Robot Motion Planning in Dynamic Environment: A Comparative Study

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Introduction I

What is motion planning?

- A mobile robot needs to
  - Reach goal in **minimal** time
  - Avoid **static** *and* **moving** obstacle
  - Consider **kinematics** *and* **dynamic** constraints

What is our aim?

Find out the "best" planner

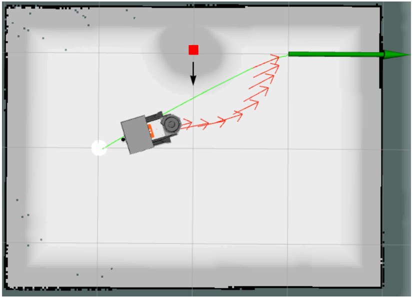


Figure: Robot motion planning in dynamic environment

Introduction II

What are the benefits?

- **Safer** environment for humans *and* for robots
- **Cost effective** transportation of goods

State of the art I

Survey of motion planning in dynamic environment (2018)[4]

- Covers 101 research papers published between 1985 and 2016
- Only introduces approaches.
- Contains almost no comparison.

[4] M.G. Mohanan and Ambuja Salgoankar. "A survey of robotic motion planning in dynamic environments". In: *Robotics and Autonomous Systems* 100 (2018), pp. 171 –185. ISSN: 0921-8890. DOI: https://doi.org/10.1016/j.robot.2017.10.011. URL: http://www.sciencedirect.com/science/article/pii/S0921889017300313.

State of the art II

Collision avoidance algorithm survey (2015)[5]

- Compares collision avoiding algorithms in detail.
- Does not validate the comparison with experiments.
- Mainly focuses on boundary following algorithms.

[5] Michael Hoy, Alexey S. Matveev, and Andrey V. Savkin. "Algorithms for collision-free navigation of mobile robots in complex cluttered environments: a survey". In: *Robotica* 33.3 (2015), pp. 463 –497. DOI: 10.1017/S0263574714000289.

State of the art III

Field contribution survey (2009)[6]

- Introduces 150 papers from 1986 to 2008. Compares contribution in different area of motion planning
- Only provides contributions of different fields. Does not compare the approaches at all.

[6] 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.* 2009, pp. 152–159.

State of the art IV

Dated comparison (1992)[7]

- Surveys papers from 1979 to 1989 for all types of motion planning.
- Compares time and complexity
- Significantly old
- Does not compare with common parameters.

[7] Yong K Hwang and Narendra Ahuja. "Gross motion planning–a survey". In: *ACM Computing Surveys (CSUR)* 24.3 (1992), pp. 219–291.

What is lacking?

Surveys

The surveys do not test the approaches.

Individual published approaches

The individual published approaches test themselves

- on different robots[8]
- with different kinodynamic constraints [8]
- with different assumptions
- in different environments
- to optimize different parameters [8]

[8] **Michael Hoy; Alexey S. Matveev and Andrey V. Savkin**; **"Algorithms for collision-free navigation of mobile robots in complex cluttered environments: a survey"**; **In: Robotica 33.3 (2015)**; **pp. 463 497. doi: 10.1017/S0263574714000289.**.

Qualitative Comparison

We qualitatively compare 30+ planners based on

Vehicle type

Holonomic, unicycle or bicycle

Restrictions on obstacle

- Constant or varying direction
- Constant or varying velocity

Obstacle shape

Circular or polygonal

Experiment environment

Simulated and/or real

Experimental setup

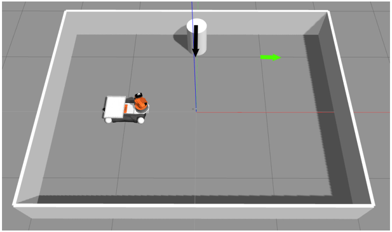
Setup

- **Robot**: KUKA youBot with 2 laser rangefinders
- **Environment**: Gazebo simulator
- **Obstacle**: Cylinders with varying velocity and varying direction
- **Optimisation parameter**: Minimise time

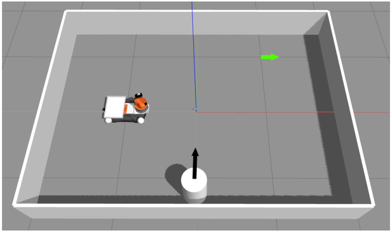
Measured values

- Travel time
- Number of collisions
- Number of re-plans

Test case 1 (Single room single obstacle)



(a) t=0.0s

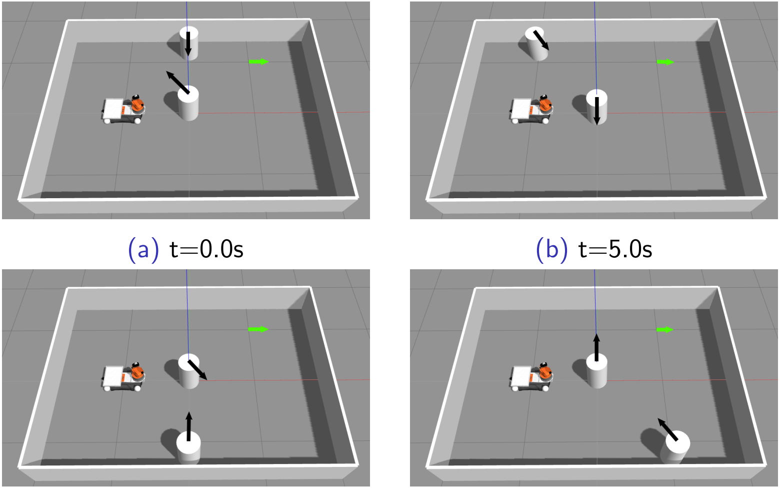


(b) t=10.0s

Description

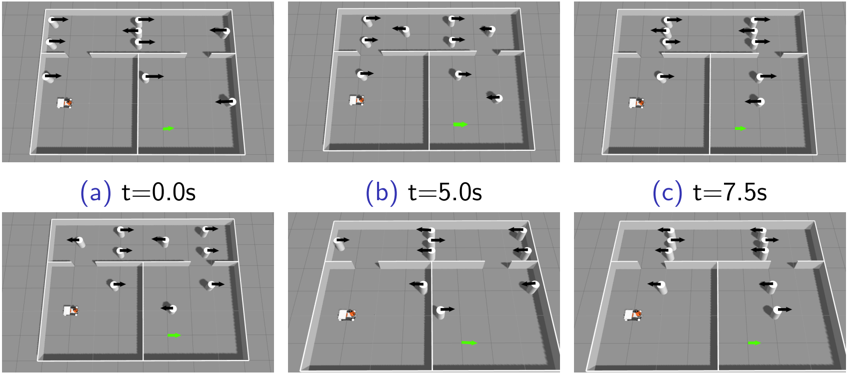
- Room size: 4 meters x 3 meters
- Starting position: `x=-1.0, y=0.0, theta=0.0`
- Goal position: `x=1.0, y=1.0, theta=0.0`

Test case 2 (Single room two obstacles)



(a) t=0.0s (b) t=5.0s (c) t=10.0s (d) t=15.0s

Test case 3 (Double room nine obstacles)



(a) t=0.0s (b) t=5.0s (c) t=7.5s

(d) t=10.0s (e) t=15.0s (f) t=22.5s

Figure: Test case 3 (Total size: 8m x 6m)

Compared Planners

- Timed elastic band planner (TEB)[9]
- Spline based planner[10].
- Elastic band approach (EBand)[11].
- Eband* (EBand2)
- Dynamic window approach* (DWA)[12]

* with obstacle position look ahead of 3 seconds

[9] Christoph Rosmann, Frank Hoffmann, and Torsten Bertram. "Planning of multiple robot trajectories in distinctive topologies". In: *European Conference on Mobile Robots (ECMR)*. 2015, pp. 1–6.

[10] Tim Mercy, Ruben Van Parys, and Goele Pipeleers. "Spline-based motion planning for autonomous guided vehicles in a dynamic environment". In: *IEEE Transactions on Control Systems Technology* (2017).

[11] Sean Quinlan and Oussama Khatib. "Elastic bands: Connecting path planning and control". In: *IEEE International Conference on Robotics and Automation*. 1993, pp. 802–807.

[12] Dieter Fox, Wolfram Burgard, and Sebastian Thrun. "The dynamic window approach to collision avoidance". In: *IEEE Robotics & Automation Magazine* 4.1 (1997), pp. 23–33.

Results I (Travel time)

Planner	Static single room	Test case 1	Test case 2	Static double room	Test case 3
TEB	**5.205**	5.972	6.083	**27.139**	**35.330**
Spline	5.421	**5.574**	**5.819**	-	-
DWA	19.526	17.625	17.114	39.004	-
EBand	6.270	6.570	6.240	30.862	71.968
EBand2	6.270	6.025	6.234	30.862	-

Table: Average time of travel for planners for different test cases

Results II (Re-plans)

Planner	Static single room	Test case 1	Test case 2	Static double room	Test case 3
TEB	**0**	**0**	1	**0**	**4**
Spline	**0**	**0**	**0**	Fail	Fail
DWA	**0**	**0**	2	**0**	Fail
EBand	**0**	1	Fail	**0**	Fail
EBand2	**0**	1	1	**0**	Fail

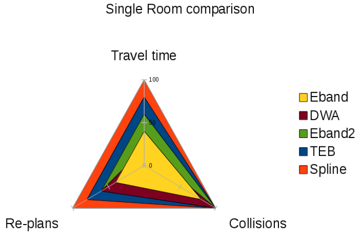
Table: Maximum re-plan attempts of planners for different test cases

Results (collisions)

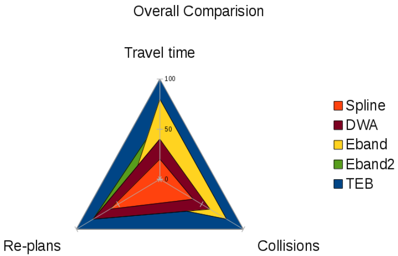
Planner	Static single room	Test case 1	Test case 2	Static double room	Test case 3
TEB	**0**	**0**	**0**	**0**	**0.75**
Spline	**0**	**0**	**0**	-	-
DWA	**0**	**0**	**0**	**0**	-
EBand	**0**	0.25	0.5	**0**	4
EBand2	**0**	**0**	**0**	**0**	-

Table: Average collisions of planners for different test cases

Results visualised



(a) Ranking comparison for test case 1 and 2



(b) Ranking comparison for all test cases

Verdict

TEB planner performs best for our experiments out of 5 planners.

Conclusion and future work

Conclusion

- Qualitative comparison
- Develop an open source software to help test
- Test cases and framework for objective comparison
- TEB planner performs “best” for given scenarios

Future work

- Test more planners on these test cases.
- Test with humans as obstacles for real robots.
- Test with different models of robots.

References I

Fox, Dieter, Wolfram Burgard, and Sebastian Thrun. "The dynamic window approach to collision avoidance". In: *IEEE Robotics & Automation Magazine* 4.1 (1997), pp. 23–33.

Hoy, Michael, Alexey S. Matveev, and Andrey V. Savkin. "Algorithms for collision-free navigation of mobile robots in complex cluttered environments: a survey". In: *Robotica* 33.3 (2015), pp. 463 –497. DOI: 10.1017/S0263574714000289.

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