

A Review on Local Minimum and Multiple Minimum Avoidance Techniques in Local Path Planning

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Abstract - In the local path planning navigation, a particular focus is given to local minimum problem. This problem occurs when a robot manoeuvre towards a desired target with no initial information of the environment and gets trapped in an infinite loop or also known as a dead end trap. Besides the local minimum situation, there are even worse situation in which when a mobile robot encounters two or more dead ends in a row. This situation is known as "multiple minimum" situation. The situation is forming more complicated problem than the local minimum problems and the available solutions for these situations are discussed in detail. **Copyright © 2016 Penerbit Akademia Baru - All rights reserved.**

Keywords: Local path planning, Local minimum situation, Multiple minimum situation, Behaviour based path planning

1.0 INTRODUCTION

These last two decades have been a milestone for autonomous mobile robots development which leads to vast application in many fields of technology, particularly in mobile and distributed technology and also field and service technology. Autonomous mobile robots are robots that are capable to execute desired tasks in unstructured environments and able to perform intelligent motion or action without incessant human guidance. There are numerous types of robot that have some degree of autonomy, which involves the integration of many different bodies of knowledge. These demanding capabilities give a challenge to the mobile robotics field. Autonomous mobile robots should be capable to apprehend the environment and navigate itself by a stored navigation program in its memory.

Because of the capabilities to sense its environment and navigate themselves without continuous human guidance, autonomous mobile robots are widely used in various applications now days such as in industrial applications [1, 2, 3, 4], home cleaning robot [5, 6, 7], autonomous underwater vehicle [8, 9, 10], search and rescue robot [11, 12, 13] and service robot [14, 15, 16]. All given applications required a level of robustness and adaptable methods for path planning. The robot has to find a safe collision-free trajectory and the optimum path



between the starting point and the goal configurations either in a static or a dynamic environment that consist of several obstacles.

There are three main issues that is very important "to enable an autonomous mobile robot to construct (to use) a map (floor plan) and localize itself in it" [17]. The three main issues are:

- 1. Map learning
- 2. Localization
- 3. Path Planning

For the first two issues which are map learning and localization, the mobile robots usually need to have prior knowledge of their environment. The situation is different for an exploratory mission of a space robot or a search and rescue mission of a rescue robot, where their works are in a fully unknown environment. This makes only the third issue, which is Path Planning as the main issue to be considered. This type of autonomous navigation is known as a local navigation or local path planning.

Path planning is one of the most important issues in mobile robot navigation. Path planning for mobile robot is divided into two main parts: the global path planning and the local path planning [18]. For global path planning, also known as deliberative navigation [19, 20, 21], the entire environment is fully known by the robot. The robot only needs to plan and calculate the path initially and then just execute the planned path to the target position. On the contrary, for local path planning or also known as reactive navigation [22, 23, 24], there is no prior knowledge available and the environment is assumed to be fully unknown by the robot. The robot knows only its own position in the environment and usually only decides the direction to move without computing the path in the beginning.

Owing to there is no prior knowledge of the environment that is available in local path planning and the environment is also changing uncertainties, it can be considered as one of the most challenging and interesting issue in robotics. There are three main questions need to be answered and solved when dealing with the robot navigation matters. The first question is where I am? The second is where I am going? And the third is how to get there? To answer these questions, autonomous mobile robot should capable to:

- 1. Perceive its surrounding environment.
- 2. Analyse the perceived information.
- 3. Plan a real-time route from the initial position to a given target with obstacle avoidance capability.
- 4. Execute the movement by controlling the robot turning direction and velocity during navigate itself towards the target.

Point-to-point path planning of autonomous mobile robot is defined as finding a safe collisionfree path from a given start configuration to a goal configuration. This type of path planning has been extensively explored in the last two decades which is also known as a real time local navigation. Some examples of the path planning online approaches are fuzzy logic techniques [25, 26, 27], neural network approaches [28, 29, 30], wall following methods [31, 32], genetic algorithm methods [33, 34], edge-detection method [35], vector field histogram approaches [36, 37], virtual potential field methods [38, 39] and dynamic window approaches [40, 41].

In the local path planning navigation, a particular focus is given to a local minimum problem [42, 43, 44, 45]. This problem occurs when a robot manoeuvre towards a desired target with



no initial information of the environment and gets trapped in an infinite loop or also known as a dead end trap. The example of the environment that can represent this local minimum problem can be shown by Figure 1. This Figure shows a mobile robot that uses pure fuzzy logic navigator gets trapped in a U-shape dead end trap.



Figure 1: Local minimum situation [42]

The robot gets into an infinite loop or a local minimum because of "the rules that are fired for target attractor and obstacle repulsor modules give output action that neutralize each other" [42]. To solve the local minimum situation many previous approaches have been developed and one of it was the method which developed by Xu and Tso [46, 47]. This method is a hybrid approach of fuzzy logic and technique called "virtual target".

Beside the local minimum situation there are even worse situation where a mobile robot encounters two or more dead ends in a row. This situation is known as "multiple minimum" situation. The situation is forming more complicated problem than the local minimum situation. The example environment of multiple minimum situation shown in Figure 2 which a mobile robot encounters another local minimum between point "c" and point "d" when it is still working under the influence of previous virtual sub goal created to guide the robot out of the first minimum dead end at location "a" and "b" [48].



Figure 2: Multiple minimum situations [48]

2.0 EXISTING METHOD

Since late 1980s there are a lot of researchers putting their effort and works on mobile robot navigation, particularly in overcome the local and multiple minimum situation. Here, some of the previous works on overcoming the local and multiple minimum situations are introduced. All the introduced methods used either one of behaviour based robotic systems and fuzzy logic



system or the hybrid between this two systems as their navigation system core. Each technique has its own advantages and its own drawbacks.

2.1 Wall following method based on general perception concept

The wall following method [31, 32, 49], has been widely utilized for its simplicity, practicability and the implicit ability of collecting global information. This method is well known for traversing mazes. It is also known as either the right-hand rule or the left-hand rule. If we have the maze (floor plan) that its walls are connected together or to maze's outer boundary, then by keeping one hand in contact with one wall of the maze the robot should be able to reach a target. Wall following method has been incorporated with fuzzy logic control as a kernel of navigation algorithm [50]. This method also has been integrated into artificial potential field to overcome the local minimum situation [31]. Thus, this method is seen to have a potential in solving "multi minimum" problem. This wall following method will not be fully functional or will not be guarantee to help the target to be reached when the maze is not simply connected together. This is a major drawback of the wall following method.

2.2 A state memory approach to the local minimum problem

A state memory approach method [51] is a reactive navigation of a behaviour-based mobile robot for a dynamic environment. The method was developed by Anmin in 2004. The robot equipped with multiple sensors to receive input such as obstacle position, target location and current robot speed. Anmin's method was a fuzzy logic control system consists of 48 fuzzy rules with three main behaviour which are target seeking behaviour, obstacle avoidance behaviour and barrier following behaviour. The "dead cycle" problem is resolved by a state memory strategy [51].

Even though this method has been proven to solve the "dead cycle" problem, but it still encounter two main drawbacks. First, after the robot overcome the obstacle through point B, C and D (Figure 3), it have to satisfied the memorized distance "Dm" which taken at point A previously before the robot can pursue the target at point E. Only at point E the current position of the robot "Dc" is shorter than "Dm". This makes the robot trajectories poor as shown in Figure 3. The second drawback is this method also has a large size of algorithm which consist of 48 rules and the assistant state memorizing algorithm which make the method more complicated.



Figure 3: Distance-based memory states method [51]



2.3 Minimum risk approach

The minimum risk approach [48] combined a strategy of multi behaviour coordination, which a path-searching behaviour is evolved to advise the regional direction with minimum risk. This method used a fuzzy logic framework as a core of its algorithm to implement the behaviour design and coordination [48]. Wang's method mainly uses "trial and return" behaviour to reach the target from starting position. Although this method can solve "multiple minimum" problem, due to trial and return behaviour, a lot of power consumption and time needed when implementing this method. Figure 4 shows the example of minimum risk approach trial and return behaviour.

2.4 Spatio temporal landmark learning for minimum avoidance

The spatio temporal landmark learning method was based on [52, 53] works and unfolded by Krishna in 2001 [42]. The different between this method with others is, this method are depend on memory and basically made up from memory modules integrated with variant forms of fuzzy logic controller. This method relies on the concept that "to come out of the loop the robot must comprehend its repeated traversal through the same environment, which involves memorizing the environment already seen", [42]. Krishna's method has a fuzzy logic controller as a kernel and consists of target reaching module and obstacle avoidance module. Despite that this method can overcome the "multiple minimum" problem, it highly depends on the landmark recognition and needs exact coordination localization which makes it not very robust. Figure 5 shows the example of spatio landmark learning method.



Figure 4: Minimum risk approach method [48]



Figure 5: Spatio temporal landmark learning method [42]



2.5 Fuzzy logic control and actual virtual target switching

This method is a hybrid mode of fuzzy logic control with the virtual target switching method. This system is developed for reactive navigation of a behaviour-based mobile robot in dynamic environments. A fusion of multiple sensors is attached to the robot, to sense the obstacle near the robot, the target location and the current robot speed. The system has three main behaviours which target seeking, obstacle avoidance and barrier followings. There are 18 fuzzy rules designed as a kernel of this system. This method have solved the drawback of the virtual target approach by [46] which multiple minimum situation by calculating the sum of turning angle from the point the robot shift from actual target to the virtual target. The total amount of turning angle must equal to zero before the robot able to shift back to actual target mode. The "multiple minimum" problem is resolved by a fuzzy logic control and actual virtual target switching approach [54]. Even though this method has solved the multiple minimum problems, it still has two limitations; which the method relies to the sum of turning angle consideration and also depends to the memorized minimum target distance.



Figure 6: Fuzzy logic control and actual virtual target switching method [54]

2.6 Fuzzy-Braitenberg (behaviour based) approach for local navigation

One of the famous applications on behaviour based method is Braitenberg vehicles. This method takes the surplus of a psychologist by extending the principles of analogue circuit behaviour to a series of gedanken experiments involving the design of a collection of vehicles [55]. There are four types of Braitenberg vehicles which Braitenberg vehicle 1, Braitenberg vehicle 2, Braitenberg vehicle 3 and Braitenberg vehicle 4. Braitenberg vehicle 1 equipped with single motor and single sensor, while Braitenberg vehicle 2, 3 and 4 each attached with two motors and two sensors. This method also has been basic idea to subsumption behaviour based architecture by Brooks [22].

The Fuzzy-Braitenberg approach for local navigation [56], are focusing on Braitenberg vehicle 2 and 3 [55]. The successful path planning navigation is the navigation scheme that can navigate the robot to desired point or target with ability to avoid collision with obstacles or barriers. Based on these criteria, Yang identified and used the basic concept of Braitenberg vehicle 2 and vehicle 3 then merged it into one mobile robot navigation scheme. He developed a differential drive mobile robot navigation system as shown in Figure 7.





Figure 7: A differential drive mobile robot navigation system [56]

There are two main algorithms that have been developed as a kernel of fuzzy logic in Fuzzy-Braitenberg navigation strategy for differential drive mobile robot [56]. The complete algorithm is obtained by merge this 2 main algorithm. The main algorithms are:

- 1. Obstacle avoidance algorithm.
- 2. Goal seeking algorithm.

Obstacle avoidance algorithm consists of four fuzzy rules, while goal seeking algorithm also consists of four fuzzy rules. The overall total fuzzy rules for this method are eight fuzzy rules. Yang's method shows effectiveness in an unknown static environment (Figure 8(a)) and also in a dynamic environment (Figure 8(b)). In both environments the robot always tries to pursue its goal position at a constant speed but slow down prior to the obstacles availability and adjustment the motor speed on each side to perform the obstacle avoidance behaviour.

However, in some situation the method encountered problems. In a corridor-like path which is narrow enough for the robot to detect objects on both its sides simultaneously, the robot oscillates from side to side (Figure 9) due to the properties of the Braitenberg algorithm in that any perturbation in sensory readings changes the speed of the corresponding motor. Based on this result we can understand that Yang's method doesn't have good ability to follow a corridor or wall (wall following behaviour) which required and important in local or multiple minimum situation.



Figure 8: (a) Robot navigating in a static environment (b) Robot navigating in a dynamic environment [56]





Figure 9: Robot navigating along a corridor [56]

Table 1, summarised the comparison between all the methods that have been discussed in subsection 2.1 until 2.6.

| | Implemented behaviour | Required fuzzy rules | Local minimum | Multiple minimum |
|-----------------------|--------------------------|-------------------------|------------------|---------------------|
| Fuzzy-Braitenberg | 1. Goal seeking. | 8 | / | / |
| | 2. Obstacle avoidance. | | | |
| Fuzzy logic and | 1. Target seeking. | 18 | / | / |
| actual virtual target | 2. Obstacle avoidance. | | | |
| | 3. Barrier following. | | | |
| Spatio temporal | 1. Target seeking. | 9 | / | / |
| landmark learning | 2. Obstacle avoidance. | | | |
| Minimum risk | 1. Goal seeking. | 7 | / | / |
| approach | 2. Obstacle avoidance. | | | |
| | 3. Path searching. | | | |
| A state memory | 1. Target seeking. | 48 | / | / |
| approach | 2. Obstacle avoidance. | | | |
| | 3. Barrier following. | | | |
| Wall following | 1. Wall following | - | / | X |
| method | - | | | |

Table 1: Comparison of the local and multiple minimum avoidance techniques

Based on the comparison (table 1), a mobile robot was able to overcome the local minimum problem by implementing the wall following behaviour. In multiple minimum problems, a mobile robot required at least 2 behaviours which, target seeking behaviour and obstacle avoidance behaviour to be implemented in the avoidance technique algorithm.

2.7 Other methods and techniques

Beside the method and technique that have been discussed in above, there were others technique that focus in mobile robot navigation. There are mainly, using behaviour based reactive method combine with fuzzy logic (FL) techniques [57, 58, 59], neural network (NN) technique [60, 61] or genetic algorithm (GA) [62]. There are also technique that combines between neural network and fuzzy logic [63, 64, 65], or genetic algorithm and fuzzy logic [66, 67, 68]. Others techniques like artificial potential field (APF) method [69, 70], random walk (RW) method [71], and edge detection (ED) method [35] also have widely been used in mobile robot navigation.



3.0 CONCLUSION

In this paper, a compact overall review of the local and multiple minimum problem in the local path planning are introduced and discussed in details. All of the discussed previous methods, used a behaviour based method as the main consideration in its navigation algorithm. The idea of combining the behaviour based method with others artificial intelligent (A.I) method such as fuzzy logic, neural network and genetic algorithm also can be seen selected by the previous researcher. It is hoped this review paper can give future researcher, the insight depth regarding the solution of local and multiple minimum problem in the local path planning.

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