Robotic Waypoint Coverage Under Soft Parallel Path Constraints

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Abstract

This project aims to compare two methods of coverage path planning algorithms for an agricultural robot. The motivation behind this project stems from the need to reduce the amount of energy consumption used in farming in order to save costs, reduce the price of fruit and vegetables and also to reduce the harmful effects of climate change caused by burning fossil fuels to power the robot. In summary the following tasks will be achieved during the project:

.Create a cost coverage path planning algorithm using both the Dijkstra's algorithm and a hybrid Dijkstra's-A star search algorithm.Obstacles are bounded by a square box in which agents cannot cross.Each algorithm has penalties applied to each node that favour horizontal movement and heavily penalise diagonal movement and also collisions with objects. Vertical movement is lightly penalised so that the agent can traverse up and down the map.Evaluate the algorithms in terms of their average percentage coverage across all iterations, their, the total number of violations produced by an agent and also the percentage of unique nodes traversed by the agent.

Introduction

The UK agricultural labour sector continues to suffer from a severe labour shortage due to the effects of Brexit[1]. The industry has been struggling to meet the demand for produce due the mass migration of skilled farm workers to other European countries inside the EU. If the UK aims to replace these workers in order to reach adequate supply levels, it must look to automate the farming tasks whereby labour is scarce. This very issue has been the motivation behind the creation of the coverage path planning algorithm presented in this paper.

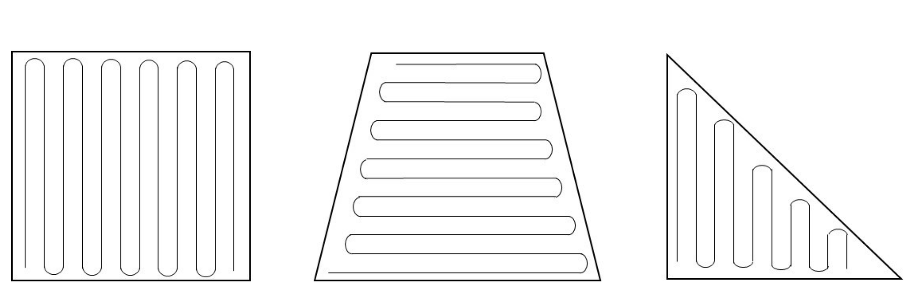

Figure: Parallel coverage path planning

Aim and Objectives

The project's overall aim is to create a coverage path planning algorithm to minimizes the costs of mobile robot navigation. The following research objectives are listed below:

- Generate way-points for an agricultural robot to navigate it's environment.
- Compare two graph based path planning algorithms in their ability to satisfy the metric TSP triangle inequality and reduce the overall cost of coverage path planning based tasks.
- Make sure that the robot moves in parallel horizontal lines by applying soft constraint's that apply a penalty to non-horizontal movement.

Experimental Design

In this project a purely quantitative methodology will be employed. This is because the coverage path planning algorithm needs to be evaluated using numerical evaluation metrics as opposed to the descriptive/conceptual. The algorithms will be created and simulated using the matplot library and networknx that allow for a 2d simulated environment to be created. The performance of these algorithms will be evaluated based on the number of repeated waypoints visited (denoted by percentage coverage), the number of repeated nodes in the path and also the number of violations that occur (in other words, the number of times that the agent either moves diagonally and also the number of times its collides with an obstacle).

Important Results

The most important evaluation metric is the coverage percentage.

Research Methods

The research methods will require a 2d graph based map to be created in a simulated environment. Then two coverage path planning algorithms will be created, the first will be based on the Dijkstra's path planning algorithm and the second is an A star-Dijkstra hybrid path planning algorithm. These algorithms will have soft constraints applied to them in the form of penalties that penalise non-horizontal movement between nodes. No diagonal movement is permitted between nodes. Each algorithm must satisfy the metric TSP's triangle inequality as show in equation 1.

$$d(i,j) + d(j,k) \geq d(i,k) \quad \forall i,j,k \in V \tag{1}$$

where:

- $d(i,j)$ represents the distance between nodes i and j.
- V denotes the set of all nodes in the TSP problem.
- The beta distribution of the coverage percentage was used to decide the minimum amount of iterations of each algorithm.
- The variance of the Beta distribution is given by:

$$\text{Var}(X) = \frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)}$$

- The Method of moments was used to give insight into the skew of coverage percentages.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2$$

$$\mu = \frac{\alpha}{\alpha+\beta}$$

$$\sigma^2 = \frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)}$$

$$\alpha = \bar{x}\left(\frac{\bar{x}(1-\bar{x})}{s^2} - 1\right)$$

$$\beta = (1-\bar{x})\left(\frac{\bar{x}(1-\bar{x})}{s^2} - 1\right)$$

Risk Analysis

Since this project is done purely in a simulated environment, there are no immediate risks to consider. No animals or humans will harmed as result of conducting the tests mentioned in this project, nor will there be environmental damage caused by this project. No personal data will be used so the project is safe in terms of data privacy.

The only risks that can occur are from the reuse of these algorithms in real robots used by researchers trying to test these ideas. In order to make sure that the algorithms proposed in this project are safe, further research papers will need to be done in a 3d simulation environment like gazebo to assess how safe the algorithms would be in a real world setting.

References

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[2]E. Galceran and M. Carreras, "A survey on coverage path planning for robotics," Robotics and Autonomous Systems, vol. 61, no. 12, pp. 1258–1276, Dec. 2013, doi: https://doi.org/10.1016/j.robot.2013.09.004.

[3]J. Cox, "TSP Review for Robot Route Planning," presented at the University of Lincoln, Lincoln, U.K., February 2021.

[4] I. Vandermeulen, R. Gros, and A. Kolling, "Turn-minimizing multirobot coverage," 2019 International Conference on Robotics and Automation (ICRA), May 2019, doi: https://doi.org/10.1109/icra.2019.8794002. [note] A complete list of references can be given upon request.

Acknowledgements

Thank you to Dr Charles fox and Dr Jonathan Cox for supervising my project and allowing to access their previous publications for ideas for the algorithm.