Proceeding International conference on Recent Innovations is Signal Processing and Embedded Systems (RISE-2017) 27-29 October,2017

A Survey of Autonomous Mobile Robot Path Planning Approaches

Anantha Sai Hari Haran VInjarapu
department of Electrical Engineering
Maulana Azad National Institute of Technology
Bhopal, Madhya Pradesh, India
ananthhariharan611@gmail.com

Suresh Kumar Gawre
department of Electrical Engineering
Maulana Azad National Institute of Technology
Bhopal, Madhya Pradesh, India
sgawre28@gmail.com

***Abstract*—Navigation is one of the pivotal and defining features of an autonomous robot. Essentially, the autonomous robot navigation problem can be divided into four parts namely: perception, localisation, cognition and path planning, out of which path planning is important and has been a constant research topic. In this paper, a brief introduction and review of some of the path planning approaches (both classical and heuristic) is provided. The advantages and disadvantages of the methods are discussed.**

***Keywords*—Autonomous robot navigation, path planning, classical and heuristic approaches,**

I. INTRODUCTION

One of the key features desirable in the autonomous robots is the ability to navigate through the environment. Most of the robot applied fields these days like mining, agriculture etc. require the robots to move and perform tasks in a variety of environments which are sometimes even unpredictable. The navigation problem consists of four integral parts namely perception, localization, motion control and path planning. The path planning is the determination of a collision-free path in a given environment which is often a cluttered environment in a real world situation(1).

A lot of different path planning approaches have been proposed and tested in various environments with static and dynamic obstacles. These include both classical approaches like potential fields, cell decomposition, bug algorithm, roadmap etc. and heuristic approaches like neural networks, fuzzy logic, wavelets etc. (2). Both of these approaches have various advantages anddisadvantages in various cases. The two categories namely global and local path planner make use of all of these approaches to find an optimal path for the robot in a given environment. The former generates low resolution high level plan of the environment while the latter generates a high resolution plan of a part of the global path (3, 4). Hybrid planners integrating these two into a single planner have been proposed in (5,6). In the following section some of the prominent heuristic path planning approaches have been reviewed in II followed by some classical path planning approaches in III.

II. HEURISTIC APPROACHES

The Heuristic path planning approaches, though have come into use recently as compared to the Classical approaches, have gained a lot of importance due to their human like behaviour-based learning. Some of the popular approaches of this class such as Artificial Neural Networks(ANN), Fuzzy Logic, Wavelets, Genetic Algorithm are discussed here

A. Artificial Neural Networks(ANNs)

An ANN is a bio-inspired artificial model of a human brain with the ability to mimic the behaviour based learning. The basic computational unit of an ANN is called a neuron which has the ability to store and reproduce experiential information similar to the human brain. These have been widely used in many search optimization, learning and pattern recognition problems due to their ability to produce simple and optimal solutions in complex situationsMaintaining the Integrity of the Specifications

In (7), the authors study in Self Supervised Learning (SSL), how the arrangement of robot's learning behaviour should be in order that it performs the assigned task even in case the original sensor que becomes unavailable. A hybrid method using a combination of ANN and Particle Swarm Optimization (PSO) is proposed in (8). In this, the PSO is used to provide a smooth trajectory for NN to reach the goal. An ANN based path planner with the ability to plan paths for multiple robots simultaneously while avoiding obstacles in dynamic environments is proposed in (9). A complete coverage path planning which is necessary in cleaning robots is proposed in (10) using ANN. However there are certain disadvantages to using ANNs. The training data required may be quite large in some cases to ensure that the results are statistically correct (11). Also the minimisation of error between the computed and required output in case of supervised learning ANNs is difficult.

ISBN 978-1-5090-4760-4/17/$31.00©2017 IEEE

B. Fuzzy Logic

The concept of fuzzy sets was first proposed by Zadeh [12] in 1965. This approach has wide application in the robot path planning as it provides a formal technique for representing and implementing the human experts' heuristic knowledge and perception-based actions. The methodology of a Fuzzy Logic controller(FLC) is very useful in dealing with the real world uncertainties without the requirement of an absolute model of the environment [13].

A path planner based on fuzzy logic and filter smoothing in a dynamic environment is implemented on an autonomous mobile robot in [14]. An FLC for an Unmanned Aerial Vehicle(UAV) in a 2-D space is developed in [15]. A hybrid algorithm using fuzzy logic and genetic algorithm was for path planning of a mobile robot in [16]. The GA was used to modify the input and output membership functions for the FLC. A path planning approach for humanoid robots based on Fuzzy Markov Decision Process(FMDP) is proposed in [17]. The proposed method is focused on the issue of unavailability of thorough sensory information of the environment.

C. Wavelets

The wavelet transform is a mathematical tool that decomposes a signal into a representation that shows signal details and trends as a function of time. This approach has been implemented successfully to solve the path planning problem. A hierarchical on-line path planning approach is proposed in [18]. The method uses a multiresolution of the environment at different distances from the robot which is obtained by wavelets. However, this method has a drawback of global re-planning at each step. This has been resolved in [19] in which a global plan is created and local re-planning is done at each step. A hierarchicalmotion planning is proposed in [20] keeping in view the compatibility between the high-level logic task and the low-level vehicle dynamics. The proposed planner is based on a special interaction between these two levels of planning. A motion planner based on cell decomposition is proposed in [21] which enables the use of wavelet transforms in both perception and motion planning simultaneously thus reducing computing cost. The multi resolution cell decomposition can be achieved through quad-trees as well. However, this has the disadvantage that the cells around all the obstacles in the environment map have high resolution irrespective of the distance of the obstacle from the robot. This adds to the computational cost.

D. Genetic Algorithm(GA)

GA is an optimization tool that is most commonly used to generate high quality solutions for combination optimization problems and search problems. The GA is inspired from the process of natural selection and relies on evolutionary operators like mutation, crossover and selection. The GA starts with no knowledge of correct solution and entirely depends on the responses of the environment and the above mentioned evolutionary operators and arrive at the best solution [22].

A knowledge-based genetic algorithm for path planning is proposed in [23]. In this, the operators are applied based on heuristic knowledge to the parents from the initial generation In [24], a GA based path planning algorithm is proposed in which chromosome has a variable length. A global path planner based on GA is proposed in [25]. In the proposed method, the length of the binary strings is shortened by projecting the two-dimensional coordinates of points in the workspace into one dimensional ones. In [26], implementation of GA is given. The algorithm is adjusted to the resource constraints of the microcontroller used in embedded environments. Figure 1. shows the process flowchart of a basic genetic algorithm. Theuse of genetic operations like crossover, mutation and selection depends on the particular problem.

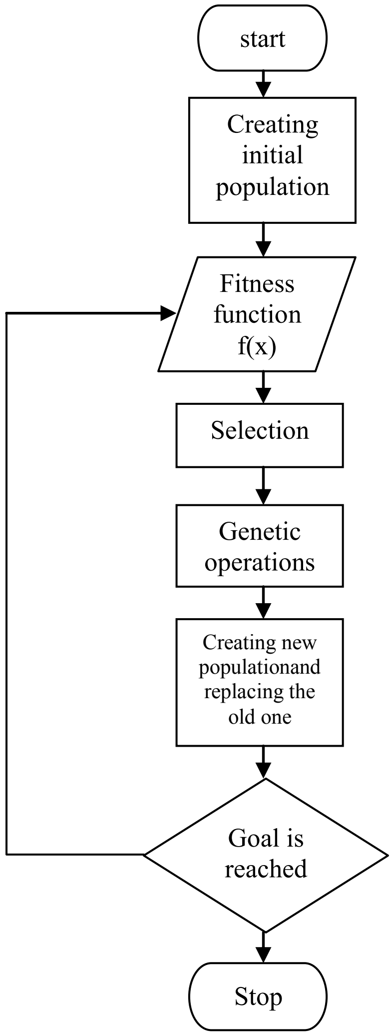

Fig 1. Process flowchart of a basic genetic algorithm

III. CLASSICAL APPROACHES

The classical methods have been in use majorly before 2000s though heuristic approaches sprung into domination later [27]. The classical path planners either find a solution or prove that such solution does not exist. Their usage in real world is limited due to their computational intensiveness and inability to cope with uncertainties [28]. Following classical methods are discussed here: Cell Decomposition (CD), Potential Fields (PF), Roadmap.

A. Potential Fields

The concept of using Artificial Potential Fields(APF) in autonomous robots for obstacle avoidance was first proposed by Khatib.O [29]. The main idea of this method is to guide the robot to the target by generation of attractive and repulsive forces within the robot's working environment. The attractive forces are assigned to the targets and repulsive forces are assigned to the obstacles.

A path planning method for an Autonomous Surface Vessel based on APF is provided in [30]. Inthis, the APF method is used as a local path planning algorithm for maintaining the vessel in the centre of the river simultaneously avoiding the obstacles. A hybrid approach using APF in combination with PSO is proposed in [31] where PSO is used to reduce local minima of APF. An APF based regression search method is proposed in [32]. Here, virtual local targets are used to escape oscillations and then the path produced by this modified APF method is optimised by regression search.The main disadvantage of this method is the occurrence of trap local minima [33, 34] in which case the robot keeps oscillating between the obstacles. Various techniques are available to overcome this like Simulated Annealing[27], PSO [31]. Figure 2. shows the variation of the attractive potential field with the distance of the robot. The attractive potential is given as

$$U_{att}(q) = \frac{1}{2} \cdot \zeta \cdot d^2(q, q_{goal}) \tag{1}$$

Here, ζ is a proportionality constant and is the coefficient of attractive field potentials. The term d(q, q_{goal})is the eucledian distance between the position of the robot, q and the position of the goal q_{goal}..

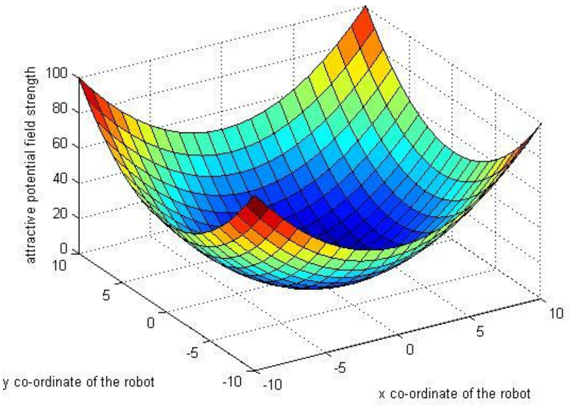

Fig.2:Variation of attractive potential field with the distance of the robot from goal.

As can be seen from the plot of Figure(2), the attractive potential is a paraboloid. But this causes the attractive force obtained by gradient of the potential to be out of bound. This can be overcome by using a conic well in combination with this parabolic well.

$$U_{att}(q) = d_0 \cdot \zeta \cdot d^1(q, q_{goal}) \tag{2}$$

Here d_0 is the threshold distance. If the robot-goal distance is greater than this, the conic well potential is taken for force calculation.

B. Roadmap

In this approach, the roadmaps are built with a set of paths where each path consists of collision free area connections. These roadmaps are later used for path planning. The path planning is thus reduced to searching for a series of roads from initial position to the goal from a road network connecting the initial and goal points [35]. A safe clearance path planning method using Voronoi diagram is proposed in [36] with an attempt to solve the optimality issue. A two phase path planning method for high dimensional configuration space based on PRM is proposed in [37]. The two phases are namely learning phase and query phase. The proposed method is for robots in static workspace. The method is claimed to be highly time efficient. A method for solving single-query path planning problems in high-dimensional configuration spaces by incrementally building two rapidly exploring random trees (RRTs) is proposed in [38]. The trees explore the space around them and also advance towards each other by a simple greedy heuristic. However, the PRM method is not complete in the sense that it may not find a path even though one exists as it is probabilistic.

C. Cell Decomposition

Cell Decomposition(CD) is highly used by literature in path planning problems. Cell Decomposition is the representation of search space in the form of individual units called cells. The goal is to provide a sequence of obstacle free steps from the starting point through the goal. Such a sequence of steps would be provided by using cells without obstacles. The cells with obstacles are first divided into two new cells and then the pure cells(cells without obstacles) are added to the sequence [28]. In [39], a novel approximate cell decomposition strategy is developed in which the obstacles, targets, sensor's platform and field of vision(FOV) are represented as closed and bounded subsets of a Euclidean workspace. In [40], a hierarchical approximate cell decomposition strategy is proposed. The methodology was to include time as one of the dimensions of the model world which allows the dynamic obstacles to be regarded as stationary in an extended world. Hierarchical approximate cell decomposition method is also used in [41]. A path planning technique using harmonic functions and probabilistic cell decomposition is given in [42]. However, CD method is not usable in 8-directional planning [43] and also involves more tedious mathematical operations.

IV. CONCLUSION

The classical approaches, though have been widely used in the early years of research, have been largely replaced by the heuristic approaches in the recent times. This is due to the fact that the heuristic approaches are close to the human way of behavior learning. However, inspite of the drawbacks of the classical, they can be used for effective path planning by combining them with the heuristic approaches to minimize their errors. These kind of hybrid algorithms are developed even with multiple heuristic algorithms for more efficiency and optimality.

REFERENCES

[1] ThiThoa Mac, Cosmin Copot, Duc Trung Tran, Robin De Keyse, "Heuristic approaches in robot path planning: a survey", Robotics and Autonomous Systems 86(2016), pp.13-28J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.

[2] N.Sariff, N. Buniyamin, "An overview of autonomous mobile robot path planning algorithms",4 th Student Conference on Research on Development (Scored 2006), June 2006

[3] S.H Tang, W.Khaksar, N.B.Ismail, M.K.A.Ariffin, "A review on robot motion planning approaches", J Adv Robot Autom 2015, 4:2

[4] P.Raja, S.Pugazhenthi, "Optimal path planning of mobile robots: a review", International journal of physical sciences, Vol 7(9), pp 1314-1320-February 2012

[5] Lim Chee Wang, Lim Ser Yong, Marcelo H.Ang Jr., "Hybrid global path planning and local navigation implemented on a mobile robot in indoor environment", Proceedings of the 2002 IEEE International Symposium on Intelligent Control Vancouver, Canada-October 27-30, 2002.

[6] Andrea Signifredi, Bombini Luca, Alessandro Coati, "A general purpose approach for global and local path planning combination", IEEE 18th Internal Conference on Intelligent Transportation Systems 2015

[7] Kevin van Hecke, Guido de Croon, Laurens van der Maaten, Daniel Hennes, Dario Izzo, "Persistant self-supervised learning principle: from stereotomonocular vision for obstacle avoidance", CoRR, Mar. 2016.

[8] Yangmin Li, Xin Chen, "Mobile robot navigation using particle swarm optimization and adaptive NN", ICNC 2005, pp. 628-631

[9] Yangmin Li, Xin Chen, "mobile robot navigation using particle swarm optimization and adaptive NN", ICNC 2005, pp. 628-631

[10] Simon X.Yang, Chaomin Luo, "A neural network approach to complete coverage path planning", IEEE Transactions on Systems, Man. and Cybernetics-Part B:Cybervetics, Vol. 34, No. 1, February 2004, pp. 718-724.

[11] James Cannady, "Artificial neural networks for misuse detection", National Information Systems Security Conference 1998, pp. 443-456.

[12] L.A.Zadeh, "Fuzzy sets", Information and Control 8, pp.-338-353, 1965.

[13] Tang Sai Hong, Danial Nakhaeinia, BabakKarasfi, "Application of fuzzy logic in mobile robot navigation", Fuzzy Logic-Controls, Concepts, Theories and Applications, March 28, 2012, pp. 21-36.

[14] Yipei Yan, Yangmin Li, "Mobile robot autonomous path planning based on fuzzy logic and filter smoothing in dynamic environment", World Congress on Intelligent Control and Automation (WCICA), June 12-15, 2016, Guilin, China, pp. 1479-1484

[15] Chelsea Sabo, Kelly Cohen, "fuzzy logic unmanned air veicle motion planning", Advances in Fuzzy Systems, Volume 2012(2012), pp.

[16] IrajHassanzadeh, SevilM.Sadigh, "Path planning for a mobile robot using fuzzy logic controller tuned by GA", Proceeding of the 6 th International Symposium on Mechatronics and its Applications(ISMA09), Sharjah, UAE, March24-26, 2009, pp. ISMA09-1 – ISMA09-5.

[17] Mahdi Fakoor, AmirrezaKosari, Mohsen Jafarzadeh, "Humanoid robot path planning with fuzzy markov decision processes", Journal of Applied Research and Technology Volume 14, Issue 5, October 2016, pp.300-310.

[18] Panagiotis Tsiotras, EfstathiosBakolas, "A hierarchical on-line path planning scheme using wavelets", Proceedings of the European Control Conference 2007, Kos, Greece, July 2-5, 2007, pp. 2806-2812.

[19] RaghavendraV.Cowlagi, Panagiotis Tsiotras, "Multiresolution path planning with wavelets: a local replanning approach", American Control Conference, Seattle, Washington, June 11-13, 2008, pp. 1220-1225.

[20] RaghavendraV.Cowlagi, Panagiotis Tsiotras, "Hierarchical motion planning with dynamical feasibility guarentees for mobile robotic vehicles", IEEE Transactions on Robotics, Vol. 28, No.2,April 2012, pp. 379-395.

[21] RaghavendraV.Cowlagi, Panagiotis Tsiotras, "Multi-resolution motion planning for autonomous agents via wavelet-based cell decompositions", IEEE Transactions on Systems, Man. and Cybernetics:Part B(Cybernetics), Vol.42, Issue5, Oct. 2012, pp. 1455-1469.

[22] Leena.N, K.K.Saju, "A survey on path planning techniques for autonomous mobile robots", International Conference on Advances in Engineering & Technology-2014(ICAET-2014).

[23] Yanrong Hu, Simon X. Yang, "A knowledge based genetic algorithm for path planning of a mobile robot", Proceedings of the 2004 IEEE International Conference on Robotic & Automation, New Orleans, LA, April 2004, pp.4350-4355.

[24] Jianping Tu, Simon X.Yang, "Genetic algorithm based path planning for a mobile robot", Proceedings of the 2003 IEEE International Conference on Robotics &Automatio, Taipei, Taiwan, September 2003, pp. 1221-1226.

[25] Amin Ghorbani, Saeed Shiry, Ali Nodehi, "Using genetic algorithm for a mobile robot path planning", 2009 International Conference on Future Computer and Communiction, pp.164-166.

[26] H.Burchardt, R.Salomon, "Implementation of path planning using genetic algorithms on mobile robots", IEEE Congress on Evolutionary Computation, Canada, July 16-21, 2006, pp. 1831-1836.

[27] EllipsMasehian, DavoudSedighizadeh, "Classical and heuristic approaches in robot motion planning-a chronological review", International Journal of Mechanical, Aerospace, Industrial,Mechatronic and Manufacturing Engineering Vol:1, Nov 5, 2007.

[28] AdhamAtyabi, David M.W.Powers, "Review of classical and heuristic based navigation and path planning approaches", International Journal of Advancements in Computing Technology(IJACT) Volume5, Number4, October 2013.

[29] Oussama Khatib, "Real-time obstacle avoidance for manipulators and mobile robots", The International Journal of Robotics Research Vol.5, No.1, Spring 1986.

[30] Mei Jian Hong, M.R.Arshad, "A balance-artificial potential field method for autonomous surface vessel navigation in unstructured Riverine Environment", IEEE International Symposium on Robotics and Intelligent Sensors(!RIS), 2015 published in Procedia Computer Science 76 (2015) pp 198-202.

[31] AlaaA.Ahmed, Turki Y. Abdulla, Ali A.Abed, "Path planning of mobile robot by using modified optimized potential field method", International Journal of Computer Applications(0975-8887) Volume 113-No.4, March 2015 pp 6-10.

[32] Guanghui Li, Atsushi Yamashita, Hajime Asama, Yusuke Tamura, "An efficient improved artificial potential field based regression search method for robot path planning", Proceedings of 2012 IEEE International Conference on Mechatronics and Automation August 55-8, Chengdu, China pp.1227-1232.

[33] Milos Seda, "Roadmap method vs. cell decomposition in robot motion planning", Proceedings of the 6th WSEAS International Conference on Signal Processing, Robotics and Automation, Corfu Island, Greece, February 16-19, 2007.

[34] AdhamAtyabi, David M.W.Powers, "Review of classical and heuristic based navigation and path planning approaches", International Journal of Advancements in Computing Technology(IJACT) Volume5, Number4, October 2013.

[35] Roland Siegwart, IllahR.Nourbakhsh, "Introduction to autonomous mobile robots", TheMIT Press Cambridge, Massachusetts London, England 2004, pp. 261-264.

[36] Priyadarshi Bhattacharya, Marina L.Gavrilova, "Roadmap-based path planning using the Voronoi diagram for a clearance-based shortest path", IEEE Robotics and Automation Magazine, June 2008, pp. 58-66.

[37] Lydia E.Kavraki, Petr Svetka, Jean-Claude Latombe, Mark H.Overmars, "Probabilistic roadmaps for path planning in high-dimensional configuration spaces", IEEE Transactions On Robotics And Automation vol. 12, No.4, 1996, pp. 566-580.

[38] James J. Kuffner, Steven M.LaValle, "RRT-connect: an efficient approach to single-query path planning", Proceedings of the 2000 IEEE International conference on Robotics and Automation, pp. 995-1001.

[39] Chenghui Cai, Silvia Ferrari, "Information-driven sensor path planning by approximate cell decomposition", IEEE Transactions on Systems, Man and Cybernetics, Part B(Cybernetics) (Volume 39, Issue 3, June 2009).

[40] Kikuo Fujimura, Hanan Samet, "A hierarchical strategy for path planning among moving obstacles", IEEE Transactions on Robotics and Automation, Vol.5 No.1, February 1989.

[41] D.J.Zhu, J.C. Latombe, "New heuristic algorithms for efficient hierarchical path planning", IEEE Transactions on Robotics and Automation (Volume: 7, Issue: 1, February 1991).

[42] J.Rosell, P.Iniguez, "Path planning using harmonic functions and probabilistic cell decomposition", IEEE International Conference on Robotics and Automation Barcelona, Spain, April 2005.

[43] Milos Seda, "Roadmap method vs. cell decomposition in robot motion planning", Proceedings of the 6th WSEAS International Conference on Signal Processing, Robotics and Automation, Corfu Island, Greece, February 16-19, 2007.