Penerbit Akademia Baru

Journal of Advanced Research in Applied Sciences and Engineering Technology
ISSN (online): 2462-1943 I Vol. 4, No.1. Pages 58-71, 2016

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

G. Hamami [,a], M. Mazni [b], M. S. Amir [c], F. Sukarman [d] and M. Katon [e]*

Faculty of Mechanical Engineering, Universiti Teknologi MARA, Cawangan Johor, Kampus Pasir Gudang, 81750 Masai Johor, Malaysia
[a,*]*ghazali.hamami@johor.uitm.edu.my*, [b]*mazleenda@johor.uitm.edu.my*, [c]*amir8776@ johor.uitm.edu.my*, [d]*firdaus@johor.uitm.edu.my*, [e]*matzainikaton@johor.uitm.edu.my*

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 situation. In this paper, a complete review is given on the local minimum and multiple minimum problems and the available solutions for these situations are discussed in detail.*

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 collision-free 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

Journal of Advanced Research in Applied Sciences and Engineering Technology
ISSN (online): 2462-1943 I Vol. 4, No.1. Pages 58-71, 2016

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.

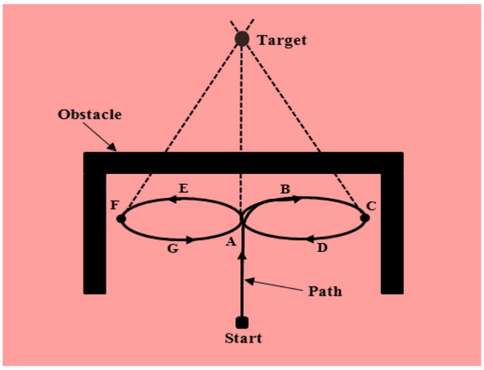

Figure 1: Local minimum situation [42]

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].

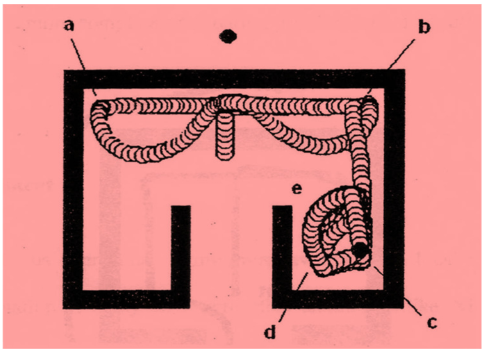

Figure 2: Multiple minimum situations [48]

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

Journal of Advanced Research in Applied Sciences and Engineering Technology
ISSN (online): 2462-1943 I Vol. 4, No.1. Pages 58-71, 2016

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.

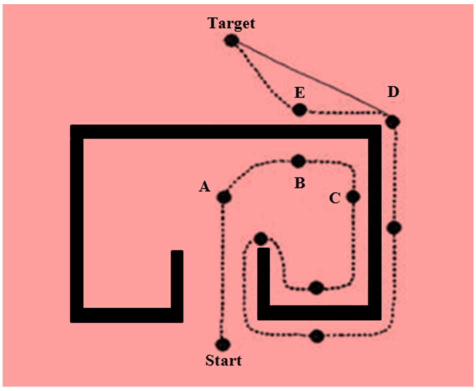

Figure 3: Distance-based memory states method [51]

Journal of Advanced Research in Applied Sciences and Engineering Technology
ISSN (online): 2462-1943 I Vol. 4, No.1. Pages 58-71, 2016

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.

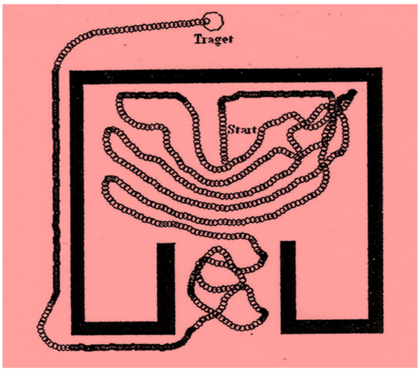

Figure 4: Minimum risk approach method [48]

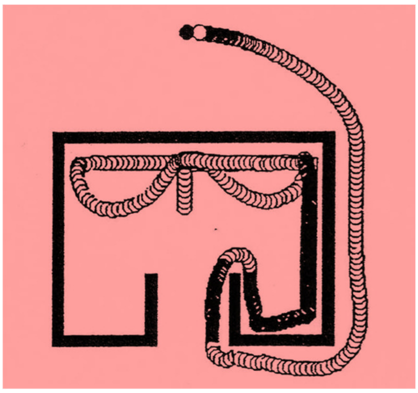

Figure 5: Spatio temporal landmark learning method [42]

Journal of Advanced Research in Applied Sciences and Engineering Technology
ISSN (online): 2462-1943 I Vol. 4, No.1. Pages 58-71, 2016

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.

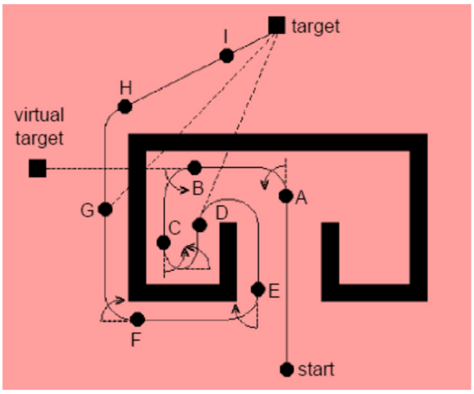

Figure 6: Fuzzy logic control and actual virtual target switching method [54]

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.

Journal of Advanced Research in Applied Sciences and Engineering Technology
ISSN (online): 2462-1943 I Vol. 4, No.1. Pages 58-71, 2016

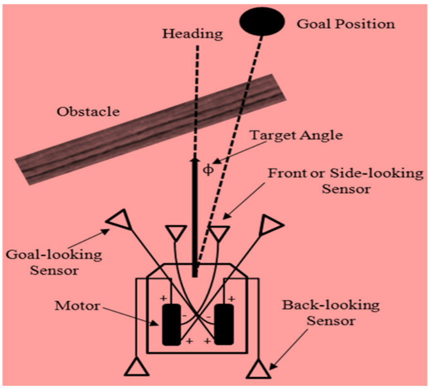

Figure 7: A differential drive mobile robot navigation system [56]

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.

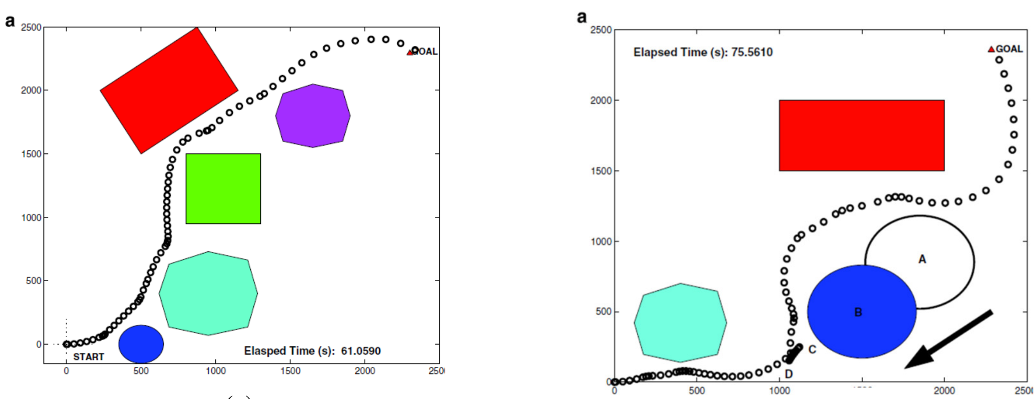

Figure 8: (a) Robot navigating in a static environment (b) Robot navigating in a dynamic environment [56]

Penerbit Akademia Baru
Journal of Advanced Research in Applied Sciences and Engineering Technology
ISSN (online): 2462-1943 I Vol. 4, No.1. Pages 58-71, 2016

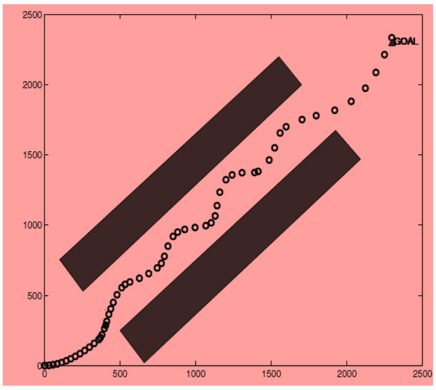

Figure 9: Robot navigating along a corridor [56]

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

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

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

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.

Journal of Advanced Research in Applied Sciences and Engineering Technology
ISSN (online): 2462-1943 | Vol. 4, No.1. Pages 58-71, 2016

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.

REFERENCES

[1] Robert Krug, Todor Stoyanov, Vinicio Tincani, Henrik Andreasson, Rafael Mosberger, Gualtiero Fantoni, and Achim J. Lilienthal. "The Next Step in Robot Commissioning: Autonomous Picking and Palletizing." IEEE Robotics and Automation Letters 1, no. 1 (2016): 546-553.

[2] Lee Wun Chen, Abdullah Syafiq Abdul Salam, Mohd Faisal Ibrahim, Ashrani A. Abd Rahni, and Abdullah Zawawi Mohamed. "Autonomous Industrial Tank Floor Inspection Robot." IEEE 2015 International Conference on Signal and Image Processing Applications, pp. 473-475. IEEE, 2016.

[3] Md. Abdul Kadir, Md. Belayet Chowdhury, Jaber Al Rashid, Shifur Rahman Shakil and Md. Khalilur Rhaman. "An autonomous industrial robot for loading and unloading goods." 2015 International Conference on Informatics, Electronic & Vision (ICIEV), pp. 1-6. IEEE, 2015.

[4] S Vivekanandan, a Koleti, and M Devanand. "Autonomous Industrial Hazard Monitoring Robot with GSM Integration." 2013 4th Nirma University International Conference on Engineering, NUiCONE 2013, pp. 4-7. IEEE, 2013.

[5] Ma, Youngkak, and Seungwoo Kim. "A Study on Development of Home Mess-Cleanup Robot McBot." 2008 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 114-119. IEEE, 2008.

[6] Yu Liu, Shiqiang Zhu, Bo Jin, Shenshen Feng, and Huafeng Gong. "Sensory Navigation of Autonomous Cleaning Robots." Fifth World Congress on Intelligent Control and Automation 2004, pp. 4793-4796. IEEE, 2004.

[7] Sewan Kim. "Autonomous Cleaning Robot: Roboking System Integration and Overview." IEEE International Conference on Robotics and Automation, pp. 4437-4441. IEEE, 2004.

[8] Kukulya, a., a. Plueddemann, T. Austin, R. Stokey, M. Purcell, B. Allen, R. Littlefield, et al. "Under-Ice Operations with a REMUS-100 AUV in the Arctic." 2010 IEEE/OES Autonomous Underwater Vehicles, pp. 1-8. IEEE, 2010.

[9] S. Afzulpurkar, P. Maurya, G. Navelkar, E. Desa, A. Mascarenhas, N. Dabholkar, R. Madhan, and S. Prabhudesai. "Acoustic Communication for Maya Autonomous Underwater Vehicle- Performance Evaluation of Acoustic Modem." Proceedings of the International Symposium on Underwater Technology (UT-2015), pp. 1-6. IEEE 2015.

[10] A Ridolfi, R Costanzi, F Fanelli, N Monni, B Allotta, S Bianchi, R Conti, et al. "FeelHippo : A Low-Cost Autonomous Underwater Vehicle for Subsea Monitoring and Inspection." 2016 IEEE 16th International Conference on Environment and Electrical

Engineering(EEEIC), pp. 1-6. IEEE, 2016.

[11] Espinosa, Andre Possani, Danu Pranantha, and Alessandro De Gloria. "Multi-Robot Search and Rescue Team." 2011 IEEE International Symposium on Safety, Security, and Rescue Robotics, pp. 296-301. IEEE, 2011.

[12] Aaron M. Johnson, Matthew T. Hale, G. C. Haynes, and D. E. Koditschek. "Autonomous Legged Hill and Stairwell Ascent." 9th IEEE International Symposium on Safety, Security, and Rescue Robotics, pp. 134-142. IEEE, 2011.

[13] Javier Serón, Jorge L. Martinez, Anthony Mandow, Alfonso J. Garcia-Cerezo, Jesus Morales, Antonio Reina, and Jesus Garcia. "Terrace Climbing of the Alacrane Mobile Robot with Cooperation of Its Onboard Arm." International Workshop on Advanced Motion Control, AMC, pp. 1-6. IEEE, 2012.

[14] Antonio, Carlos, Acosta Calderon, and Changjiu Zhou. "Development of an Autonomous Service Robot for Social Interactions." Information, Communications and Signal Processing (ICICS) 2011 8th International Conference, pp. 1-6. 2011.

[15] Satoru Satake, Kotaro Hayashi, Keita Nakatani, and Takayuki Kanda. "Field Trial of an Information-Providing Robot in a Shopping Mall." IEEE International Conference on Intelligent Robots and Systems, pp. 1832-1839. IEEE, 2015.

[16] Durmus Halil, Ece Olcay Gunes, Murvet Kirci, and Burak Berk Ustundag. "The Design of General Purpose Autonomous Agricultural Mobile-Robot: 'AGROBOT.'" 2015 4th International Conference on Agro-Geoinformatics, Agro-Geoinformatics 2015, pp. 49-53. IEEE, 2015.

[17] Levitt, T., and Lawton, D.T. "Qualitative navigation for mobile robots." Artificial Intelligence 44, no. 3 (1990): 305-360.

[18] Motlagh, O. R. E. "Development of A Mobile Robot Local Navigation System based on Fuzzy-Logic Control and Actual-Virtual Target Switching." Master Thesis, University Putra Malaysia, 2006.

[19] Schwartz JT, and Sharir M. "On the "piano movers" problem. General techniques for computing topological properties of real algebraic manifolds." Advance Applied Math 4, no. 1 (1983): 298-351.

[20] Nagatani K, Choset H, and Thrun S. "Towards exact localization without explicit localization with the Voronoi graph." International Conference of Robot Automation, pp. 342-348. IEEE, 1998.

[21] Pruski A, and Rohmer S. "Robust path planning for non-holonomic robots." Journal of Intelligent Robot System: Theory Appl. 18, no. 4 (1997): 329-350.

[22] Brooks, R. "A Robust Layered Control System for a Mobile Robot." IEEE Journal of Robotics and Automation RA 2, no. 1 (1986): 14-23.

[23] Arkin RC. "Motor schema-based mobile robot navigation." International Journal of Robot Automation 8, no. 4 (1989): 92-112.

[24] Vukovic N, and Miljkovic Z. "New Hybrid Control Architecture for Intelligent Mobile Robot Navigation in a Manufacturing Environment." FME Trans. 37, (2009): 9-18.

[25] Ismail, I.I., and M.F. Nordin. "Reactive Navigation of Autonomous Guided Vehicle Using Fuzzy Logic." 2002 Student Conference on Research and Devlopment, pp. 153-156. IEEE, 2002.

[26] Anish Pandey, Rakesh Kumar Sonkar, Krishna Kant Pandey, and D R Parhi. "Path Planning Navigation of Mobile Robot With Obstacles Avoidance Using Fuzzy Logic Controller." International Conference on Intelligent Systems and Control, pp. 36-41. 2014.

[27] Tharindu Fernando, Harshala Gammuller and Chamilla Wlgampaya. "Fuzzy Logic Based Mobile Robot Target Tracking in Dynamic Hostile Environment." 2015 IEEE International Conference on Computational Intelligent and Virtual Environments for Measurement System and Application (CIVEMSA), pp. 1-6. IEEE, 2015.

[28] Yang, S X, and M Meng. "Neural Network Approaches to Dynamic Collision-Free Trajectory Generation." IEEE Transactions on Systems, Man, and Cybernetics. Part B, Cybernetics : A Publication of the IEEE Systems, Man, and Cybernetics Society 31, no. 3 (2001): 302-318.

[29] Yi-Wen Chen, and Wei-Yu Chiu. "Optimal Robot Path Planning System by Using a Neural Network-Based Approach." Proceedings of 2015 International Automatic Control Conference (CACS), pp. 85-90. 2015.

[30] V. Kroumov, and Jianli Yu. "3D Path Planning for Mobile Robots Using Annealing Neural Network." 2009 International Conference on Networking, Sensing and Control, pp. 130-135. 2009.

[31] Zhu, Yi, Tao Zhang, and Jingyan Song. "An Improved Wall Following Method for Escaping from Local Minimum in Artificial Potential Field Based Path Planning." Proceedings of the 48h IEEE Conference on Decision and Control (CDC) Held Jointly with 2009 28th Chinese Control Conference, pp. 6017-6022. IEEE, 2009.

[32] Amir Nooraliei, and R. Iraji. "Robot Path Planning Using Wavefront Approach with Wall-Following." International Conference on Computer Science and Information Technology, pp. 417-420. 2009.

[33] Abdurrahim Sonmez, Emre Kocyigit, and Emin Kugu. "Optimal Path Planning for UAVs Using Genetic Algorithm." 2015 International Conference on Unmanned Aircraft Systems (ICUAS), pp. 50-55. 2015.

[34] Rajat Kumar Panda, and B.B. Choudhury. "An Effective Path Planning of Mobile Robot Using Genetic Algorithm." 2015 IEEE International Conference on Computational Intelligence & Communication Technology, pp. 287-291. IEEE, 2015.

[35] Xie, Yang, Wei Wang, Jiajie Guo, and Kok-Meng Lee. "Edge Detection Using Structured Laser Pattern and Vision for Mobile Robot Navigation." 2011 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM), pp. 910-915. IEEE, 2011.

[36] Borenstein, J., and Koren, Y. "The vector field histogram-Fast obstacle avoidance for mobile robots." IEEE T. Robot. Autom. 7, no. 3 (1991): 278-288.

[37] I Ulrich, and J Borenstein. "VFH*: Local Obstacle Avoidance with Look-Ahead verification." Proceedings of the 2000 IEEE Intl. Conf. on Robotics and Automation (ICRA), pp. 2505-2511. IEEE, 2000.

[38] Fu-guang, Ding, and Jiao Peng. "AUV Local Path Planning Based on Virtual Potential Field." Proceeding of the IEEE International Conference on Mechatronics & Automation, pp. 1711-1716. IEEE, 2005.

Journal of Advanced Research in Applied Sciences and Engineering Technology
ISSN (online): 2462-1943 I Vol. 4, No.1. Pages 58-71, 2016

[39] Luh, G. C., and Liu, W. W. "An immunological approach to mobile robot reactive navigation." Appl. Soft Comput. 8, no. 1 (2008): 30-45.

[40] Fox, D., Burgard, W., and Thrun, S. "The dynamic window approach to collision avoidance." IEEE Robot. Autom. Mag. 4, no. 1 (1997): 23-33.

[41] Oliver, B., and Oussama, K. "High-speed navigation using the global dynamic window approach." Proceedings of the 1999 IEEE International Conference on System, Man and Cybernatics, pp. 1291-1296. IEEE, 1999.

[42] Krishna, K Madhava, and Prem K Kalra. "Perception and Remembrance of the Environment during Real-Time Navigation of a Mobile Robot." Robotics and Autonomous Systems 37, (2001): 25-51.

[43] H.P. Huang and P.C. Lee. "A real-time algorithm for obstacle avoidance of autonomous mobile robots." Robotica 10, (1992): 217-227.

[44] I. Kamon and E. Rivlin. "Sensory-based motion planning with global proofs." IEEE Transaction on Robotics and Automation 13, no. 6 (1997): 814-822.

[45] F.G. Pin and S.R bender. "Adding memory processing behavior to the fuzzy behaviourist approach: Resolving limit cycle problems in mobile robot navigation." Intelligent Automation and Soft Computing 5, no. 1 (1999): 31-41.

[46] W.L. Xu, and S K Tso. "Sensor-Based Fuzzy Reactive Navigation of a Mobile Robot Through Local Target Switching." IEEE Transaction on Systems, Man, and Cybernatics. Part C, Applications and Reviews 29, no. 3 (1999): 451-459.

[47] W.L Xu. "A virtual target approach for resolving the limit cycle problem in navigational of a fuzzy behavior-based mobile robot." Robotics and Autonomous System 30, no. 4 (2000): 315-324.

[48] Wang, Meng, and James N K Liu. "FUZZY LOGIC BASED ROBOT PATH PLANNING IN UNKNOWN ENVIRONMENT." Proceedings of the Fourth International Conference on Machine Learning and Cybernetics, pp. 18-21. 2005.

[49] Mahadevan, Sridhar, and Jonathan Connell. "Automatic Programming of Behavior-Based Robots Using Reinforcement Learning." Artificial Intelligence 55, no. 2 (1992): 311-365.

[50] Braunstingl, Reinhard, Jokin Mujika, Juan Pedro, J M Arizmendianieta, E- Mondragon, and Guiplizcoa I Espaiia. "A Wall Following Robot With A Fuzzy Logic Controller Optimized By A Genetic Algorithm 1 Description Of The Mobile Robot." Fuzzy Systems, 1995. International Joint Conference of the Fourth IEEE International Conference on Fuzzy Systems and The Second International Fuzzy Engineering Symposium pp. 77-82. IEEE, 1995.

[51] Anmin, Zhu and Simon, X. Yang. "A Fuzzy Logic Approach to Reactive Navigation of Behavior-Based Mobile Robots." Proceedings of the 2004 IEEE International Conference on Robotics & Automation, pp. 5045–5050. IEEE, 2004.

[52] T. Kohonen. "Self-organizing map." Proceedings of the IEEE 78, no. 9 (1990): 1460-1480.

[53] G.A. Carpenter, S. Groosberg, D.B. Rosen. "Fuzzy ART: Fast stable learning and categorization of analog patterns by an adaptive resonance system." Neural Networks 4, (1991): 759-771.

Journal of Advanced Research in Applied Sciences and Engineering Technology
ISSN (online): 2462-1943 | Vol. 4, No.1. Pages 58-71, 2016

[54] Motlagh, Omid Reza Esmaeili, Tang Sai Hong, and Napsiah Ismail. “Development of a New Minimum Avoidance System for a Behavior-Based Mobile Robot.” Fuzzy Sets and Systems 160, no. 13 (2009): 1929-1946.

[55] Braitenberg, V. "Vehicles: Experiments in Synthetic Psychology." Cambridge, MA: MIT Press. (1984).

[56] Yang, X., Patel, R. V., and Moallem, M. "A Fuzzy-Braintenberg Navigation Strategy for Differential Drive Mobile Robots." Intelligent Robot Systems 47, (2006): 101-124.

[57] Seraji, H., and a. Howard. “Behavior-Based Robot Navigation on Challenging Terrain: A Fuzzy Logic Approach.” IEEE Transactions on Robotics and Automation 18, no. 3 (2002): 308-321.

[58] Yang, X., Moallem, M., & Patel, R.V. "A layered goal-oriented fuzzy motion planning strategy for mobile robot navigation." IEEE Trans. Syst, Man Cyber Part B: Cybernetics. 35, no. 6 (2006): 1214-1224.

[59] Bao, Qing-yong, Shun-ming Li, Wei-yan Shang, and Mu-jin An. “A Fuzzy Behavior-Based Architecture for Mobile Robot Navigation in Unknown Environments.” 2009 International Conference on Artificial Intelligence and Computational Intelligence, pp. 257-261. IEEE, 2009.

[60] Romero, Felipe Trujillo, and Gabriel Rojas Villanueva. “Robotic System for Reactive Navigation in Dynamic Environments.” Electrical Communications and Computers (CONIELECOMP), 2011 21st International Conference, pp. 200-205. 2011.

[61] Sharma, S., Otunba, S., Ogunlana, K., and Tripathy, T. “Intelligent Agents in a Goal Finding Application for Homeland Security.” Proceedings of the 2012 IEEE Southeastcon, pp. 1-5. IEEE, 2012.

[62] Shi, Pu, and Yujie Cui. “Dynamic Path Planning for Mobile Robot Based on Genetic Algorithm in Unknown Environment.” 2010 Chinese Control and Decision Conference, pp. 4325-4329. IEEE, 2010.

[63] Azouaoui, O., N. Ouadah, I. Mansour, and a. Semani. “Neural Networks and Fuzzy Logic Navigation Approach for a Bi-Steerable Mobile Robot.” 2011 8th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), pp. 44-49. IEEE, 2011.

[64] Wei Li. “A Hybrid Neuro-Fuzzy System for Sensor Based Robot Navigation in Unknown Environments.” Proceedings of the American Control Conference, pp. 2749-2753. 1995.

[65] S J Vestli, N TschicholdGurman, M Adams, and S Sulzberger. “Integration of Path Planning, Sensing and Control in Mobile Robotics.” Robotics and Automation, 1993. Proceedings., 1993 IEEE International Conference on Robotics and Automation, pp. 243-248. IEEE, 1993.

[66] Samsudin, K., Ahmad, F. A., and Mashohor, S. “A Highly Interpretable Fuzzy Rule Base using Ordinal Structure for Obstacle Avoidance of Mobile Robot.” Appllied Soft Computing Journal 11, no. 2 (2010): 1631-1637.

[67] Mahmoud Tarokh. “A Genetic Robot Path Planner with Fuzzy Logic Adaptation.” Proceedings - 6th IEEE/ACIS International Conference on Computer and Information Science, ICIS 2007; 1st IEEE/ACIS International Workshop on E-Activity, IWEA 2007, pp. 388-393. IEEE, 2007.

Journal of Advanced Research in Applied Sciences and Engineering Technology
ISSN (online): 2462-1943 | Vol. 4, No.1. Pages 58-71, 2016

[68] Shijing Wu, Qunli Li, Enyong Zhu, Jing Xie, and Gong Zhichao. "Fuzzy Controller Pipeline Robot Navigation Optimized by Genetic Algorithm." Chinese Control and Decision Conference, pp. 904-908. 2008.

[69] Pradhan, Ninad, Timothy Burg, and Stan Birchfield. "Robot Crowd Navigation Using Predictive Position Fields in the Potential Function Framework." 2011 American Control Conference, pp. 4628-4633. 2011.

[70] Guanghui, L., Yamashita, A., Asama, H., and Tamura, Y. "An Efficient Improved Artificial Potential Field Based Regression Search Method for Robot Path Planning." Proceedings of the 2012 IEEE International Conference on Mechatronic and Automation, pp. 1227-1232. IEEE, 2012.

[71] Bates, a.R., a.S. Bijral, J. Mulligan, and G. Grudic. "Traversable Path Identification in Unstructured Terrains: A Markov Random Walk Approach." 2009 IEEE International Conference on Robotics and Automation, pp. 3423-3430. IEEE, 2009.