Hochschule
Bonn-Rhein-Sieg
University of Applied Sciences

Bonn-Aachen
International Center for
Information Technology

R&D Project Proposal

Robot motion planning in dynamic environment: A comparative study

Dharmin Bakaraniya

Supervised by

Prof. Dr. Ervin Prassler
Dr. Cesar Lopez Martinez

May 2018

1. Introduction

- Mobile robot needs a plan to reach to its desired goal. This plan is provided by motion planning algorithms.
- Robot motion planning (RMP) for static environment is not sufficient for most of the application.
- Take for example, a robotic wheel chair or robot carrying hospital bed. These robot needs to tackle moving obstacle like patients, other wheel chairs, hospital beds, etc. while safely moving towards its goal.
- This type of problem applications need RMP for dynamic environment.
- By solving this problem, we can ensure
  - Safe environment for humans and for robots
  - Cost effective transportation of goods

1.1. Problem Statement

- RMP in dynamic environment needs to perform the following task
  - Reach the desired target
  - Avoid static and moving obstacle
- It needs to perform these tasks in *fast* and *efficient* manner.
- This work will provide a comparative study on existing approaches for RMP in dynamic environment.
- This comparative study will include
  - An in depth literature review of existing approaches
  - Identifying top solutions

- Evaluating these candidates on various benchmark practical test on a real and simulated environment
- Identifying the best solution based on the performance measure

2. Related Work

- All the existing approaches have tested their efficiency on different robots and in different test environment.
- As the measuring criterion for each of them is different, it becomes an impossible task to determine a clear winner.
- There are several existing survey article:
  - Mohanan et al. [20] covers 101 research papers that were published between 1985 and 2016 in the field of RMP in dynamic environment. They have addressed all the approaches but a comparative analysis of all the approaches with their contributions and deficiencies is left to be desired.
  - Hoy et al. [11] provides a survey for algorithms which provide collision free navigation for robots. This survey is not only detailed but also quite broad as it covers obstacle avoidance algorithm as well. Even though it provides a comparison between main approaches based on numerous criterion, it still does not evaluate these approaches on a standard uniform test.
  - Keshmiri et al.[13] provides a survey specifically for RMP in dynamic environment. It covers all the approaches presented in research papers published between 1986 and 2008 totalling up to 150 papers. They have provided a comparison on how much contribution has been made in RMP field based on different approach but regarding the actual approaches itself, only a summary of at most 2-3 sentences for each approach is provided.
  - [8] and [32] are quite dated and does not cover any state of the art approaches in RMP for dynamic environment.
- Existing approaches generally provide critique and deficiencies on their previous works. These are generally helpful but they mostly compare their approach with the existing solutions and only point out the deficiencies that

they have addressed. Therefore, though these comparisons are helpful, they might not be completely reliable.

2.1. Approaches in RMP for dynamic environment

2.1.1. Velocity based

- *Dynamic window approach*: Fox et al. [6] proposed the original idea for simply optimizing a function which balances robot's distance from goal, distance from nearest obstacle and current velocity. This approach, despite being robust, simple and fast did not work for dynamic environment. Later, Brock et al. [2] extended this approach for global path planning and for dynamic environments by combining it with NF1 algorithm. This eradicated the problem of local minima. It has been since extended in [29] and [22]

- *Velocity obstacle (VO)*: Originally developed by Fiorini et al.[5], this approach proposes to avoid obstacles by choosing velocity outside *collision cone*. This approach unifies the representation for avoiding static and dynamic obstacles. This idea has since been transformed to incorporate many scenarios[30][24][23][10]. For multi robot systems, Van den berg et al.[35][34][33] have extended VO approach.

- *ICS based approach*: Inevitable collision states (ICS) [7][25][18] have proposed a solution to avoid states that has no outcome other than collision. They propose that this states if avoided will ensure that the robot will never collide. They have approached this problem in a mathematical way. They provide a very fast and almost infinite look ahead option[20].

2.1.2. Roadmap based

- *Randomized kinodynamic planning*: Hsu et al.[12] provides an extension of probabilistic roadmap approach by considering kinodynamics of the robot before choosing a motion control.
- Van den berg et al.[36] provides an extension on roadmap based motion planning for static and dynamic obstacles.

2.1.3. Other

- *Nearness diagram*: [19] proposes a *divide and conquer* strategy for RMP in dynamic environment using a geometry based implementation of their approach.

3. Project Plan

3.1. Work Packages and milestones

The bare minimum will include the following packages:

Work packages	**Milestones**
Literature search	Gather literature
Literature review	Create review criteria and use case Compare different approaches Create annotated bibliography Exclude approaches based on review criteria Create summary of review
Experiments	Choose approaches to test Implement approaches Perform experiments and gather results Evaluate results
Documentation	Document conclusion and review Refine report for better readability

Table 3.1: Work packages and milestones

3.2. Project Schedule

3.3. Deliverables

3.3.1. Minimum

- Annotated bibliography on RMP for dynamic environment
- Analysis of state of the art

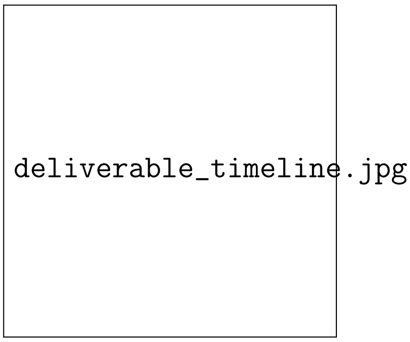

Figure 3.1: Gannt chart of milestones

- Description of review criteria
- Demonstration of 3 approaches in simulation
- Demonstration of 3 approaches on a real robot
- R & D report

3.3.2. Expected

- All items in minimum deliverable
- Description of use cases
- Demonstration of 1 additional approach in simulation

3.3.3. Desired

- All items in expected deliverable
- Detailed analysis of the result
- Demonstration of 1 additional approach in simulation

References

[1] Fares Jawad Mohd Abu-Dakka. *Trajectory planning for industrial robot using genetic algorithms*. PhD thesis, Not available, 2011.

[2] Oliver Brock and Oussama Khatib. High-speed navigation using the global dynamic window approach. In *Robotics and Automation, 1999. Proceedings. 1999 IEEE International Conference on*, volume 1, pages 341–346. IEEE, 1999.

[3] Paolo Fiorini and Zvi Shiller. Robot motion planning in dynamic environments. In *International Symposium of Robotic Research*. Citeseer, 1995.

[4] Paolo Fiorini and Zvi Shiller. Time optimal trajectory planning in dynamic environments. In *Robotics and Automation, 1996. Proceedings., 1996 IEEE International Conference on*, volume 2, pages 1553–1558. IEEE, 1996.

[5] Paolo Fiorini and Zvi Shiller. Motion planning in dynamic environments using velocity obstacles. *The International Journal of Robotics Research*, 17(7):760–772, 1998.

[6] Dieter Fox, Wolfram Burgard, and Sebastian Thrun. The dynamic window approach to collision avoidance. *IEEE Robotics & Automation Magazine*, 4(1):23–33, 1997.

[7] Thierry Fraichard and Hajime Asama. Inevitable collision states—a step towards safer robots? *Advanced Robotics*, 18(10):1001–1024, 2004.

[8] Kikuo Fujimura. *Motion planning in dynamic environments*. Springer Science & Business Media, 1991.

[9] Oren Gal, Zvi Shiller, and Elon Rimon. Efficient and safe on-line motion planning in dynamic environments. In *Robotics and Automation, 2009. ICRA'09. IEEE International Conference on*, pages 88–93. IEEE, 2009.

[10] Stephen J Guy, Jatin Chhugani, Changkyu Kim, Nadathur Satish, Ming Lin, Dinesh Manocha, and Pradeep Dubey. Clearpath: highly parallel collision

avoidance for multi-agent simulation. In *Proceedings of the 2009 ACM SIGGRAPH/Eurographics Symposium on Computer Animation*, pages 177–187. ACM, 2009.

[11] Michael Hoy, Alexey S. Matveev, and Andrey V. Savkin. Algorithms for collision-free navigation of mobile robots in complex cluttered environments: a survey. *Robotica*, 33(3):463–497, 2015.

[12] David Hsu, Robert Kindel, Jean-Claude Latombe, and Stephen Rock. Randomized kinodynamic motion planning with moving obstacles. *The International Journal of Robotics Research*, 21(3):233–255, 2002.

[13] Soheil Keshmiri and Shahram Payandeh. An overview of mobile robotic agents motion planning in dynamic environments. In *Proceedings of the 14th IASTED International Conference, Robotics and Applications (RA20), MA, Boston*, pages 152–159, 2009.

[14] B. Kluge, D. Bank, and E. Prassler. Motion coordination in dynamic environments: reaching a moving goal while avoiding moving obstacles. In *Proceedings. 11th IEEE International Workshop on Robot and Human Interactive Communication*, pages 512–517, 2002.

[15] Boris Kluge and Erwin Prassler. Reflective navigation: Individual behaviors and group behaviors. In *Robotics and Automation, 2004. Proceedings. ICRA'04. 2004 IEEE International Conference on*, volume 4, pages 4172–4177. IEEE, 2004.

[16] Florent Lamiraux, David Bonnafous, and Olivier Lefebvre. Reactive path deformation for nonholonomic mobile robots. *IEEE transactions on robotics*, 20(6):967–977, 2004.

[17] Jean-Claude Latombe. *Robot Motion Planning (the Kluwer international series in engineering and computer science).* Kluwer, 1990.

[18] Luis Martinez-Gomez and Thierry Fraichard. Collision avoidance in dynamic environments: an ics-based solution and its comparative evaluation. In *Robotics*

and Automation, 2009. ICRA'09. IEEE International Conference on, pages 100–105. IEEE, 2009.

[19] Javier Minguez and Luis Montano. Nearness diagram (nd) navigation: collision avoidance in troublesome scenarios. *IEEE Transactions on Robotics and Automation*, 20(1):45–59, 2004.

[20] M.G. Mohanan and Ambuja Salgoankar. A survey of robotic motion planning in dynamic environments. *Robotics and Autonomous Systems*, 100:171 – 185, 2018.

[21] Muhannad Mujahed, Dirk Fischer, and Bärbel Mertsching. Admissible gap navigation: A new collision avoidance approach. *Robotics and Autonomous Systems*, 103:93–110, 2018.

[22] Petter Ogren and Naomi Ehrich Leonard. A convergent dynamic window approach to obstacle avoidance. *IEEE Transactions on Robotics*, 21(2):188–195, 2005.

[23] E. Owen and L. Montano. Motion planning in dynamic environments using the velocity space. In *2005 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 2833–2838, Aug 2005.

[24] E. Owen and L. Montano. A robocentric motion planner for dynamic environments using the velocity space. In *2006 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 4368–4374, Oct 2006.

[25] Stéphane Petti and Thierry Fraichard. Safe motion planning in dynamic environments. In *Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on*, pages 2210–2215. IEEE, 2005.

[26] E. A. Prassler and E. E. Milios. Motion planning amongst arbitrarily moving unknown objects. In *Intelligent Robots and Systems '94. 'Advanced Robotic Systems and the Real World', IROS '94. Proceedings of the IEEE/RSJ/GI International Conference on*, volume 2, pages 1338–1346 vol.2, Sep 1994.

[27] Erwin Prassler, Jens Scholz, and Paolo Fiorini. A robotics wheelchair for crowded public environment. *IEEE Robotics & Automation Magazine*, 8(1):38–45, 2001.

[28] Cao Qixin, Huang Yanwen, and Zhou Jingliang. An evolutionary artificial potential field algorithm for dynamic path planning of mobile robot. In *Intelligent Robots and Systems, 2006 IEEE/RSJ International Conference on*, pages 3331–3336. IEEE, 2006.

[29] Marija Seder and Ivan Petrovic. Dynamic window based approach to mobile robot motion control in the presence of moving obstacles. In *Robotics and Automation, 2007 IEEE International Conference on*, pages 1986–1991. IEEE, 2007.

[30] Zvi Shiller, Oren Gal, Thierry Fraichard, et al. The nonlinear velocity obstacle revisited: The optimal time horizon. In *Workshop on guaranteeing safe navigation in dynamic environments. In IEEE international conference on robotics and automation*, 2010.

[31] Zvi Shiller, Frederic Large, and Sepanta Sekhavat. Motion planning in dynamic environments: Obstacles moving along arbitrary trajectories. In *Robotics and Automation, 2001. Proceedings 2001 ICRA. IEEE International Conference on*, volume 4, pages 3716–3721. IEEE, 2001.

[32] Takashi Tsubouchi. Motion planning for mobile robots in a time-varying environment: A survey. *Journal of Robotics and Mechatronics*, 8(1):15–24, 1996.

[33] Jur Van Den Berg, Dave Ferguson, and James Kuffner. Anytime path planning and replanning in dynamic environments. In *Robotics and Automation, 2006. ICRA 2006. Proceedings 2006 IEEE International Conference on*, pages 2366–2371. IEEE, 2006.

[34] Jur Van Den Berg, Stephen J Guy, Ming Lin, and Dinesh Manocha. Reciprocal n-body collision avoidance. In *Robotics research*, pages 3–19. Springer, 2011.

[35] Jur Van Den Berg, Ming Lin, and Dinesh Manocha. Reciprocal velocity obstacles for real-time multi-agent navigation. In *Robotics and Automation, 2008. ICRA 2008. IEEE International Conference on*, pages 1928–1935. IEEE, 2008.

[36] Jur P Van Den Berg and Mark H Overmars. Roadmap-based motion planning in dynamic environments. *IEEE Transactions on Robotics*, 21(5):885–897, 2005.

[37] Jur Pieter Van den Berg. *Path planning in dynamic environments*. PhD thesis, Utrecht University, 2007.