Project Proposal – Team HELlo

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1 Overview

Wildfires have the power to majorly disrupt both a farmer's livelihood as well as overall crop production. In 2024 the US lost an estimated 20.4 billion dollars in crops and rangeland from natural disasters [1]. Just over half of that came from drought, wildfires, and heat, accounting for roughly 11 billion dollars of lost revenue. With an increasingly volatile climate, weather predictions from top meteorological bodies show an increased risk of wildfires up to 50% by 2100, with even historically unaffected regions coming under threat [2, 3]. The increasing number and strength of wildfires will only exacerbate wildfire damage to crops, resulting in more pressure on farmers.

Unfortunately, organized governmental response to wildfires on cropland is limited. With constraints on both water and manpower, many farmers are forced to watch as their fields burn or risk their lives and machinery to create rudimentary fire breaks with tillage machines. For farmers who try to save parts of their fields, they are confronted with a variety of challenges, including poor visibility from wildfire smoke, heat exhaustion in vehicles not meant for these types of situations, and high risk of machine damage to both tilling components and tractor cabs.

We propose to mitigate these harms to both farmers and equipment by implementing a real-time path algorithm that can respond to an active cropland wildfire. Using bolt-on heat sensors, we plan to use real-time data collection to drive the path of an autonomous tiller to create a firebreak. Firebreaks are a tried-and-true method for slowing and potentially stopping wildfires [4]. This research connects to digital agriculture as we are utilizing technologies such as sensors, autonomous machinery, and real-time data analytics to improve disaster mitigation for farms.

2 Goals

Our goal is to build an interactive visualization software that simulates fire spreading on a soybean farm, with a tractor that computes the best and safest path to create a fire break using simulated camera, heat, and fog sensors.

2.1 MVP Features

- A basic fire spreading simulation.
- A tractor node that can drive on a simulated farm.

- A path planner that takes fire into account and computes the best safe firebreak path.
- Visualization that shows the fire spreading and tractor moving.

2.2 Good-To-Have Features

- Stop criteria and mechanism, to minimize machine damages.
- Manual override for emergencies.

3 Specifications

3.1 Related Work

There is little to no prior research on real-time path planning with dynamic barriers for agricultural machines thus far. Therefore, we draw mostly on several papers that discuss dynamic path planning for autonomous agricultural vehicles as well as several papers on dynamic obstacle avoidance in autonomous automobiles.

Several recent papers suggest using deep learning and reinforcement learning for intelligent and real-time path planning in autonomous agricultural vehicles [8, 9], while other papers focus on dynamic path planning and object avoidance for robots more generally [5, 6, 7]. While the combination of real-time path planning and dynamic object avoidance has been trivial for agriculture technologists thus far, we find it to be one of the main challenges with real-time path planning for fire breaks. We are forced to dynamically adjust our path as the fire line advances.

Although we can draw from path planning and prediction models for autonomous cars, they rely on a set of sensors and depth perception that are not reliable in smoke and dust kicked up by tilling fire breaks. Other relevant research that focuses on real-time agricultural planning either relies on additional farm-specific reinforcement [8], which is unfeasible due to the nature of crop fires, or relies on specific target/waypoints as goals [9], which we cannot guarantee based on fire progression.

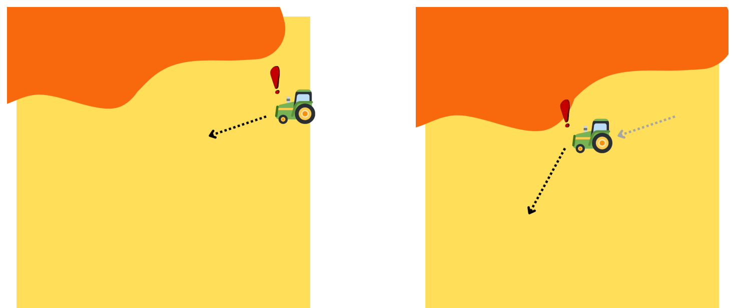
3.2 Approach

We aim to use Python with a lightweight visualization library, PyBullet, to simulate a 2D farm area using a matrix with different values symbolizing various terrain states (soybean, fire, dirt). The tractor is a movable entity on the matrix, which senses limited information through predefined sensors. Its movement will follow the limitations of real-world tractors. We will either use Cell2Fire [10] or SimFire [11] to simulate wildfire progression through our soybean field.

The simulation loop starts with an initiation state of fire root points, tractor start points, and goal location (not limited to a single point). At each timestamp, the fire spread model updates grid information, tractor sensor information updates, the planner computes the next step, the tractor moves, and states are saved. Simulation stops once robots reach out of the farm or are consumed by fire. The area of the farm burnt, tilled, and unimpacted will be documented. We aim to finetune the path by minimizing chances of tractor failure and maximizing farm area saved.

3.3 Mock-up

The orange area indicates the spreading fire; the yellow area indicates the soybean farm.



4 Milestones

- Weeks 4–6: System setup, fire simulation
- Weeks 7–8: Basic path simulation
- Midterm report
- Weeks 9–11: Optimize path simulation
- Weeks 12–14: Extra features
- Week 15: Buffer, Final presentation

5 Key Stakeholders and Work Distribution

Stakeholder	**Interest**	**Assigned Member**
Farmers	Protect crop & asset, low-cost intervention, soil health	—
Firefighters	Fire containment, risk reduction, resource reduction	—
Full-Stack Engineer	Build usable platform, build simple interface	Emerald Chang
User Researcher	Research tractor specs, guide result presentation, bridge research result with real life product	Hunter Caslin
Simulation Algorithm Researcher	Optimizing fire break path, implement core algorithm	Lanea Rohan

6 References

References

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