Loop Closures with Autonomous Robotic Exploration

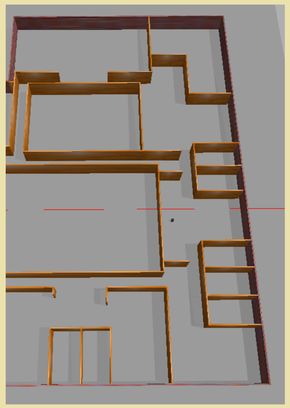
Etash Guha, Dr. Patricio Vela, Justin Smith
IVALab, Georgia Institute of Technology, Atlanta, GA

IVALAB
Intelligent Vision and Automation Laboratory

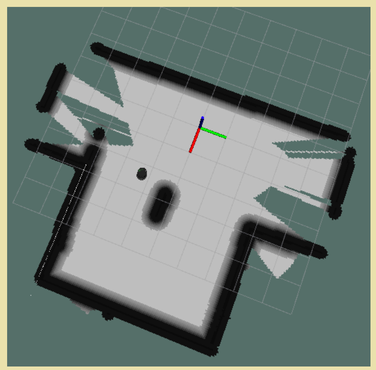
Background/Objective

The objective of this research project is to develop a method of predicting loop closures within Frontier Based Exploration, to improve the accuracy to which a robot can create a map of its surrounding area. FBE involves analyzing and moving to. "frontiers" of the explored region, using several factors to judge each frontier. One factor is the probability that we will revisit an area or close a loop, improving the map accuracy.

Simulation of Robotic Environment

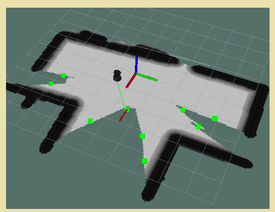


Gazebo, software the simulates a physical environment for the robot to traverse



Rviz, a method of visualizing what the robot has mapped so far

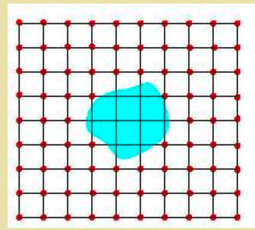
Frontier



The green dots are the centers of each frontier according to the clusters of explored points bordering unexplored points

Loop Closures

Loop Closures are where the robot revisits an area, helping piece together parts of the map. We analyzed which frontier was most likely to lead to loop closure



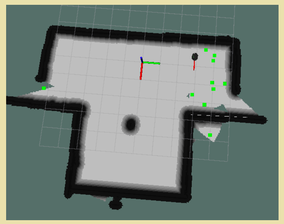
Fast March Algorithm was used to around the explored area to determine the closest frontiers which would determine the probability of Loop Closure. Based off a Breadth First Search Algorithm.

Pseudo Code for Fast March

```
for frontier in FIFO List of Points:
    point = Top of List
    if point has label:
        if point's label = our planned label;
            continue
        else:
            return point's label -> frontier
Label point with frontier label;
for neighbor of point:
    add to List
```

Results

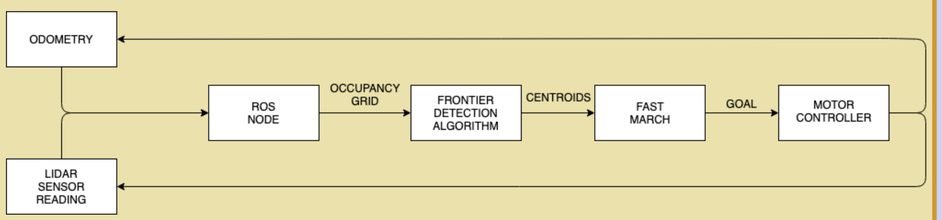
Example of a map with a robot



After moving to the second frontier

After moving to one frontier

Algorithm Design



Quantitative Data

Comparisons and analysis done using ssimval function in Matlab to compare the ground truth map and robot's perception of it's surrounding

$$\mathrm{SSIM}(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$

Starting Point	Without Loop Closures	With Loop Closures
	SSIM Values	
First	0.3705	0.4286
Second	0.4475	0.443
Third	0.441	0.41375
Average	0.4196666667	0.42845
Percent	2.1% increase	

Conclusion and Future Work

- This is a novel method of choosing and analyzing frontiers for Frontier Based Exploration
- It is very computationally inexpensive as it portrays the map as a graph of nodes and does a Breadth First Search on it
- It results in a very smooth and accurate Frontier Based Exploration Strategy
- Overall, this is a strategy that resulted in a 2.1% more accurate representation of the map surrounding the robot
- I plan to try sharpening the frontier detection using Learning algorithms
- I also plan to optimize and experiment with different loop closure probability approximations such as using Voronoi Graphs and OpenCV

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Yamauchi, B. 1997. Frontier-based approach for autonomous exploration. In Proceedings of the IEEE International Symposium on Computational Intelligence, Robotics and Automation, pp. 146-151.
J. Sethian, ªA Fast Marching Level Set Method for MonotonicallyAdvancing Fronts,° Proc. Nat'l Academy of Science, vol. 93, pp. 1,591-1,694, 1996.