Wildfires are a dangerous and costly. In 2018 costing $91 billion in economic damage from natural disasters worldwide, and $24 billion from wildfires alone in CA in [1]. Current approaches for wildfire surveillance require human operators which make remote areas often difficult for people to access. The purpose of our project is to enable drones, or multi-robot networks, to locate and track the position and status of individual trees within a forest to identify and help prevent forest fires. This location identification and status of trees within their remote environment is modulated through a reinforcement learning algorithm.

Using simulation based software, Python, we were able to identify how quickly a forest fire spreads which can be observed in Figure 1 below.

![Figure 1: Wildfire spreading simulation using Python](image)

The fire simulation executed initially, shown in Figure 1, was a forest fire that occurred at random demonstrating how forest fires overtake remote areas. Each time the code was run, it resulted in a different burn area. To further advance in our project algorithm, the trees needed to become objects that changed states to depict whether a tree is healthy, on fire, or burnt within each state step. For the simulation to produce meaningful results, a group of trees were given initial state values of being in the burning state. Trees in the healthy state were then given information of the burning trees and would either stay in the same state or transition to the next state depending on a calculated transition probability. The Markov process was implemented to calculate the probability for a healthy tree to transition to the burning state using the Markov chain model. Each time the simulation is iterated, it updates and the iteration continues with the updated version.

![Figure 2: Finite state machine with 3 states for forest fire algorithm](image)

A finite state machine is implemented to create the forest fire algorithm. Figure 2 shows a structure of the state machine used. Recall that information is only needed for the healthy trees. A healthy tree is in state 0 with initial conditions that contain information on the trees that were set to be burning and performs a transition probability calculation to determine whether it will go to the next state or remain in the same state. A healthy tree cannot go to S2, the burnt state, without transitioning to the burning state, S1, first. This process repeats with each healthy tree that was set in an array of x and y positions. Once every healthy tree finishes through the FSM, the array is updated and the iteration continues with the updated version.

![Figure 3: Reinforcement Learning](image)

The fire simulation provides a platform for multi-agent networks to be used as an environment that will allow the agent to detect the change in states of trees. Furthermore, the forest fire environment promotes reinforcement learning by agents to detect changes in the environment and updating a corresponding action that will change the agent's state and provide a reward depending on the action [3].

![Figure 4: Initial starting point of the algorithm when a tree in the forest is identified as the start of a fire](image)

Additionally, through knowing the states of each tree, with array knowledge, we know precisely which tree is burning and where. With our improved algorithm in combination with simulation analysis, this provides a platform for future multi-robot networks through its reinforcement learning capabilities and its proven location and status tracking which allows for the identification and mitigation of forest fires. Through the incorporation of UAVs, or multi-robot networks with our simulation and array output algorithm, our project has the potential for real time forest monitoring and forest fire mitigation, saving money, and our planet.

![Figure 5: Mid-point of algorithm with few trees burning (1)](image)

**Methodology**

Methodology was developed through the use of finite state machines with 3 states for forest fire algorithm. A finite state machine is implemented to create the forest fire algorithm. Figure 2 shows a structure of the state machine used. Recall that information is only needed for the healthy trees. A healthy tree is in state 0 with initial conditions that contain information on the trees that were set to be burning and performs a transition probability calculation to determine whether it will go to the next state or remain in the same state. A healthy tree cannot go to S2, the burnt state, without transitioning to the burning state, S1, first. This process repeats with each healthy tree that was set in an array of x and y positions. Once every healthy tree finishes through the FSM, the array is updated and the iteration continues with the updated version.

![Figure 6: Mid-point of algorithm with few trees burning (1)](image)

The fire simulation provides a platform for multi-agent networks to be used as an environment that will allow the agent to detect the change in states of trees. Furthermore, the forest fire environment promotes reinforcement learning by agents to detect changes in the environment and updating a corresponding action that will change the agent's state and provide a reward depending on the action [3].

![Figure 7: Post advanced point of algorithm, some trees burning (1), and some trees already burnt (2)](image)

**Conclusions and Future Work**

In conclusion, our project sought to understand the complexity of forest fire spread and provide a monitoring solution for the identification and mitigation of damaging forest fires. Our team was able to generate a forest fire simulation to further understand how quickly these fires spread, as well as generate an algorithm that provided a numerical value of arrays representing individual trees, their position, and status of healthy (0), burning (1), or burnt (2). Our improved algorithm provides a platform for future multi-robot networks through its reinforcement learning capabilities and its proven location and status tracking which allows for the identification and mitigation of forest fires. Through the incorporation of UAVs, or multi-robot networks with our simulation and array output algorithm, our project has the potential for real time forest monitoring and forest fire mitigation, saving money, and our planet.

**Key References**


**Acknowledgements**

We would like to acknowledge San Jose State University for offering the EE 168B Senior Project course that this project was completed within. We would also like to acknowledge Thuy Le, San Jose State Electrical Engineering Department Chair, and Professor Jonathan Ponniah who served as our project advisor for the duration of this course and project. Additionally, we would like to acknowledge Ravi Haksar who inspired our project.

https://zoom.us/j/94595951531?pwd=V30URy9QaWI5bE9ZdWpsSFJaeUJHR1dpZz09

Meeting Password: 138255