Report of Fields2Cover: An Open-Source Powerhouse for Autonomous Agricultural Path Planning

This report delves into Fields2Cover, a groundbreaking open-source library designed for coverage path planning (CPP) for agricultural machinery. Faced with a growing labor shortage, the agricultural sector desperately needs efficient solutions for autonomous vehicles. Fields2Cover addresses this challenge by offering a comprehensive set of algorithms and functionalities, promoting advancements in CPP research and development.

The Problem: Labor Shortage and Inefficient Path Planning

The agricultural industry grapples with a critical shortage of skilled labor to operate machinery [1]. This necessitates the adoption of autonomous vehicles, but these require meticulous pre-planning of their paths across fields. Traditional path planning methods often lack efficiency, leading to wasted time, resources, and potentially uneven coverage.

Existing Solutions and Their Shortcomings

Several CPP solutions exist, employing various algorithms for path generation. However, a significant limitation lies in their lack of open-source availability [1]. This restricts collaboration and hinders the development of more efficient algorithms. Additionally, some existing open-source solutions may not be readily adaptable to different types of agricultural vehicles or specific field conditions.

Fields2Cover: A Modular and Open-Source Solution

Fields2Cover emerges as a game-changer, offering a comprehensive and open-source CPP library specifically designed for agricultural applications. Its modular architecture allows for

customization and integration of various algorithms, catering to diverse needs. Here's a closer look at its core functionalities:

1. **Headland Generation:** This module optimizes the allocation of space around the field perimeter, specifically designated for vehicle turning maneuvers. It ensures efficient use of field area by minimizing unnecessary headland size while guaranteeing smooth turns.
2. **Swath Generation:** This module focuses on creating efficient paths within the field for the vehicle to traverse. It considers factors like field shape, vehicle turning radius, and desired coverage pattern to generate optimized swaths that minimize travel distance and wasted time.
3. **Route Planning:** Once swaths are generated, the route planning module determines the optimal sequence for completing them. This involves algorithms that consider factors like travel distance, turning efficiency, and potential obstacles to create the most time-efficient route that ensures complete field coverage.
4. **Path Planning:** This module takes the planned route and generates smooth, continuous paths connecting the individual swaths. It incorporates algorithms like Dubins' curves or Reeds-Shepp's curves to ensure minimal path length and smooth turning maneuvers while navigating between swaths and headlands.

Benefits and Advantages

Fields2Cover offers a multitude of benefits for researchers, developers, and agricultural practitioners:

1. **Open-Source Accessibility:** By being open-source, Fields2Cover fosters collaboration and knowledge sharing within the research community. This accelerates the development of new and improved CPP algorithms, leading to even more efficient path planning solutions.
2. **Modular Architecture:** The modular design allows users to customize the library by integrating novel algorithms or modifying existing ones to suit their specific needs. This flexibility empowers developers to tailor CPP solutions for different types of agricultural vehicles and diverse field conditions.
3. **Benchmarking and Development:** Fields2Cover facilitates the benchmarking of various CPP algorithms by providing a standardized platform for comparison. This

allows researchers to identify the most effective algorithms for different scenarios, accelerating the development of optimal path planning solutions for the agricultural sector.

4. **Future-Proof Design:** While currently focused on convex fields, Fields2Cover's design philosophy allows for future expansion to incorporate functionalities for handling non-convex fields and obstacles. This ensures its continued relevance in the face of increasingly complex agricultural environments.

Impact and Future Potential

Fields2Cover has the potential to revolutionize the agricultural sector by enabling:

1. **Increased Efficiency:** Optimized path planning leads to reduced operational time, fuel consumption, and wear and tear on machinery.
2. **Improved Productivity:** Efficient path planning allows vehicles to cover fields more quickly and thoroughly, leading to increased productivity and potential yield improvements.
3. **Reduced Labor Costs:** By automating path planning and potentially reducing reliance on human operators, Fields2Cover can contribute to cost savings in the agricultural sector.

Results

The Results section of the Fields2Cover paper details the functionalities of the library through various experiments. Here's a breakdown of the key findings:

1. **Simulation Results**
    a. **Optimal Swath Generation:** The experiments demonstrate how different objective functions in the Swath Generator module (minimizing sum of swath lengths, number of swaths, maximizing field coverage) influence the generated path.
        i. Minimizing swath length may lead to many short swaths, reducing total length but potentially increasing turning needs.
        ii. Minimizing number of swaths reduces turns but may not achieve complete coverage.

iii. Maximizing field coverage prioritizes complete traversal but might require more turns.

b. **Route Planning and Path Length:** The study compared path lengths for different route planning patterns (boustrophedon, snake, spiral) and path generation algorithms (Dubins' curves, Reeds-Shepp's curves) against paths with in-place turns (shortest possible for a perfect holonomic vehicle).
    i. The boustrophedon pattern generally resulted in the shortest path with in-place turns, followed by snake and then spiral.
    ii. The difference between path length with curves and in-place turns indicates turning time. A larger difference suggests more time spent on turns and potentially lower efficiency.
    iii. Objective functions like minimizing number of swaths or swath length generally produced shorter paths.

c. **Computation Time Analysis:** The time required to compute a coverage path was measured in relation to field area and swath generator objective function.
    i. Field coverage as the objective function was computationally most demanding, growing linearly with field area due to complex geometric calculations.
    ii. The number of swaths and swath length objective functions were faster, with computation time growing proportionally to the square root of the field area.

2. **Field Experiment**

A real-world test with an agricultural robot (AgBot) was conducted in an elongated, narrow field. A custom swath angle was used to illustrate turning capabilities. The snake route planning pattern was chosen with Dubins' curves for path generation. Deviations between the planned path and the robot's actual track were observed due to the robot's turning radius limitations (planned turns were tighter than achievable). Despite these deviations, the AgBot successfully covered the field using the path designed by Fields2Cover, demonstrating its real-world applicability. Overall, the results highlight the capabilities of Fields2Cover in:

a. Generating efficient coverage paths based on user-defined objectives.

b. Optimizing path length and minimizing turning time through route planning and path generation algorithms.

c. Adapting to real-world scenarios with limitations of agricultural vehicles.

These findings showcase Fields2Cover's potential to improve the efficiency and productivity of autonomous agricultural operations.

Conclusion

Fields2Cover stands as a cornerstone for advancing CPP in the agricultural domain. Its open-source nature, modular architecture, and comprehensive functionalities empower researchers and developers to create next-generation autonomous agricultural vehicles. By facilitating efficient path planning, Fields2Cover paves the way for a more productive, sustainable, and cost-effective future for agriculture.

Reference

[1] G. Mier, J. Valente and S. de Bruin, "Fields2Cover: An Open-Source Coverage Path Planning Library for Unmanned Agricultural Vehicles," in IEEE Robotics and Automation Letters, vol. 8, no. 4, pp. 2166-2172, April 2023, doi: 10.1109/LRA.2023.3248439. keywords: {Libraries;Linear programming;Generators;Robots;Planning;Path planning;Software algorithms;Agricultural automation;software architecture for robotic and automation;field robots},