Independent Study

April 2^{nd}, 2020

1 Description

This independent study aims at applying various motion planning algorithms using graph-based planners. The first week of the quarter will be dedicated to building a probabilistic road map and a 2D grid. Then, we can implement global planning algorithms that work on road maps, such as A* and D*. We will also implement a discrete global planner, Potential Fields, that operate on grids. After completing the base work, we can expand upon it by implementing local planning algorithms such as Dynamic Window Approach, which will allow us to expand the planning to full state space exploration. Finally, once a path has been built, we can implement Model Predictive Control for speed and steering control. The path from the local planner will serve as the reference trajectory for Model Predictive Control.

We believe that this study will useful in developing our skill set for mobile robotics. Motion planning and smooth trajectory execution are skills that are predominantly requested alongside C++ based on our job searches. Finally, this study will be our only C++ and ROS course for this quarter, which is essential for maintenance and improvement.

2 Meeting Time

Tuesday: 10:00 - 11:20
Thursday: 10:00 - 11:20

3 Software

This course aims at using rviz for the visualization component of the path planners. We will create maps that include a variety of corridors and obstacles. The components of these maps can be stored in a config file and loaded at runtime. We plan to use the fake_encoders node in addition to the rigid2d package developed from ME495 to simulate the motion of a mobile differential drive robot. This avoids the need for gazebo and SLAM algorithms. If students do join the class who have not completed ME495, they can use the unicycle model instead of rigid2d.

4 Textbooks

LaValle, Steven M. Planning algorithms. Cambridge university press, 2006. Link

Choset, Howie M., et al. Principles of robot motion: theory, algorithms, and implementation. MIT press, 2005.

5 Milestones

Week 1: Build a graph using Probabilistic Road Maps and build Grid around custom Map (walls and convex polygons).

Weeks 2-3: Heuristic and iterative heuristic search for global planning.

Weeks 4-5: Potential Field global planning on grid map.

Weeks 6-7: Dynamic Window Approach for local planning to give us pose/twist at vertices and reference trajectory for MPC.

Weeks 8-10: Model Predictive Control for smooth trajectory execution (follow path from planner).

6 Lectures

Week 1: Probabilistic Road Maps and Collisions with Convex Polygons
Reading:
Planning Algorithms pages 237-244

Latombe, Lydia E. Kavraki Jean-Claude. "Probabilistic Roadmaps for Robot Path Planning." Pratical motion planning in robotics: current aproaches and future challenges (1998): 33-53. Link

Allen, Peter. Probabilistic Road Map Planning. Link

T: (Boston) Discussion: Road map construction algorithm overview and sampling free space methods
Th: (Boston) Discussion: Adding edges (collision checking and kinematic feasibility), intro to road map query phase, and road map optimization
Assignment 1, Due 4/13 : PRM contruction, collision checking with walls and convex polygons.

Week 2: Global Path Planning - Search Algorithms
Reading:
Planning Algorithms- Section 2.3

Theta - Daniel, Kenny, et al. "Theta*: Any-angle path planning on grids." Journal of Artificial Intelligence Research 39 (2010): 533-579.*

Lazy Theta - Nash, Alex, Sven Koenig, and Craig Tovey. "Lazy Theta*: Any-angle path planning and path length analysis in 3D." Twenty-Fourth AAAI Conference on Artificial Intelligence. 2010.*

T: Guest Lecture by Matthew Elwin on C++ on Polymorphism and Modern C++ Implementations of Graph Data Structure
Th: (Michael) Value-Based Iterative Search and Djikstra
Assignment 2, Due 4/20 : grid construction of map.

Week 3: Global Path Planning - Search Algorithms
Reading:
D- Stentz, Anthony. "Optimal and efficient path planning for partially known environments." Intelligent Unmanned Ground Vehicles. Springer, Boston, MA, 1997. 203-220.*

D Lite - Koenig, Sven, and Maxim Likhachev. "Fast replanning for navigation in unknown terrain." IEEE Transactions on Robotics 21.3 (2005): 354-363.*

Field D - Ferguson, Dave, and Anthony Stentz. "Field D*: An interpolation-based path planner and replanner." Robotics research. Springer, Berlin, Heidelberg, 2007. 239-253.*

Incremental Phi - Nash, Alex, Sven Koenig, and Maxim Likhachev. "Incremental Phi*: Incremental any-angle path planning on grids." Twenty-First International Joint Conference on Artificial Intelligence. 2009.*

T: (Michael) A* and Theta* and variants
Th: (Michael) D* / D* Lite
Assignment 3, Due 4/27 : A* applied to PRM graph

Week 4: Global Path Planning - Potential Fields
Reading:
Choset, Howie. "Robotic motion planning: Potential functions." Robotics Institute, Carnegie Mellon University (2010). Presentation for book Chapter 4

Principles of robot motion, Chapter 4.1-4.2.

Planning algorithms, Chaper 5.4.3.

T (Michael): Field D* and Incremental Phi*
Th (Maurice): Gradient Descent on Attractive and Repulsive Fields.
Assignment 4, Due 5/5 : Incremental Phi* method applied to grid map.

Week 5: Global Path Planning - Potential Fields
Reading:
Principles of robot motion, Chapter 4.3-4.5, 4.6.

Park, Min Gyu, and Min Cheol Lee. "A new technique to escape local minimum in artificial potential field based path planning." KSME international journal 17.12 (2003): 1876-1885.

Q. Zhu, Y. Yan and Z. Xing, "Robot Path Planning Based on Artificial Potential Field Approach with Simulated Annealing," Sixth International Conference on Intelligent Systems Design and Applications, Jinan, 2006, pp. 622-627.

T (Maurice): Bushfire: Algorithm Overview + Escaping Local Minima using Wave-Front Planner.
Th (Maurice): Escaping Local Minima using Virtual Objects and/or Random Walk (Simulated An-

nealing)..
Assignment 5, Due 5/12: Implement PF Motion Planning on Full Map (Continuous or Grid-based).

Week 6: Dynamic Window Approach and Global Variant
Reading:
The Dynamic Window Approach to Collision Avoidance — Authors: Thrun et al.

Dynamic Window Algorithm motion planning — Author: Adrian Boeing *Nice tutorial on DWA*

T (Maurice): Survey Lecture on Local Planning Techniques.
Th (Rico): Original DWA algorithm and Mathematical Derivation
Assignment 6, Due 5/19: Implement PF Motion Planning with local minimum escape.

Week 7: DWA Library and MPC-inspired DWA
Reading:
Advanced Dynamic Window based Navigation Approach using Model Predictive Control — Authors: Kiss et al.

High-speed navigation using the global window approach — Authors: Brock et al.

T (Rico): Continue With Tuesday's Material and Cover Global DWA
Th (Rico): The library of DWA and DWA Implementations using different motion models.
ROS Package
Assignment 6, Due 5/26: Naive DWA. Reach Goal: MPC-based DWA covered in Week 9 (implemented later)

Week 8: Model Predictive Path Integral Control
Reading:
Findeisen, Rolf, and Frank Allgöwer. "An introduction to nonlinear model predictive control." 21st Benelux meeting on systems and control. Vol. 11. Eindhoven, The Netherlands: Technische Universiteit Eindhoven Veldhoven, 2002. Link

Heckman, C. R., Nima Keivan, and Gabe Sibley. "Simulation-in-the-loop for planning and modelpredictive control." Robotics Science and Systems (RSS) Workshop on Realistic, Rapid and Repeatable Robot Simulation. 2015.

Aghli, Sina, and Christoffer Heckman. "Terrain Aware Model Predictive Controller for Autonomous Ground Vehicles."

Ipopt Example

T: (Ian) Guest Lecture: MPPI
Th: (Ian) Guest Lecture: MPPI

Week 9: Nonlinear Model Predictive Control and Nonlinear Optimization Libraries
Reading:
A Convergent Dynamic Window Approach to Obstacle Avoidance — Authors: Orgen et al.

Advanced Dynamic Window based Navigation Approach using Model Predictive Control — Authors: Kiss et al.

T: (Boston) Formulate NMPC reference tracking problem for diff drive robot
Th: (Boston) Ipopt Optimization Library and minimizing objective functions

Assignment 7, Due 6/13 : Reference tracking (local planner DWA) and follow entire global path from PRM.

Week 10: MPC-Based Dynamic Window Approach
Reading:
T: Work Session
Th: Guest Lecture on Optimally of covered algorithms (will contact Samir

7 Final Code Base

Custom Map.

Graph building (Probabilistic Road Map).

Grid Map.

Global Planner (A* Search with D* Lite or Phi* Extension)

Global Planner (Potential Field with choice of Local Minimum Escape)

Local Planner (Dynamic Window Approach).

Motion Execution (Model Predictive Control using Ipopt or Ceres solver Optimization Libraries).

8 Risks, Challenges, and Uncertainties

These algorithms will be implemented using a ground-truth data set, similarly to how we performed implementations in ME469 (MLAI). Students who have not taken ME495 can use the unicycle kinematic model (or develop their own motion model), while those who have can use rigid2d. This shouldn't cause any issues.

We used Zoom to talk to each other and make this document, and have found it to be a reliable means of communication. The trajectory execution portion of the study is possible over-ambitious for the time frame, but we believe that the preceding components make up a good navigation package with tangible learning outcomes.