UNIVERSITY OF MARYLAND

18 56

Implementation of D* Lite With Human Assistance

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Project Goal

1. Use D* Lite Algorithm to navigate the robot from start to goal

2. Replan trajectory by identifying static obstacles in real-time

3. Inform human to remove the obstacle if replanned path is too large or goal is impossible to reach

4. Benchmark the results with reference research papers.

Why D* Lite?

1. Unlike traditional path finding algorithms, D* Lite holds on to its search data.
2. If connections between path nodes are modified or removed, only changed nodes are used to recalculate the path.
3. No need to start searching from scratch
4. Ideal for poorly traversable and partially unknown search spaces.
5. Extensively used in real robots. Eg. Household Robots, Warehouse Robots, Mars Rovers.

D* Lite Algorithm

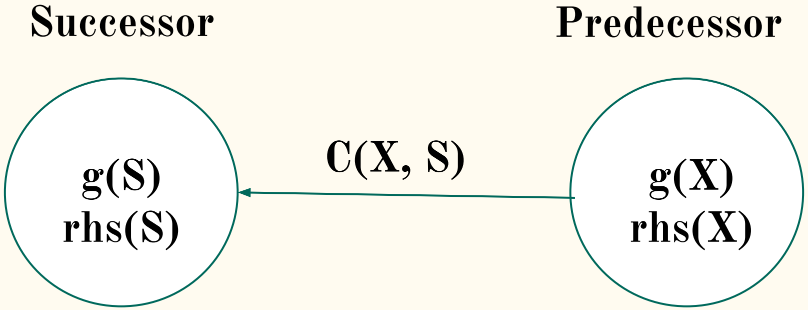
1. Similar to D*, But based on Lifelong planning A*

2. Each node X has two cost parameters:

   a. g(X) - objective function value

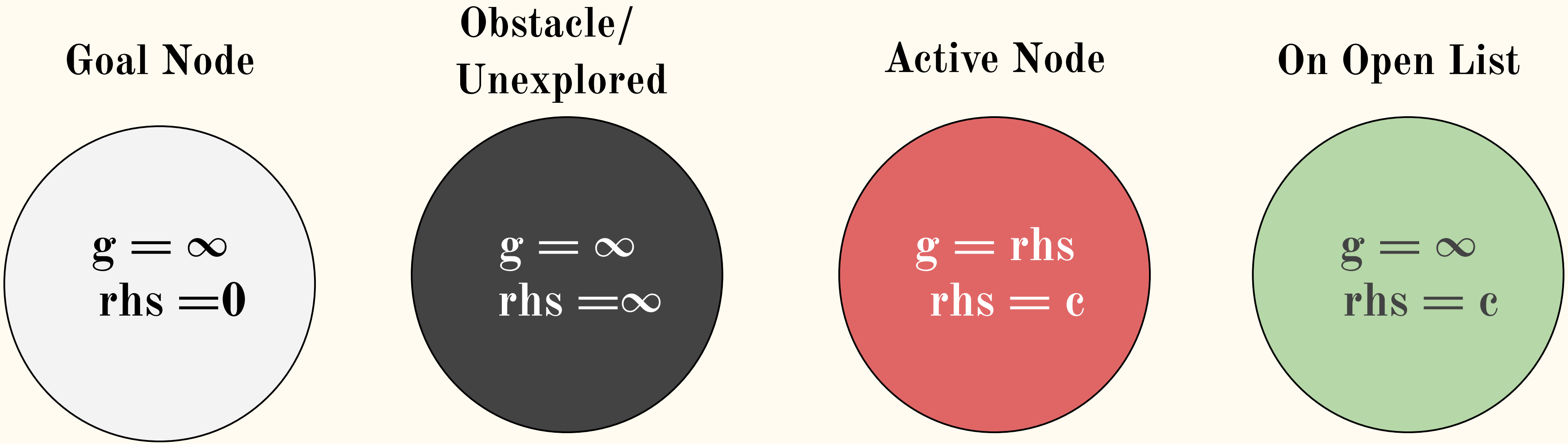
   b. rhs(X) - cost to the parent node g(S) plus the cost to travel to that node c(X,S)

3. The algorithm starts from the given goal node, and backtracks to the start node by minimizing the rhs value. [3]



$$\mathbf{rhs(X) = g(S) + C(X, S)}$$

Node States



Goal Node

$g = \infty$
$rhs = 0$

Obstacle/ Unexplored

$g = \infty$
$rhs = \infty$

Active Node

$g = rhs$
$rhs = c$

On Open List

$g = \infty$
$rhs = c$

A node is added to the open list if it has local inconsistency and active nodes (node under consideration) is made consistent.

Inconsistency

1. When node is found to be underconsistent ($g(x) < rhs(x)$), it signifies that the path to that node was made more costly.

2. This can happen if a node which was previously in free space and now obstructed by an obstacle making it unreachable.

3. When node is found to be overconsistent ($g(x) > rhs(x)$), it signifies that the path to that node was made less costly.

4. This can happen if a node which was previously occupied by the obstacle is now cleared making it reachable now.

Key

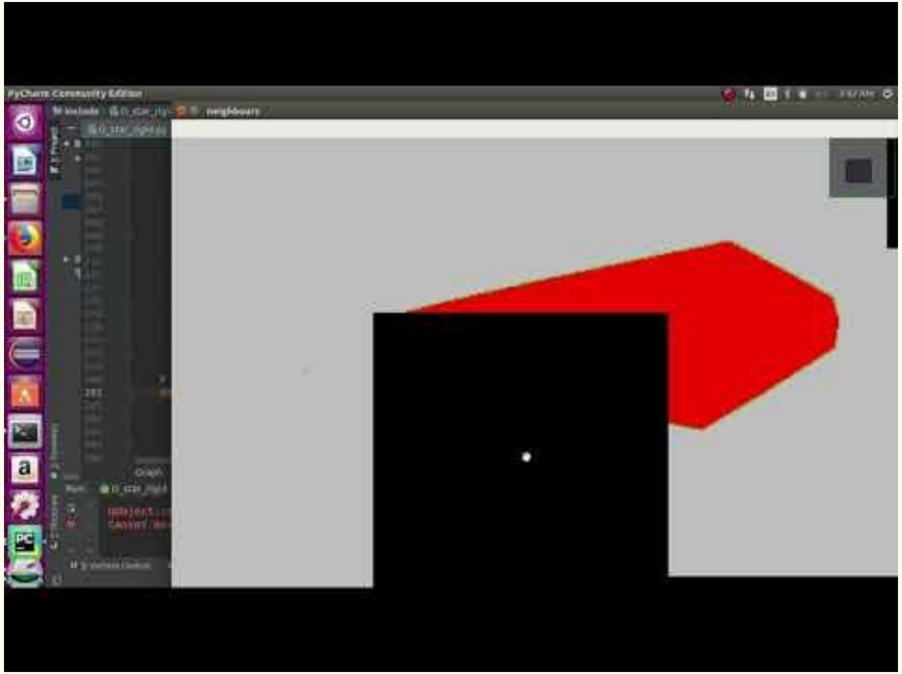
1. A key is the value used by the algorithm to sort the priority queue.

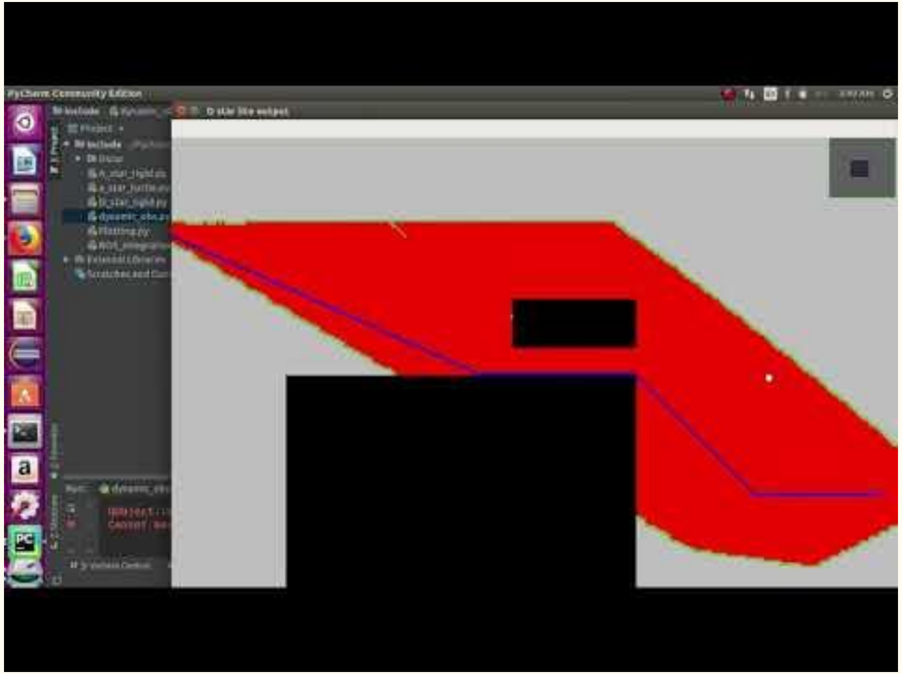
2. The key/priority of a node X on the open list is the minimum of g(X) and rhs(X) plus a focusing heuristic h

$$\text{Key} = [\min(g(X); \text{rhs}(X)) + h(X); \min(g(X), \text{rhs}(X))]$$

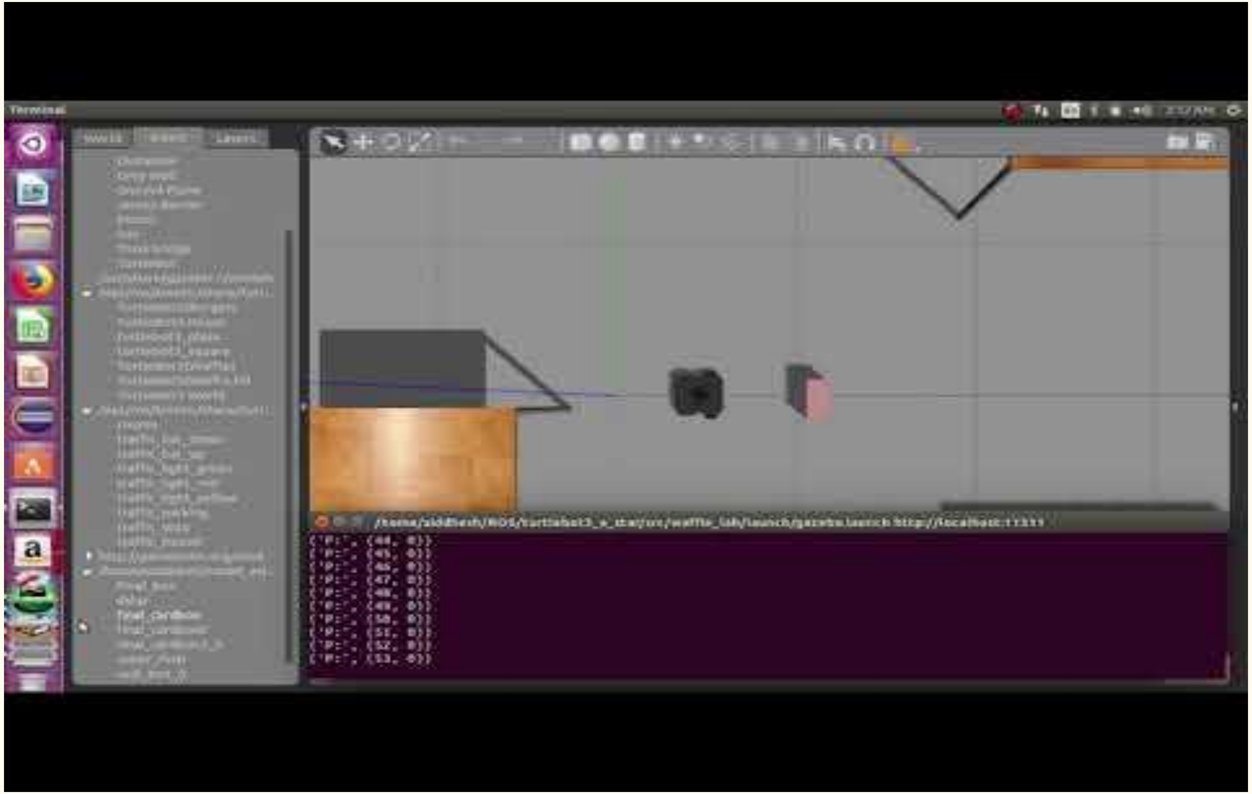
3. h(X) is the distance of the current node X from the start node. [4]

Exploration using D*Lite



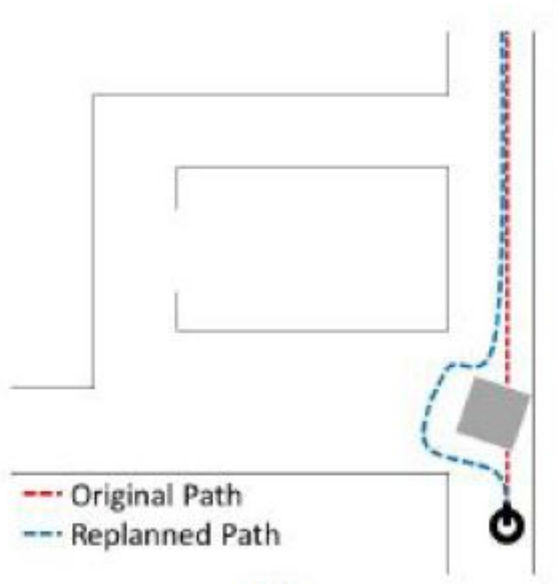


Static Obstacle avoidance in Simulation

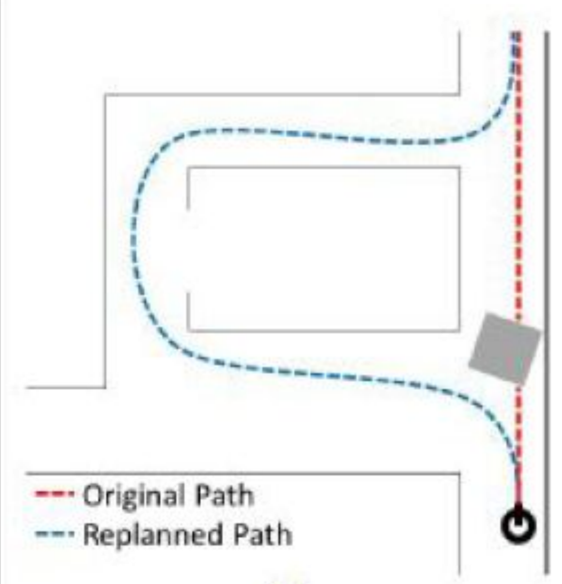


```
/home/siddhesh/ROS/turtlebot3_a_star/src/waffle_lab/launch/gazebo.launch http://localhost:11311
('P:', (44, 0))
('P:', (45, 0))
('P:', (46, 0))
('P:', (47, 0))
('P:', (48, 0))
('P:', (49, 0))
('P:', (50, 0))
('P:', (51, 0))
('P:', (52, 0))
('P:', (53, 0))
```

Call for Human Assistance

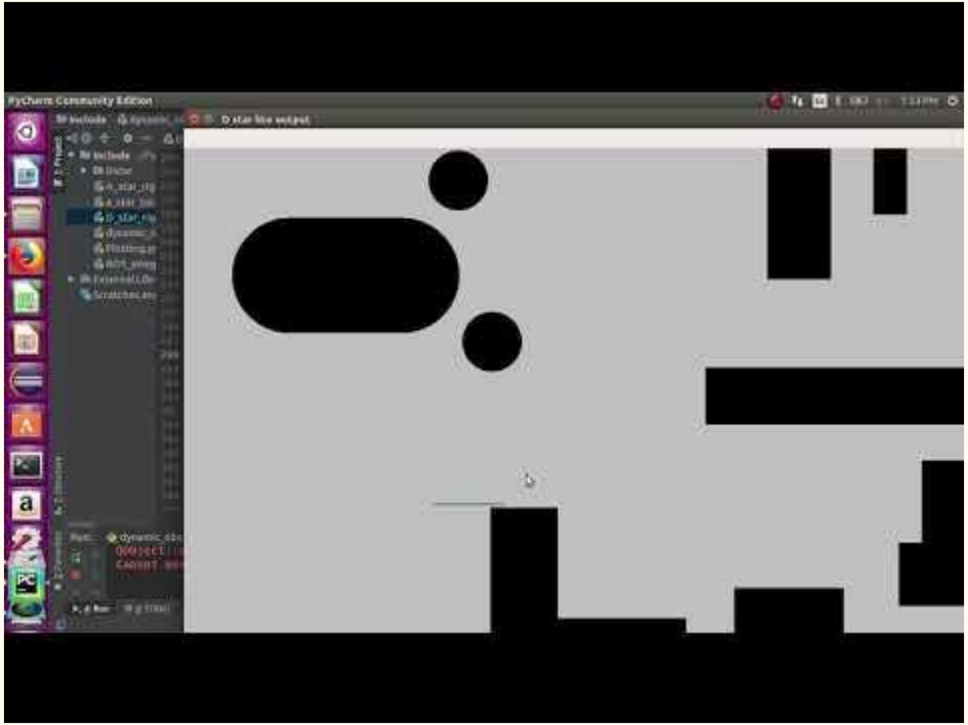


Human assistance
not required

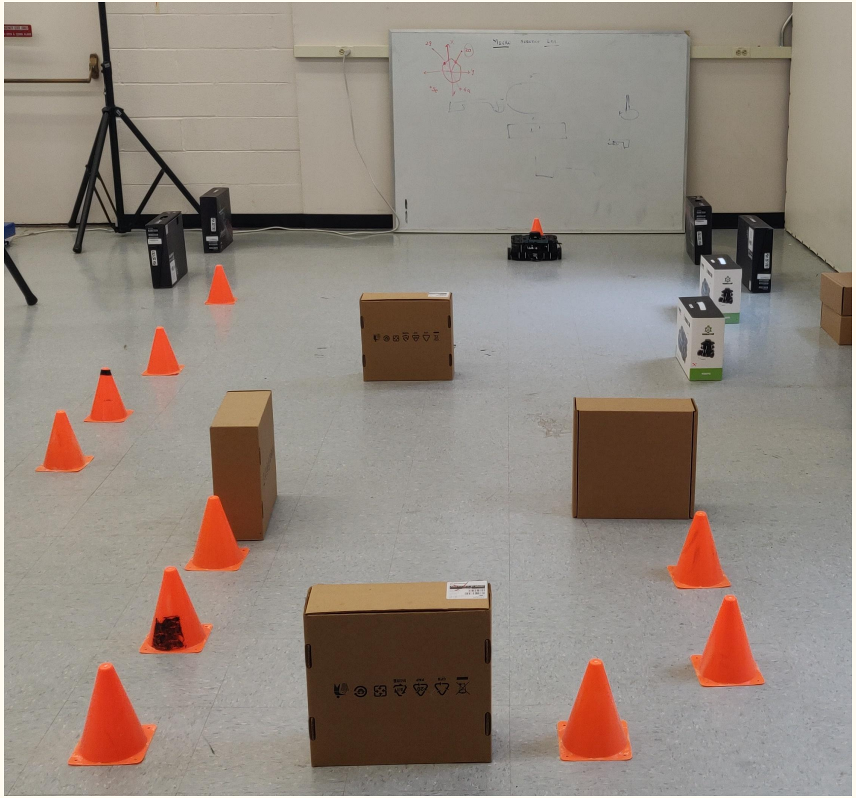


Human assistance
required

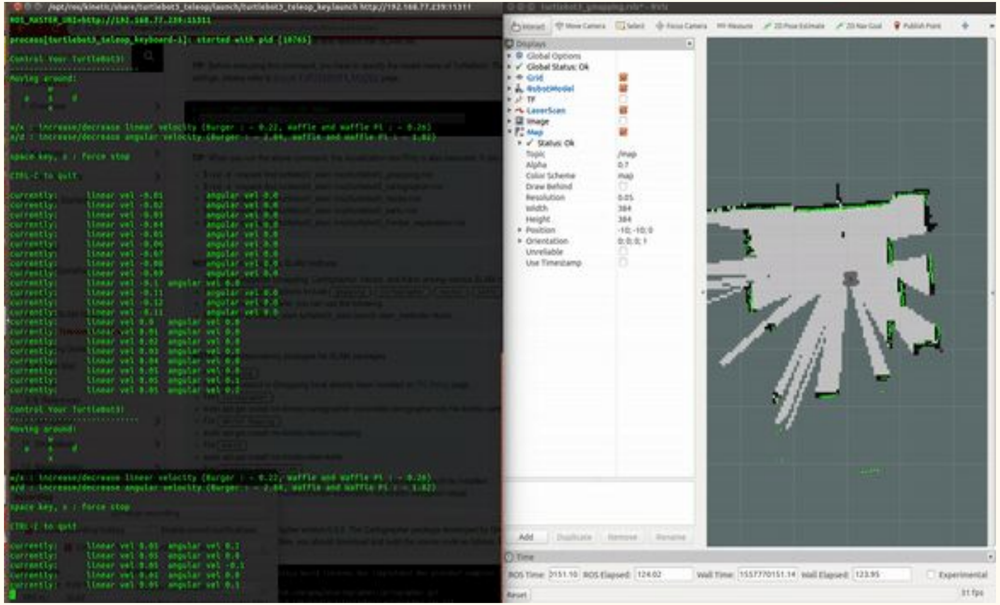
Human Assistance Demonstration



Setup



Mapping the setup using SLAM

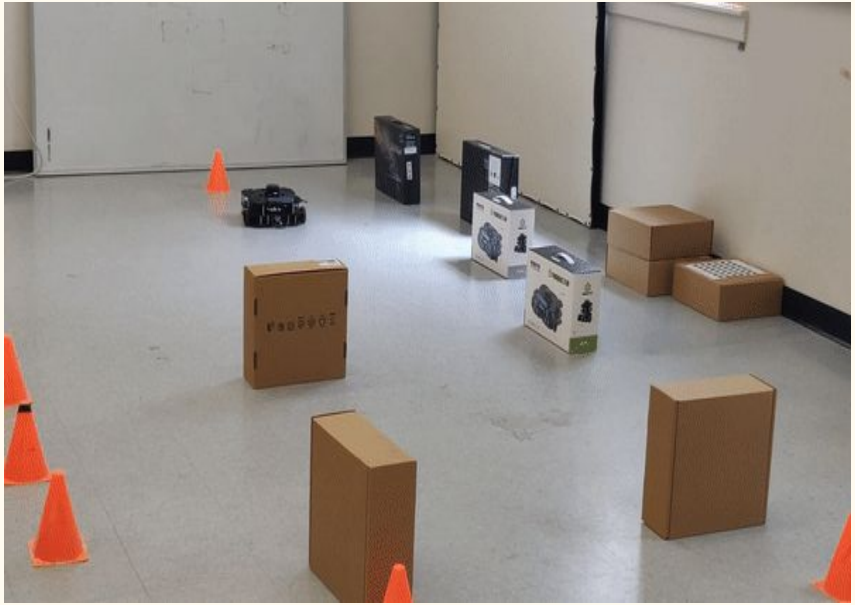


```
/opt/ros/kinetic/share/turtlebot3_teleop/launch/turtlebot3_teleop_key.launch http://192.168.77.239:11311
ROS_MASTER_URI=http://192.168.77.239:11311

process[turtlebot3_teleop_keyboard-1]: started with pid [10765]

Control Your TurtleBot3!
---------------------------
Moving around:
        w
   a    s    d
        x

w/x : increase/decrease linear velocity (Burger : ~ 0.22, Waffle and Waffle Pi : ~ 0.26)
a/d : increase/decrease angular velocity (Burger : ~ 2.84, Waffle and Waffle Pi : ~ 1.82)

space key, s : force stop

CTRL-C to quit

currently:      linear vel -0.01         angular vel 0.0
currently:      linear vel -0.02         angular vel 0.0
currently:      linear vel -0.03         angular vel 0.0
currently:      linear vel -0.04         angular vel 0.0
currently:      linear vel -0.05         angular vel 0.0
currently:      linear vel -0.06         angular vel 0.0
currently:      linear vel -0.07         angular vel 0.0
currently:      linear vel -0.08         angular vel 0.0
currently:      linear vel -0.09         angular vel 0.0
currently:      linear vel -0.1  angular vel 0.0
currently:      linear vel -0.11         angular vel 0.0
currently:      linear vel -0.12         angular vel 0.0
currently:      linear vel -0.11         angular vel 0.0
currently:      linear vel 0.0   angular vel 0.0
currently:      linear vel 0.01  angular vel 0.0
currently:      linear vel 0.02  angular vel 0.0
currently:      linear vel 0.03  angular vel 0.0
currently:      linear vel 0.04  angular vel 0.0
currently:      linear vel 0.05  angular vel 0.0
currently:      linear vel 0.05  angular vel 0.1
currently:      linear vel 0.05  angular vel 0.2

Control Your TurtleBot3!
---------------------------
Moving around:
        w
   a    s    d
        x

w/x : increase/decrease linear velocity (Burger : ~ 0.22, Waffle and Waffle Pi : ~ 0.26)
a/d : increase/decrease angular velocity (Burger : ~ 2.84, Waffle and Waffle Pi : ~ 1.82)

space key, s : force stop

CTRL-C to quit

currently:      linear vel 0.05  angular vel 0.1
currently:      linear vel 0.05  angular vel 0.0
currently:      linear vel 0.05  angular vel -0.1
currently:      linear vel 0.05  angular vel 0.0
currently:      linear vel 0.05  angular vel 0.1
```

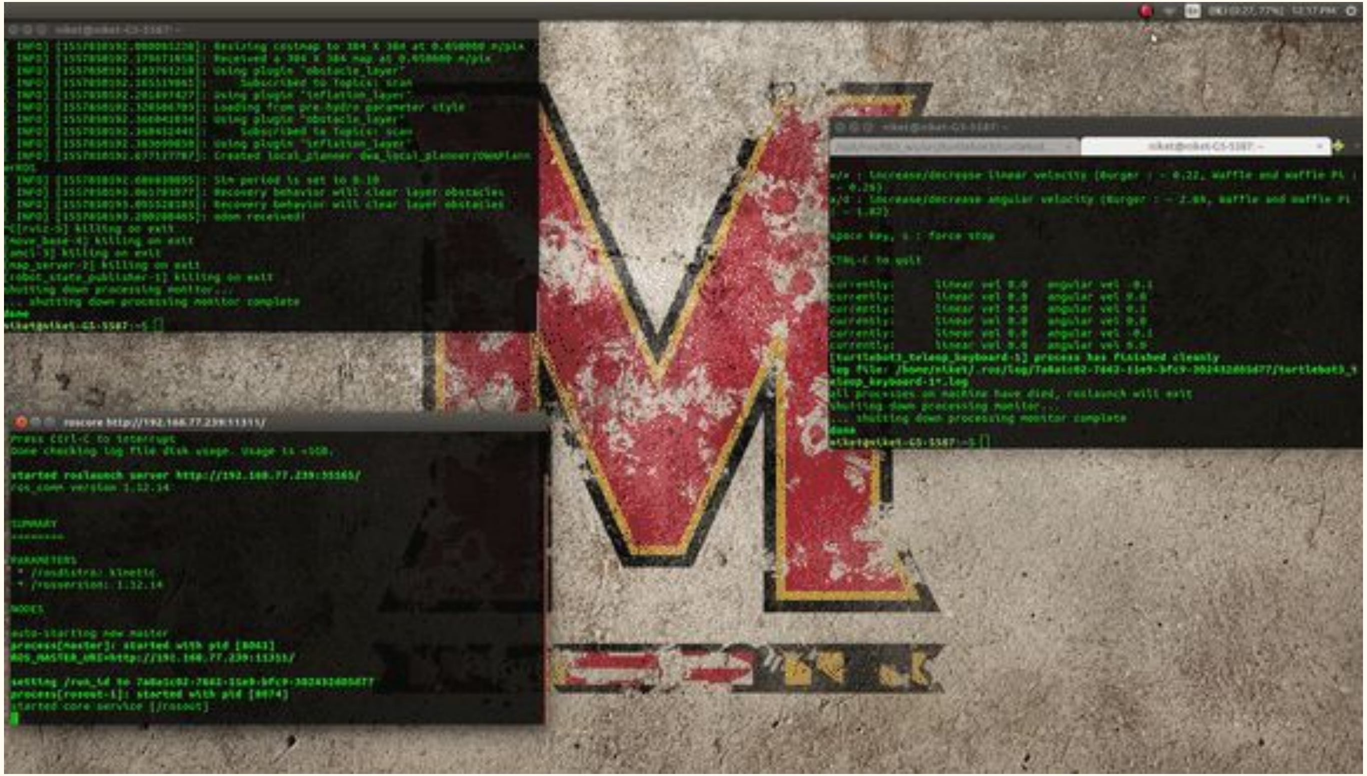
- Global Options
- ✓ Global Status: Ok
- Grid ☑
- RobotModel ☑
- TF □
- LaserScan ☑
- Image □
- Map ☑
  - ✓ Status: Ok
  - Topic: /map
  - Alpha: 0.7
  - Color Scheme: map
  - Draw Behind: □
  - Resolution: 0.05
  - Width: 384
  - Height: 384
  - Position: -10; -10; 0
  - Orientation: 0; 0; 0; 1
  - Unreliable: □
  - Use Timestamp: □

ROS Time: 2151.10 ROS Elapsed: 124.02 Wall Time: 1557770151.14 Wall Elapsed: 123.95 □ Experimental

31 fps



Localization Using AMCL



```
[ INFO] [1557858592.080081220]: Resizing costmap to 384 X 384 at 0.050000 m/pix
[ INFO] [1557858592.178671858]: Received a 384 X 384 map at 0.050000 m/pix
[ INFO] [1557858592.183791258]: Using plugin "obstacle_layer"
[ INFO] [1557858592.185519861]:     Subscribed to Topics: scan
[ INFO] [1557858592.281897427]: Using plugin "inflation_layer"
[ INFO] [1557858592.320506785]: Loading from pre-hydro parameter style
[ INFO] [1557858592.360042034]: Using plugin "obstacle_layer"
[ INFO] [1557858592.368432441]:     Subscribed to Topics: scan
[ INFO] [1557858592.383690858]: Using plugin "inflation_layer"
[ INFO] [1557858592.677127787]: Created local_planner dwa_local_planner/DWAPlann
erROS
[ INFO] [1557858592.680030055]: Sim period is set to 0.10
[ INFO] [1557858593.061781977]: Recovery behavior will clear layer obstacles
[ INFO] [1557858593.095528185]: Recovery behavior will clear layer obstacles
[ INFO] [1557858593.200208465]: odom received!
^C[rviz-5] killing on exit
[move_base-4] killing on exit
[amcl-3] killing on exit
[map_server-2] killing on exit
[robot_state_publisher-1] killing on exit
shutting down processing monitor...
... shutting down processing monitor complete
done
niket@niket-G5-5587:~$ 
```

```
w/x : increase/decrease linear velocity (Burger : ~ 0.22, Waffle and Waffle Pi :
 ~ 0.26)
a/d : increase/decrease angular velocity (Burger : ~ 2.84, Waffle and Waffle Pi
: ~ 1.82)

space key, s : force stop

CTRL-C to quit

currently:      linear vel 0.0   angular vel -0.1
currently:      linear vel 0.0   angular vel 0.0
currently:      linear vel 0.0   angular vel 0.1
currently:      linear vel 0.0   angular vel 0.0
currently:      linear vel 0.0   angular vel -0.1
currently:      linear vel 0.0   angular vel 0.0
[turtlebot3_teleop_keyboard-1] process has finished cleanly
log file: /home/niket/.ros/log/7a8a1c82-7662-11e9-bfc9-302432d05d77/turtlebot3_t
eleop_keyboard-1*.log
all processes on machine have died, roslaunch will exit
shutting down processing monitor...
... shutting down processing monitor complete
done
niket@niket-G5-5587:~$ 
```

```
Press Ctrl-C to interrupt
Done checking log file disk usage. Usage is <1GB.

started roslaunch server http://192.168.77.239:35165/
ros_comm version 1.12.14


SUMMARY
========

PARAMETERS
 * /rosdistro: kinetic
 * /rosversion: 1.12.14

NODES

auto-starting new master
process[master]: started with pid [8061]
ROS_MASTER_URI=http://192.168.77.239:11311/

setting /run_id to 7a8a1c82-7662-11e9-bfc9-302432d05d77
process[rosout-1]: started with pid [8074]
started core service [/rosout]
```

Static Obstacle Avoidance in Setup

Comparison with Reference Paper

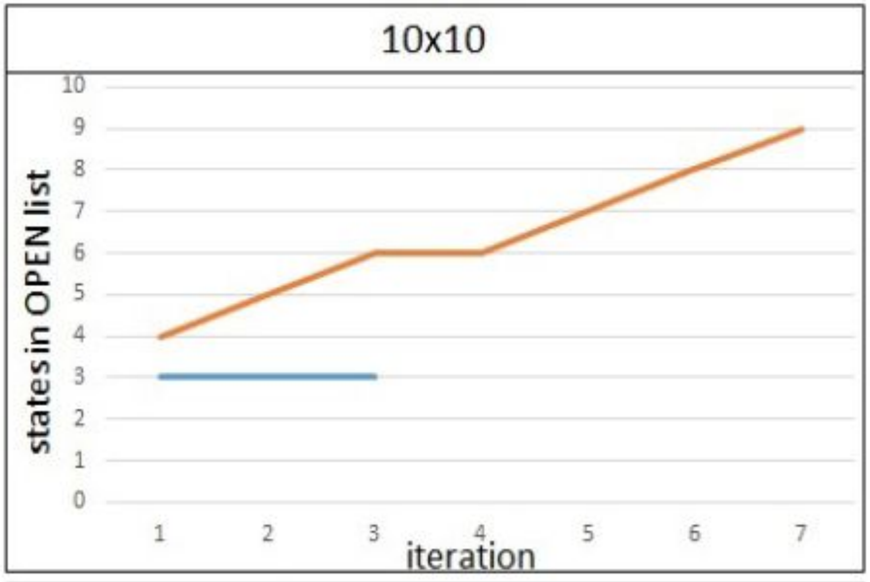
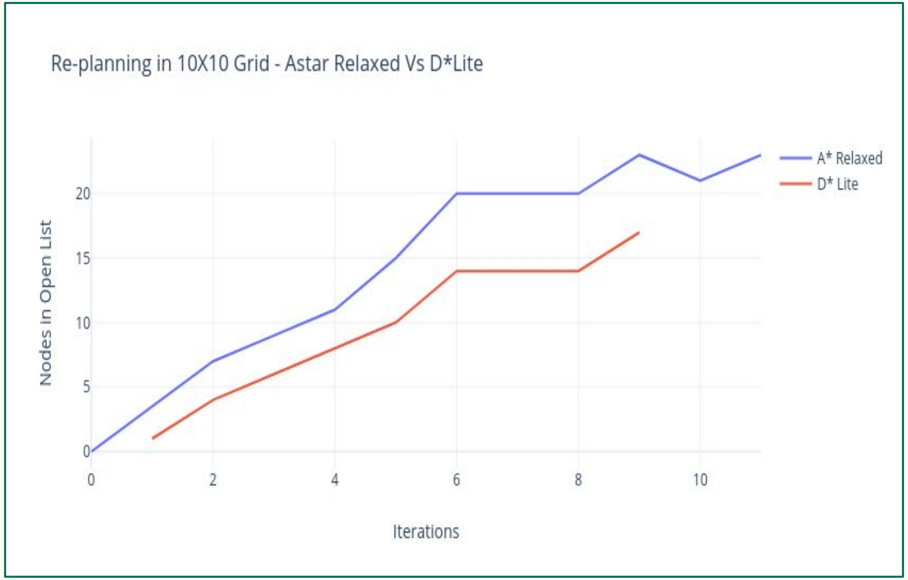


Image courtesy[4]



Relaxed A* vs D*Lite

Comparison with Reference Paper

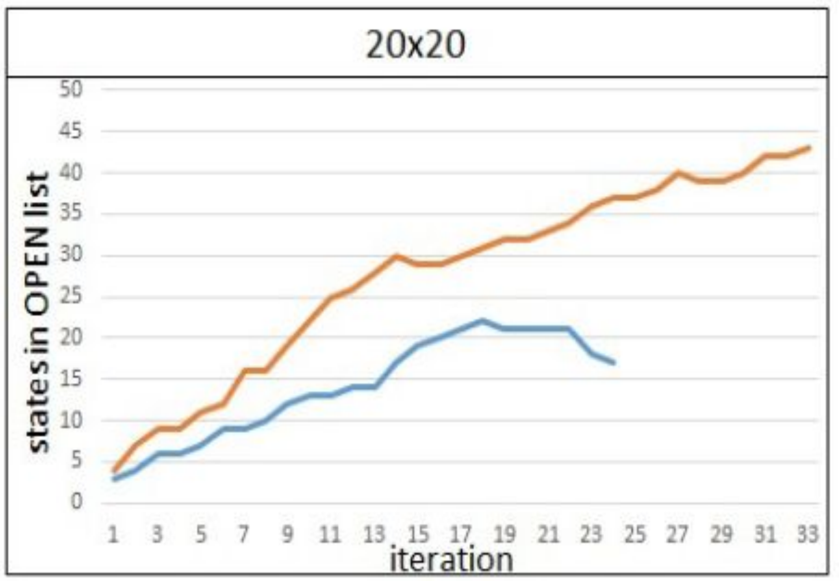
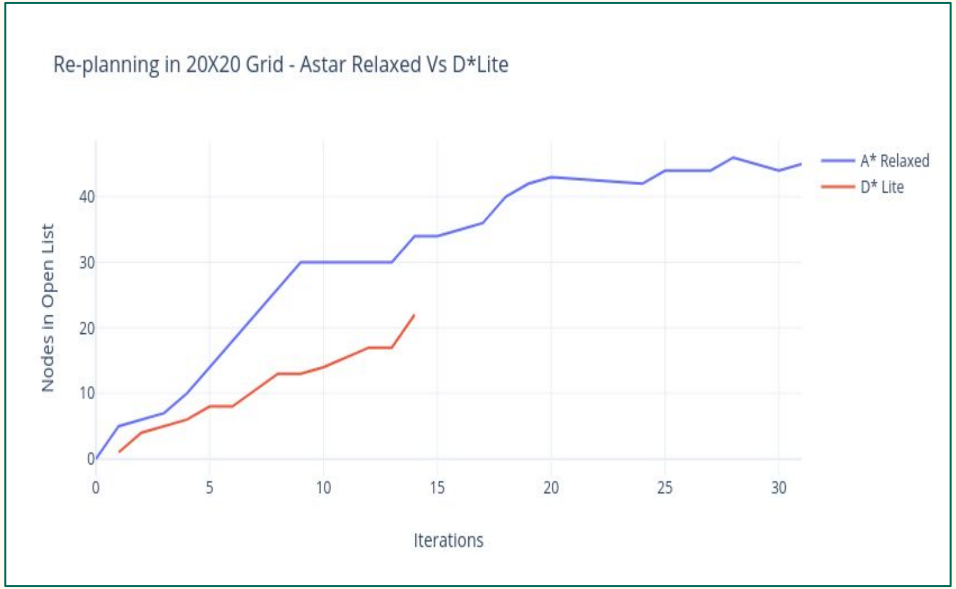


Image courtesy[4]



Relaxed A* vs D*Lite

Comparison with Reference Paper

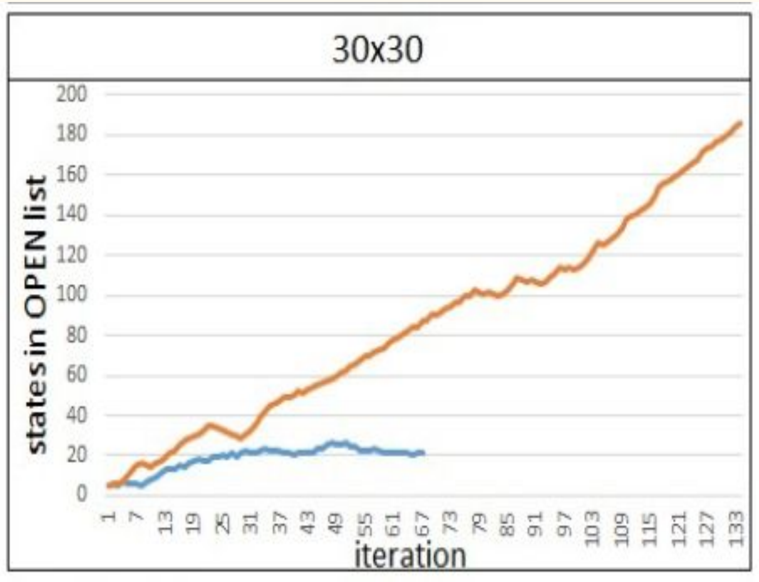
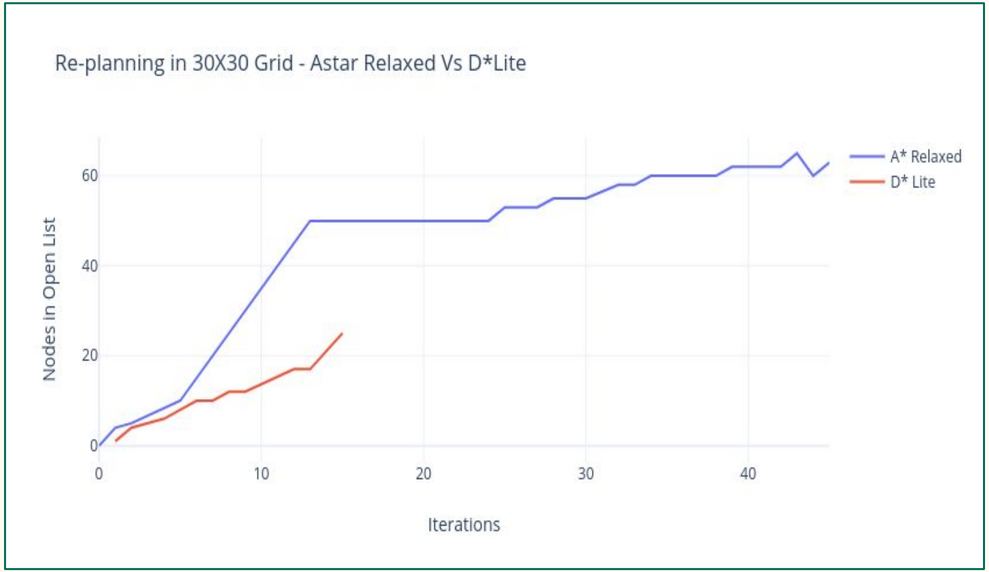
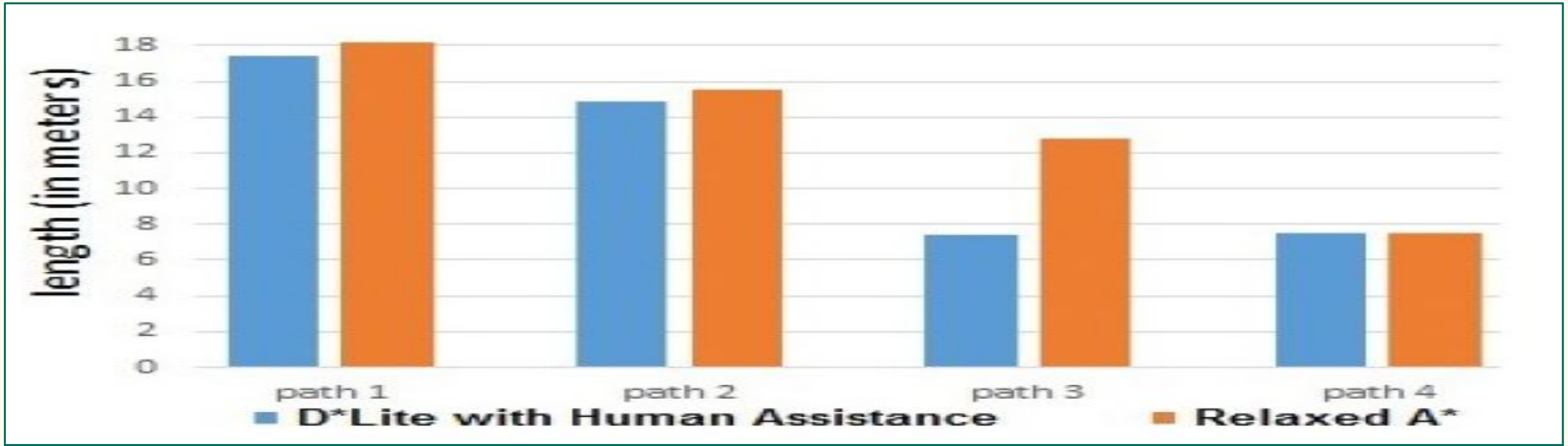


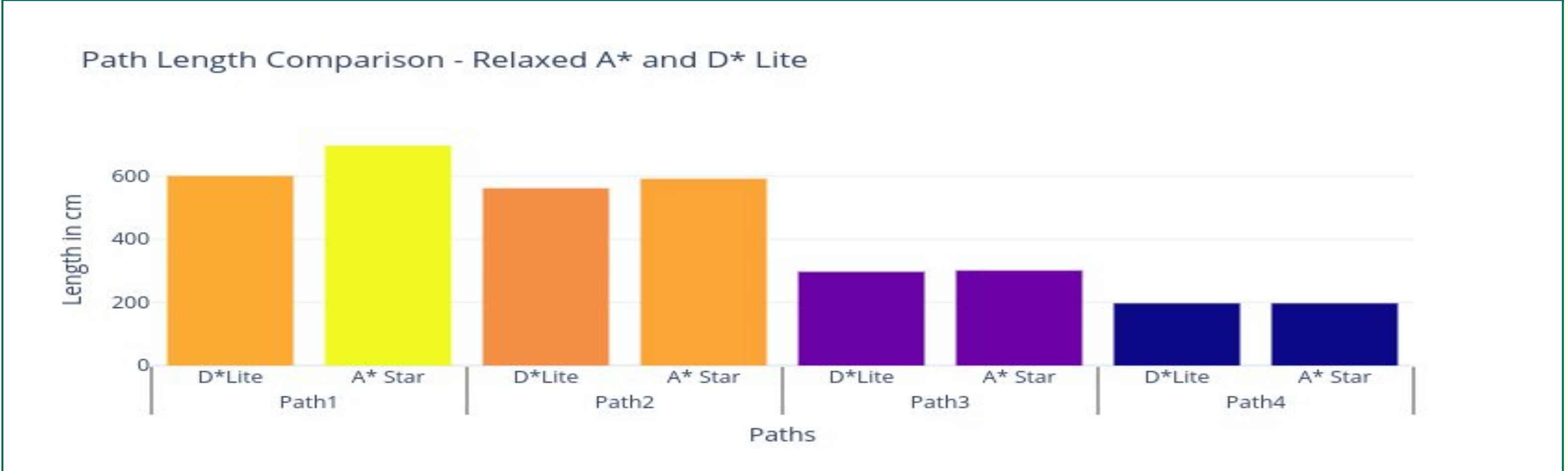
Image courtesy[4]



Relaxed A* vs D*Lite

Comparison with Reference Paper





References:

[1] N. J. N. P. E. Hart and B. Raphael, “A formal basis for the heuristic determination of minimum cost paths,” IEEE Transactions on Systems, Science, and Cybernetics, vol. SSC-4, no. 2, pp. 100–107, 1968.

[2] E. W. Dijkstra, “A note on two problems in connexion with graphs, ”NUMERISCHE MATHEMATIK, vol. 1, no. 1, pp. 269–271, 1959.

[3] Raulcezar Alves, Josu´e Silva de Morais, Carlos Roberto Lopes, “Indoor Navigation with Human Assistance for Service Robots using D*Lite“, 2018 IEEE International Conference on Systems, Man, and Cybernetics, 10.1109/SMC.2018.00696.

[4] S. Koenig and M. Likhachev, “D*lite,” in Eighteenth National Conference on Artificial Intelligence. Menlo Park, CA, USA: American Association for Artificial Intelligence, 2002, pp. 476–483. [Online]. Available: http://dl.acm.org/citation.cfm?id=777092.777167

[5] Tugcem Oral and Faruk Polat, ”MOD* Lite: An Incremental Path Planning Algorithm Taking Care of Multiple Objectives”, IEEE TRANSACTIONS ON CYBERNETICS, VOL. 46, NO. 1, January 2016.

[6] J. Kauko, and V.-V Mattila, Mobile Games Pathfinding, Proceedings of the 12th Finnish Artificial Intelligence Conference STeP 2006,
 Pp 176   182, Helsinki, Finland

[7] E. Uslu, F. akmak, M. Balclar, A. Aknc, M. F. Amasyal and S. Yavuz, ”Implementation of frontier-based exploration algorithm for an autonomous robot,” 2015 International Symposium on Innovations in Intelligent SysTems and Applications (INISTA), Madrid, 2015, pp.1-7

Thank You