A Review on Mobile robots Motion Path Planning in unknown environments

Weria Khaksar, S.Vivekananthen, Khairul Salleh Mohamed Saharia, Moslem Yousefi, and Firas B. Ismail

Center of Advanced Mechatronics and Robotics, Universiti Tenaga Nasional (UNITEN), 43000 Kajang, Selangor, Malaysia.

E-Mail: {weria, kananthen, khairuls, moslem, firas }@uniten.edu.my

Abstract— **Robotics sector have achieved enormous founds in recent years due to its high demands in factories to carry out high-precision jobs like riveting and welding. They are also often applied in special situations that would be hazardous for humans such as disposing toxic wastes or defusing bombs. Mobile robots alone however have gained much focus from researches relating optimization of their motion path planning. In this paper, a brief review on mobile robots motion path planning in unknown environment have been done based on recent founds. The paper categorizes motion path planning into two groups which is the Optimized Classic Approaches and Evolutionary and Hybrid Approaches. The optimized classic approaches represents the recent optimized motion path planning that implies the classic approaches such as A* search algorithm, Rapidly-exploring Random Trees (RRT), D* and D* Lite algorithm. The evolutionary and hybrid approaches are those adapts Artificial Intelligence (AI) such as neural networks (NN), genetic algorithms (GA), fuzzy systems and reinforced learning either acting alone or as hybrids together with other algorithms. Finally a comparison between these two categories are done differentiating their advantages and disadvantages.**

Keywords—component; motion path planning, unknown environment, artificial intelligence,mobile robot.

I. INTRODUCTION

Robotics usage have been widespread current days. It can be said that almost all sectors apply robotics systems in order to carry out technical processes. It has been a rapid growth for the robotics systems since its invention and it is getting more and more advanced. Various sectors have various reasons on developing the robots based on the usage. For example, in manufacturing sector the robotic systems capability of impressively ameliorating the quality of work without errors the way human do, leads to an efficient production time and output. Development of mobile robot to undergo tedious tasks under hazardous and hostile environment have been emphasized lately in order to minimize the risks to human beings. These sensor equipped mobile robots are applied in cases where the robot have to navigate and simultaneously complete a task such as, servicing, surveillance and exploring. The mobile robots can either be teleoperated directly by human or autonomously interact with the environment based on the system programmed. There may be various types of mobile robot equipped with different sensors, suiting the tasks given, but the main challenge here in advancing mobile robots is obstacle avoidance and path planning from start to goal position. The most rudimentary need in application of robotics is to have algorithms that help converting high level commands into low level instructions for the robot to move accordingly. The process is often described as motion path planning or navigation planning for robots. Motion path planning (MPP) are various techniques of avoiding obstacle and reaching targeted position. MPP can be categorized into global or local path planning. A global path planner usually generates a low-resolution high-level path from start to goal, avoiding only large obstacles and deals with navigation around the environment setup. Meanwhile, the local path planning is a high-resolution low-level path only in a near segment from global path start to goal, helps avoiding small obstacles and deals with the motion planning such as angles of turn, and suitable velocities when the mobile robot have no knowledge on the map of the environment. Local path planning involves real-time decision making and localization. Both the global and local path planning may involve dynamic moving obstacles in their subjected environment. It can be said that navigating through an unknown environment is much difficult than those which are known. When the environment is unknown the robot's movement desperately relies on the data collected from sensor and the efficiency of algorithm to sort out a good path. The sensors located on the mobile robot will help to detect the obstacles and map the environment as it navigates towards the targeted position. However, the sensors alone can't do all the work, the main control relies on the algorithm or techniques used to program the interaction of the mobile robot when navigating. For example, when an obstacle is encountered in front, to make decision on whether to proceed left or right depends on the algorithm. Besides that, when a virtually tested algorithm is then put into test on a real robot, there may be a certain errors since the data collected from the sensors may contain noise. The algorithm needs to be further improved to adapt and minimize the noise errors to produce better trajectory on its path. The more efficient the algorithm the more productive results such as shorter path length and lesser time consumption upon reaching the targeted position. Researchers in recent years, have been working hard producing various algorithms and ways to overcome encountered problems in MPP and improve previous founds in order to get better outcomes for mobile robot. We found that

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the review articles on motion path planning that have been done before this are too generalized and is not keeping up with the recent founds. This review article emphasizes on MPP when the robot have no prior information on the environment tested. The unknown environment may contain either static obstacles or dynamic obstacles or both. In order to produce a better review papers, a brief review on research papers that have been submitted in recent years to various conferences and mediums have been done.

II. CLASSIFICATION OF MOTION PATH PLANNING APPROACHES

The MPP for an unknown environment nowadays can be divided into several sections which ease the explanation. The sections are as stated below:

A. Optimized Classic Approaches

The optimized classic approach can be divided into three sub-group methods that have been trend of research recently;

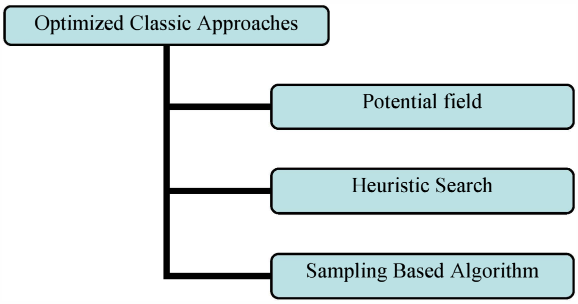

Figure 1. Common methods under Optimized Classic Approaches

The optimized classic approaches are the classic MPP that have been optimized over the year of found by recent researches. One of the most significant ways to optimize a MPP is to come up with a better algorithm that helps to improve the MPP in desired aspect. Artificial potential Field (APF) method has always been the huge interest for the researchers in mobile robot path planning since the found by Khatib (1986) [1]. According to the APF method, the obstacles presumed to generate repulsive force, while the goal point generates attractive force, all inside a configuration space. When a point mobile robot in placed in the C-space, it will travel to the goal point which have the attractive force by efficiently avoid the obstacles in between [2]. Since it was an early found, the algorithm needs improvement in various aspects. For example, the robot turn out to be trapped or stagnant when there is an equal sum of repulsive and attractive forces or when the repulsive potential is not minimal near the goal point. This situation is often described as the local minima problem [3]. One of the recent solutions to overcome this problem is to introduce a new form of repelling potential and attractive potentials with respect to relative position, velocity, and acceleration between the robot and the goal (Lu Yin, Yixin Yin and Cheng-Jian Lin, 2009) [4]. The new repulsive algorithm introduced by M.Hamani and A.Hassam, (2013) helps improve the quality of the trajectory and to reduce the oscillations when the goal is close to obstacle [3].

Heuristic search methods are one of the classic approaches. One of the earliest methods such as the A* search algorithm also been optimized over the years for path planning in unknown environment. It is an extension to the Edsger Dijikstra (1959) algorithm and utilizes the uniform–cost search and heuristic search to efficiently compute the best –first search with less time consumed [5]. However, the drawbacks of this method is its memory requirement. Taking in account that the entire open list needs to be saved, the algorithms is severely space-limited in practice. Based on the research paper done by Leszek Podsedkowski et al. 2001, by researching different A* heuristic cost functions and introducing a new statement to this functions while the nodes placed in the discretized configuration space [6]. An algorithm called Intelligent Global Path Planner with Replanning (IGPPR) was introduced which in general when the robot detects a new obstacle on its way, the algorithm will remove all the nodes colliding with the obstacle and their successors and inserts all predecessors of the removed nodes into OPEN list. If in case the robot encounters the earlier memorized obstacles, it will insert into OPEN list all the nodes, which can possibly have successors in these place of obstacles [6]. Then, the IGPPR will search for the graph in similar ways to A* search procedure.

In 1994, Anthony Stenz developed Dynamic A* Algorithm, which is also known as D* Algorithm or Stenz algorithm for partially or completely unknown dynamic environment [7]. The algorithm is capable of updating the map of the unknown environment and replanning the path when it detects a new obstacle on its path. D* Lite Algorithm determines the same path as D* Algorithm but it is reverse searching method and algorithmically different when compared to D* Algorithm. In a research conducted by Soh Chin Yun et al., (2010), the D*Lite Algorithm was investigated and enhanced [9]. The enhanced algorithm is found to be more effective in finding shorter path from start to goal with no information on obstacles via MATLAB simulation. A side from all methods mention above, the sampling based path planning algorithm such as the Rapidly-exploring Random Trees (RRT) which was originally proposed by S.M. LaValle et al. has been researched and modified to suit to be applied to the mobile robot when there is no prior information of the environment given to it [10]. In a paper that have been published recently by Zou Yipping et al. (2014), an improved Sensor-based Random Tree (SRT) path planning algorithm have been presented. This algorithm is efficient in overcoming SRT's redundant branches and low efficiency by combining the nonholonomic constrain conditions and the candidate viewpoint optimization, which directly improves SRT's path planning efficiency and stability [8,11]. In the improved SRT, the random nodes generated have to be selected to make them partial towards the targeted position. If one of the nodes generated, is found impassable, the algorithm backs up to the last node and reselects clockwise, avoiding local minima problems, and then it marks all the explored nodes [11]. When tested on the static robot simulation, it is verified that the SRT delivers better results compared to classic RRT, RRT-Dual and Probabilistic Road-Mapping (PRM). The sampling –based Tabu search algorithm have been proposed by Weria Khaksar et al. (2012) is also a potential path planning in unknown environment with low computational cost and low –memory acquiring [12].

B. Evolutionary and Hybrid Approaches

The evolutionary and hybrid approaches can be divided into two sub-group methods that have been trend of research recently;

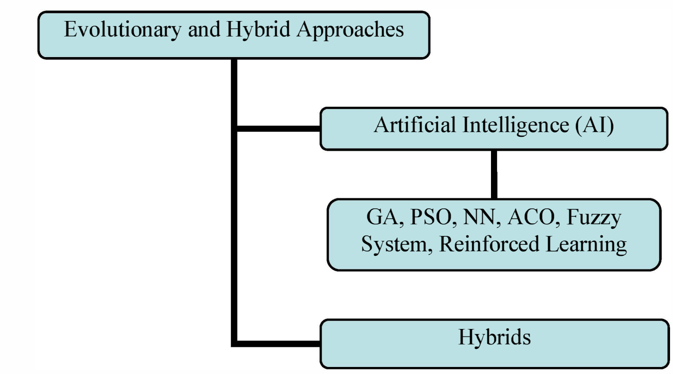

Figure 2. Methods under Evolutionary and Hybrid Approaches

MPP is always a huge area to be studied and researched upon, which means innovation is also a way of advancing it rather than optimization alone. The classic optimized approaches may seems to solve the problem, guiding the mobile robot avoiding the obstacle from start to goal, however it do have its limitations. The computational time of classic approaches seldom meets the expectation and need. In order to lower the computational time, researchers often come up with new approaches or ended up combining the classic approaches with AI's such as neural networks, genetic algorithms, fuzzy systems, reinforced learning and many others. These kind of combination often called hybrid approaches. Recent new and hybrid approaches promises better time consumption and found to be effective via simulation and tests.

Genetic Algorithm (GA) is a randomized searching strategy via utilizing mechanism analogous natural evolution. Certain potential solutions are encoded as chromosomes which forms a population and fitness function is used to evaluate each individual in these population. Soh Chin Yun et al. (2011), conducted a research on using GA to move the robot, identifying the obstacle and reaching the designated goal in an unknown environment [13]. The path remembering and virtual wall technique increased the efficiency of the algorithm and avoids the same position to be traversed over and over. In a research paper done by Wanmi Chen and Heping Qin on 2011, the genetic algorithm and simulated annealing algorithm was combined used in order to overcome the shortcomings of slow convergence of simulated annealing algorithm and poor local search of genetic algorithm [14]. When tested, the simulation results shows the hybrid genetic algorithm has higher convergence rate, probability of optimal solution accuracy and improved map adaptability compared to traditional algorithm. Genetic algorithm is also often paired with other well-known MPP such as artificial potential field techniques in order to solve the local minima problem. In a research paper done by Qing Li et al. (2011), GA is introduced as an optimizing agent for their artificial potential field mainly proposed for solving local minima problem [15]. The simulation shows a reliable efficiency and problem solving which results in shorter path length, solving local minima problem and maintains the low computational cost of traditional APF.

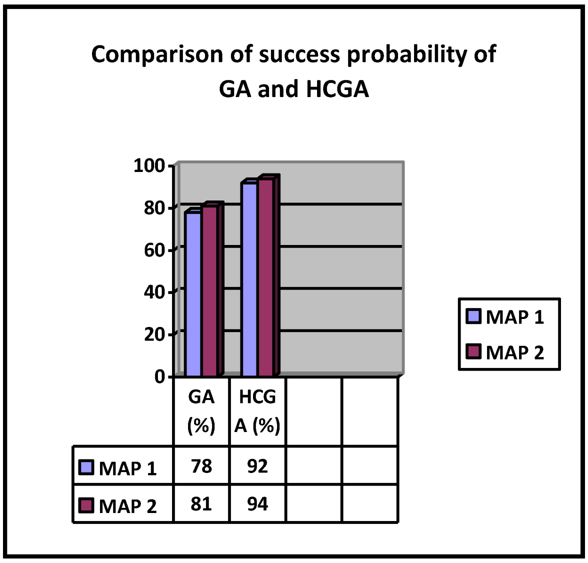

Figure 3. Comparison of success probability of GA and HCGA base on Wanmi Chen and Heping Qin, 2011 ressearch paper [14].

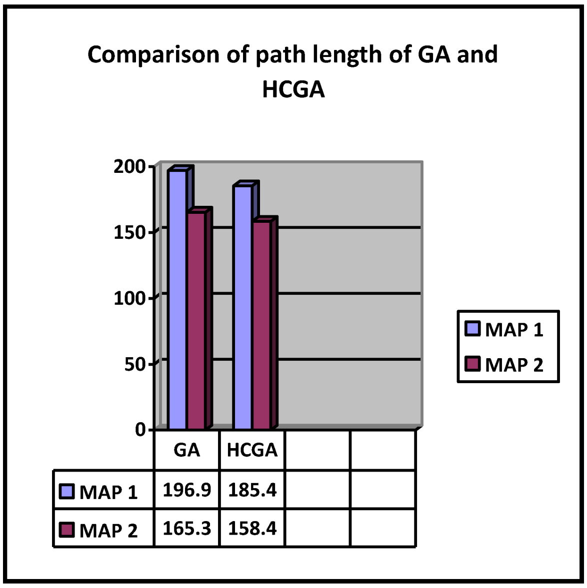

Figure 4. Comparison of path length of GA and HCGA on Wanmi Chen and Heping Qin, 2011 research paper [14].

There isn't much research falls on the usage of reinforced learning method although the method seems to have a great potential of solving the local path planning problem. A research paper by Mohammad Abdel Kareem Jaradat et al. (2010), shows a new approach of solving the problem navigating in an unknown dynamic environment based on a type of reinforcement learning method which is Q- learning [16]. The paper applies Q learning algorithm with limited number of states based on a new definition for the state spaces. It helps reducing the size of Q-table, thus increases the speed of the navigation algorithm. The results shows that the new Q-learning method is more efficient compared to the potential field method in dynamic environment. Omid Motlagh et al. (2013), utilizes expert independent navigation and neural networks making mobile robots to learn how to navigate on its own based on the principles of reinforcement learnings [17]. The navigation is made possible by the reward and punishment principles to distinct target seeking behavior and obstacle avoidance. The efficiency of the path determined by the robot will increase over time and as many iterations done due to the memorizing of the experience of previous tries. The dealings with uncertainties is made efficient due to the utilization of neural network.

AI's such as swarm intelligence also have been into researchers focus. It is a discipline that deals with both natural and artificial systems which is composed by huge number of intervals that coordinate using decentralized self-organization and control. Recently, Jun-Hao Liang and Chin-Hung Lee, (2015), proposed a more Efficient Artificial Bee Colony (EABC) online path planning design of the multiple robots system with free collision inspired by the artificial bee colony objective function which is to reach the target, avoid obstacle and avoid other operating robot via instant solution sharing strategy and population adjustment [18]. Another evolutionary swarm intelligence that often used and researched in current trends is the Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) technique. ACO was developed by Marco Dorigo can be said as a population–based metaheuristic that allows finding shortest path and it represents the foraging behavior of real ant colonies [19]. Ants will leave a trail of pheromone in their paths, and the rendering ants will converge towards to the shortest path with maximum pheromone concentration. Meanwhile, PSO was introduced by Dr. Eberhart and Dr. Kenedy year 1995, inspired by the flocking and schooling patterns of birds and fish [20]. In a research conducted by Yogita Gigras et al. (2015), both ACO and PSO was used as hybrid in order to overcome their individual shortcomings and find the optimal path [21]. Based on the simulation result, the ACO-PSO hybrid performed far much superior and the number of iterations used is far smaller compared to the algorithms acting alone.

Peng Li et al. 2010, introduced a new complex hybrid approach which allows mobile robot to efficiently planning smooth path in an unknown environment subjected [22]. The hybrid approach treats a single robot as a multi agent such as planning agent, perception agent and behavioral agent together with A* algorithm. The agents in this system could be complex entities at the same time and each agent achieves its tasks while collaborating with others. The agent will calculate temporary path with limited knowledge about surrounding based on A* algorithm and behavioral agent will smooth the planned path via go-to agent [22]. The laser error readings are efficiently cleared using the Dezert-Smarandache Theory (DSmT) which of plausible and paradoxical reasoning.

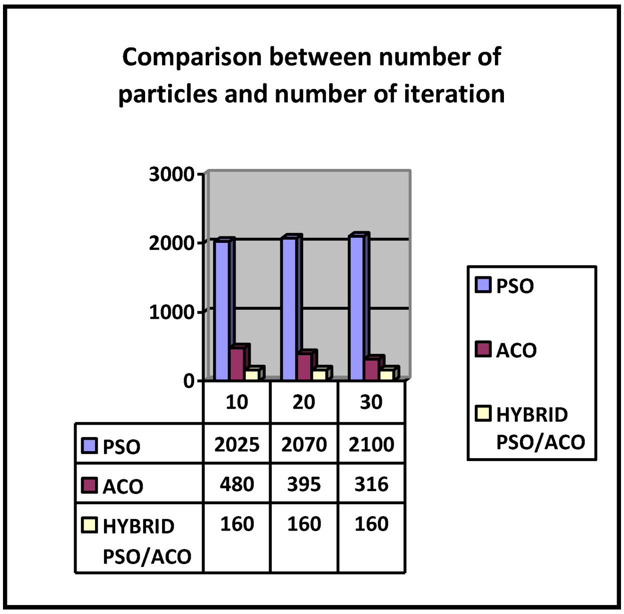

Figure 5. Comparison between number of particles and number of iterations used by different algorithms for path planning, based on research conducted by Yogita Gigras et al. (2015) [21].

As widely known, Fuzzy logics is an approach of computing based on the degrees of truth rather than just true or false, with rule base implied. This fuzzy systems are used more often in MPP system as a controller via introducing its inference mechanism to make more relevant decision in the path planning. Fuzzy logic controller often optimized via integrating fuzzy logic with certain soft computing techniques such as GA, Neural Network (NN), and PSO. Weria khaksar et al. (2013), have proposed an online sampling –based algorithm which applies a fuzzy-controller to evaluate generated samples and a GA-based optimization framework to optimize the parameters of the controller [23]. The GA acts to improve the interpretability of the fuzzy model via rule selection process which enhances the number of rules in the reasoning procedure. The simulated results shows the proposed algorithm works successfully in any type of environment without failure. The method helps to overcome the drawbacks of existing sampling-based algorithms. A research study by Mohammed Algabria et al. (2015), of this 4 soft computing techniques for unknown environment use have been designed and investigated which is manually constructed fuzzy logic (M-Fuzzy), fuzzy logic with genetic algorithm (GA-Fuzzy), fuzzy logic with neural network (Neuro-Fuzzy), and fuzzy logic with PSO (PSO-Fuzzy) [23]. Based on the comparison done between those 4 techniques via simulation on 4 alternate scenarios, it shows that the GA-fuzzy turn out to deliver a better performance in term of travelling time and average speed compared to other 3 techniques [24]. In terms of distance travelled and bending energy the PSO-fuzzy and Neuro-fuzzy performed better than others in simulation. However, according to the real experiment result using the Khepera III platform, the manually constructed fuzzy logic turn out to be better than others due to its slow travelling speed.

III. Comparison Studies

Both optimized classic approach and evolutionary and hybrid approaches have their own advantages and disadvantages when it comes to navigating in unknown environment depending on which aspect taken in account. The three main aspects of motion path planning is the computational time, obstacle avoidance efficiency and travelling distance from start to goal. The comparison is done in general.

A. *Computational Time*

When it comes to computational time aspect the evolutionary approaches consumes less processing time than most classical approaches. This is because classic approaches consumes more time to overcome its complex mathematical model and NP-Hardness. The more complex the mathematical model and rule applied in an approach, the higher the computational time. Evolutionary approaches applies Artificial Intelligence that allows self-learning and decision to be made faster especially when navigating in unknown environment.

B. *Obstacle Avoidance Efficiency*

The evolutionary and hybrid approaches have a slight advantage in avoiding the obstacle efficiently compared to classic approaches. Not to be mistaken, the classic approaches do avoid obstacle too, but when navigating in an unknown environment, classic methods such as potential field method tends to encounter local minima. Classic approaches also seldom deals with inability to cope with uncertainty in a dynamic unknown environment where it involves moving obstacles.

C. *Travelling distance from start to goal*

In terms of travelling distance, both approaches performance varies the condition of the unknown environment. In general, the curve created by mobile robot when avoiding obstacle especially in classic approaches such as potential field will increase the path length and time taken for the robot to reach the target. The evolutionary approaches in other hand, might not reach the goal in first few iterations and later will. This is because the self-learning and path remembering allows the robot to make wiser decision in increasing iterations and do not allows the same mistake to be repeated. The classic approach will tend to produce the same results is repeated over and over if no path remembering methods are implemented to it.

Hybrid approaches however will produce more promising results in all three aspects when navigating in an unknown environment. The only risk of implementing the hybrid approaches is that it might increase the computational time.

IV. Conclusion

The level of challenges involved in finding the suitable and most efficient motion path planning for an unknown environment is always higher and difficult compare to those environment with known structure. A total of 89 papers have been surveyed in this research, incorporating much recent found of motion path planning approaches in a time span from mainly from 2008 to early 2015. In this paper, a detailed overall review on motion path planning (MPP) for unknown and dynamic environment have been done focusing on techniques used in recent years only. It is clear that researches nowadays focus more on on-line path planning compared to offline. The MPP have been categorized into two separate groups which is Optimized Classic approaches and Recent Evolutionary Approaches in order to give out a clearer view. Each approaches have their unique characteristics, adaptability, advantages and disadvantages although all of them are created and optimized for path planning. As the comparison recommended, classical methods may not be dependable in this real–world applications because they are unable to stand up to with the dynamic, uncertain and changing nature of real-world. Although based on the comparison, evolutionary approaches seem to have slight advantage over classical approaches in handling dynamism, they too have shortcomings when in an uncertain environment. It is much recommended to apply hybrid approaches as it possesses higher chances of efficient outcomes and overcomes drawbacks or shortcomings of an approach. Various sectors have different reasons on developing path planning techniques focusing into certain aspect such low travelled distance, efficient obstacle avoidance, efficient time taken to complete the course and much more.

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