L. Duarte[8]*

Problem statement: In increasing of dynamic obstacles in existence unknown of an environment and the possibility of collision between the dynamic obstacles as the number of mobile robots grows.

Proposed solution / Methodology: Space D* algorithm are from D* algorithm with the space colonization algorithm developed for path planning of multiple robots in unknown environments. Each robot in the set of markers apply D* algorithm and updating the costs. By the modification of Space Colonization algorithm, the robot navigation is done. D* algorithm it calculates their directions of movement. The information of the appearance of obstacle can be exchanged when robots cross each other and that create the feasibility of avoiding paths that are blocked then that only lastly the robot will notice.

Result: The approach method are approve and find the superiority using only D* method. There occurs conflict situation where the paths of two or both intersect. In using the Space Colonization algorithm, both robots recalculate the path in order to diverge and achieve the goal.

Pros & Cons: The advantage of the proposed algorithm can avoid the collision between the dynamic obstacle when information about the presence of obstacles can be exchanged when the robot cross each other. The space D* algorithms can avoid of local minimums problem same as the conventional D*. The algorithm can generating path in spacious surroundings and dynamic environment with unknown obstacle. This can be more applicable to realistic situations.

G. A New Bug-type Navigation Algorithm for Mobile Robots in Unknown Environments Containing Moving Obstacles, by Yi Zhu, Tao Zhang, Jingyan Song and Xiaqin Li [9]

Problem statement: The limitation of the traditional bug algorithm which is generating long path, limited to static environment and ignoring implementation issues.

Proposed solution / Methodology: Bug algorithm presents a good framework to reconcile reactivity and convergence even though with limitation. Then, DH-bug algorithm (distance histogram bug) is using to maintain the framework but overcome the limitations with dynamic environment. Furthermore a new mode and the related switching conditions are designed for dealing with moving obstacles. An awareness method termed the Distance Histogram (DH) method which takes many implementations issues into full account is proposed for implementation DH-Bug on real robots. DH-bug algorithm contribute a new motion mode that is designed for avoiding moving obstacles and therefore DH-bug can applied in dynamic environments.

Result: DH-Bug shows it based on several reasonable when there are moving obstacle and it can generates shorter average path length with safely avoid moving obstacle and reach the goal. The experiments on real robots can verify its applicability in both static and dynamic environment with moving obstacles. Even though from the some simulation it find the DH-Bug cannot reach the goal, but it does not mean it is the weakness of the algorithms because it is due to unpredictable motion of the moving obstacles.

Pros & Cons: The improvement of bug algorithms overcomes the limitation of the previous work in the path planning. It generates shorter average path length and performs well on dynamic environment which is containing moving obstacle. DH-bug can implement an abstract concept and for realizing this concept on real robots.

V. DISCUSSION

From the individual papers that have been reviewed, we can see various ways to overcome the problems in path planning in terms of the unknown environment, collision avoidance and shortest path planning.

In the paper we have reviewed, the paper used all the method and algorithm for the path planning such as Bug algorithm, D* algorithm, potential filed method and particle swarm optimization. For the best result in the path planning problem, the author had make the improvement of the algorithm such as in paper B, the improvement of D* algorithm. From the improvement, the performance of autonomous robot can be increase by reduce the total length in the path planning. Same as in paper F, the author proposed the new algorithm from combination of the D* and space colonization algorithm. From that, we can find the method and algorithm suitable for multiple of dynamic obstacles.

The paper D and G described the improvement of the Bug algorithm which is PointBug and DH-Bug. From the paper introduced of PointBug, we can see the movement in path planning can be reduced and DH-Bug can proved to be used in dynamic environment with multiple of obstacles. However the DH-Bug algorithm path planning can be interrupted by unpredictable obstacles occurs.

VI. Conclusions

We can conclude that the reviews of the individual papers are important in understanding more about the path planning problem accordance with unknown or dynamic environment.

Therefore, from the review, we can see and choose the better proposed solution to implement in the path planning for UGV or mobile robots based on different situation. In unknown environment there had many kinds of situation and obstacles that occurs such as static and dynamic obstacle in the environment. Hence the suitable method and approaches are used due to complex environment with multiple of obstacles.

In addition, some of the methods and algorithms that are used in path planning are also have its advantages and disadvantages. For example, in unknown environment, D* algorithms are commonly used in the path planning and there are also make the improvements to overcome the previous work problem.

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