SwarmSense:
Effective and Resilient Drone Swarming and Search for Disaster Response and Management Application

Cheolmin Jeon, Hanbum Ko, Jeongsoo Ha, Byungman Lee, Bo Ryu
Chungnam National University
EpiSci

Agenda

1. Goal & Challenges
2. AMASE drone swarm simulator
3. Algorithm
4. Example
5. Result
6. Future work
7. Q & A

Goal & Challenges

Goal

- For a group of drones to effectively coordinate and share information for disaster response and management applications such as wildfires.

Challenges

1. limited resources in terms of the number of drones available and short battery life

1. limited information availability about the disaster

1. extremely large area with highly challenging navigation conditions.

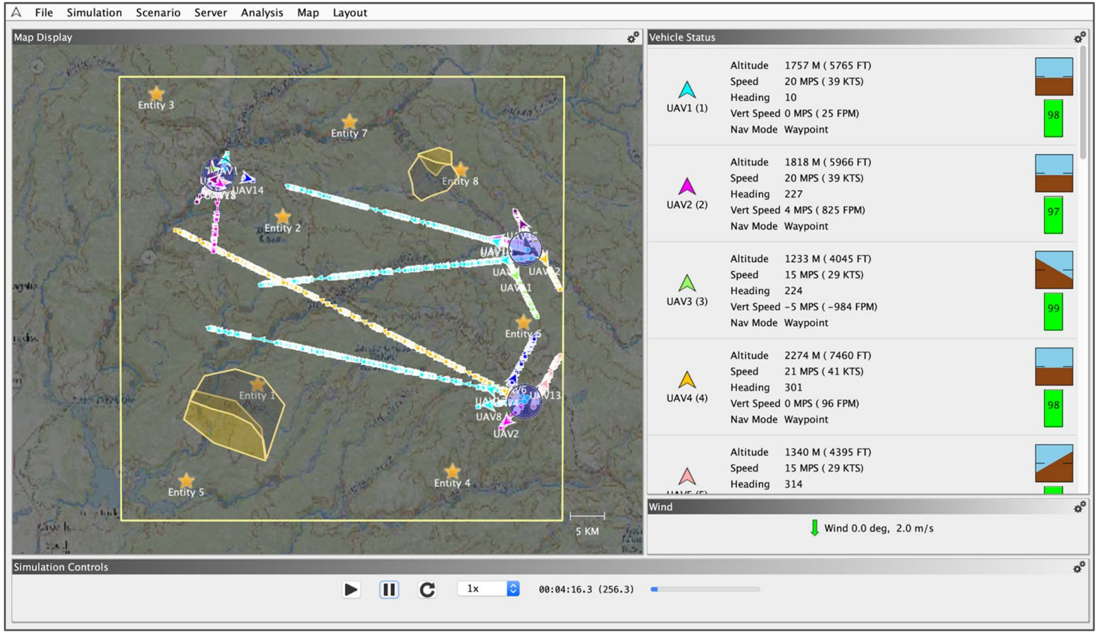
Environment

AMASE

- simulation toolset for the analysis and demonstration of aircraft automation and autonomy.

Scenarios

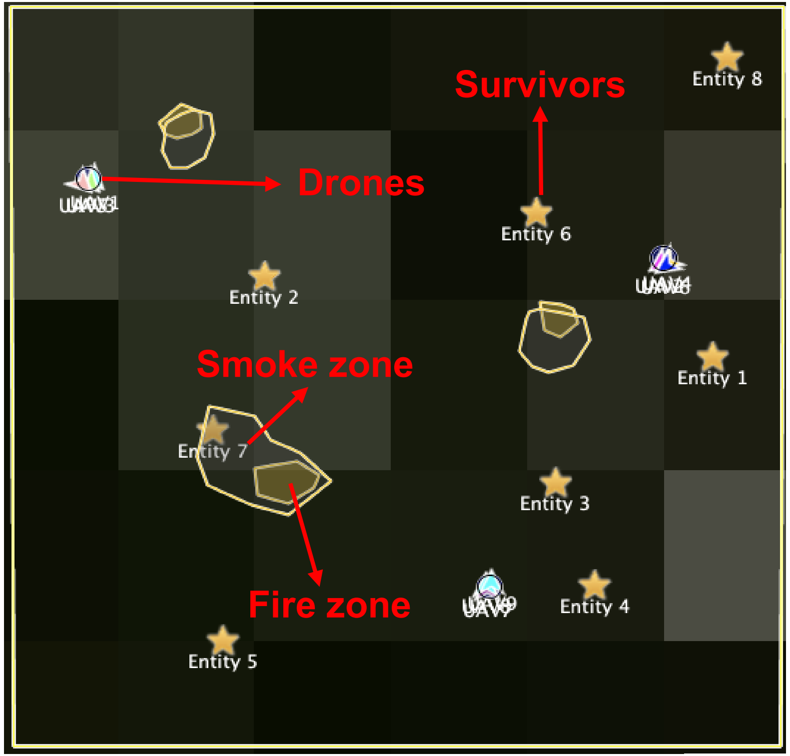
- A total of 10 scenarios from over 30 scenarios provided during the ‘Swarm and Search AI 2019 Fire Hack’ event hosted by Air Force Research Laboratory (AFRL).



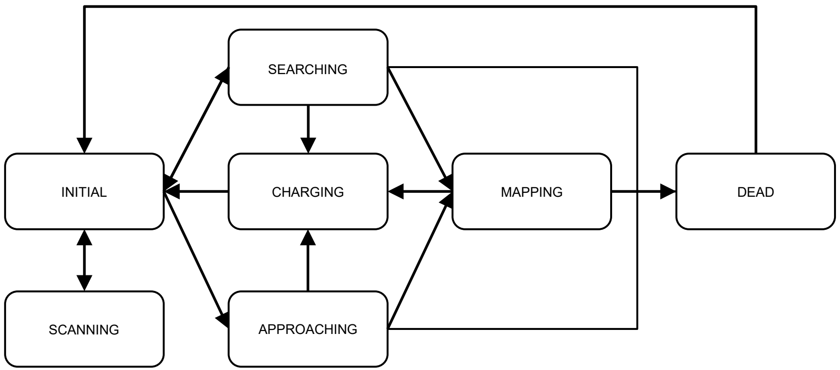
https://github.com/afrl-rq/OpenAMASE

Environment

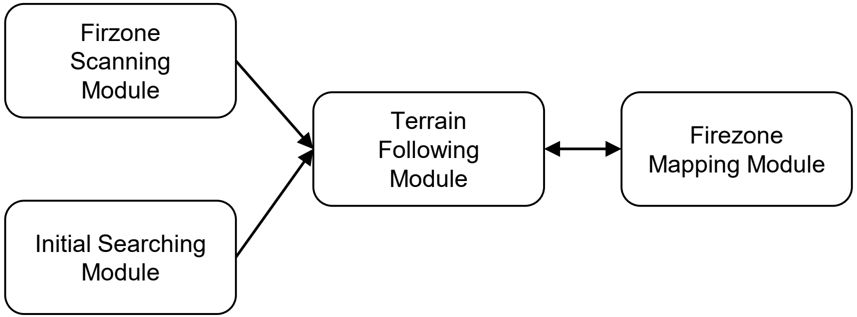
1. 9 to 18 drones
2. battery life for each drone
3. designated battery recovery zone
4. size and location of fires
5. smoke zone of fire
6. locations of ground entities to represent survivors
7. terrain information of the entire disaster area.



Algorithm - States & Software Modules



(State Transition Diagram)

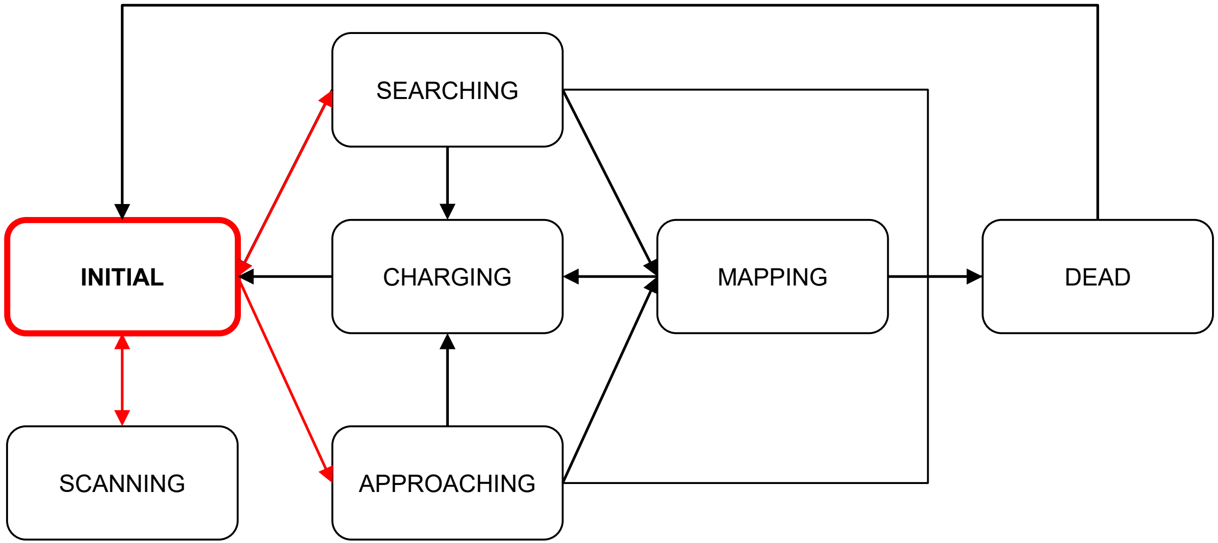


(Software Modules)

Algorithm - States

7 states

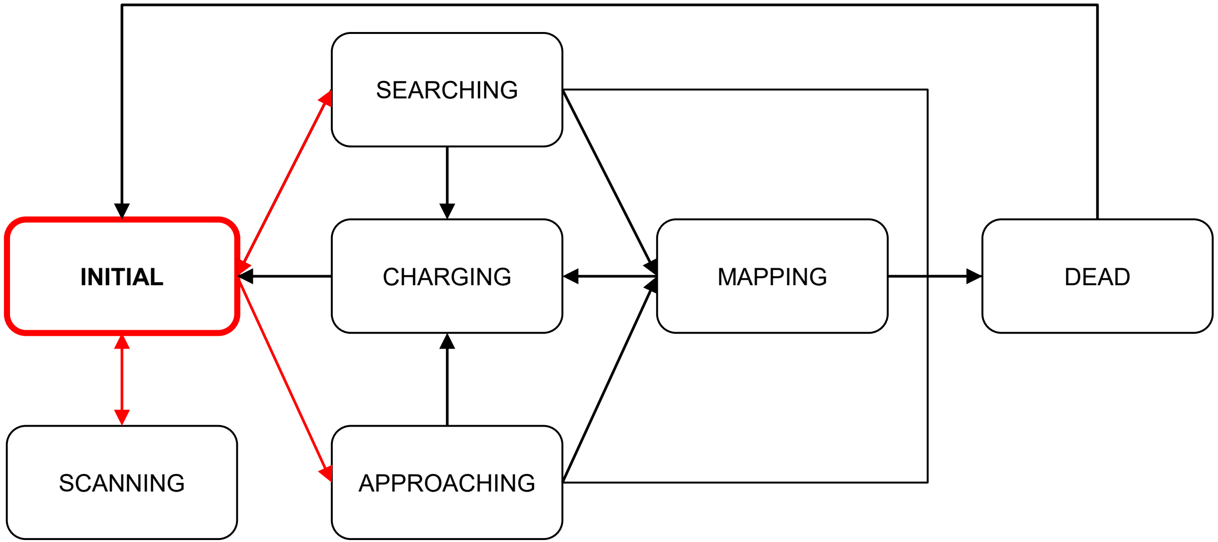
1. **INITIAL**
2. SCANNING
3. SEARCHING
4. APPROACHING
5. MAPPING
6. CHARGING
7. DEAD



Algorithm - States

INITIAL

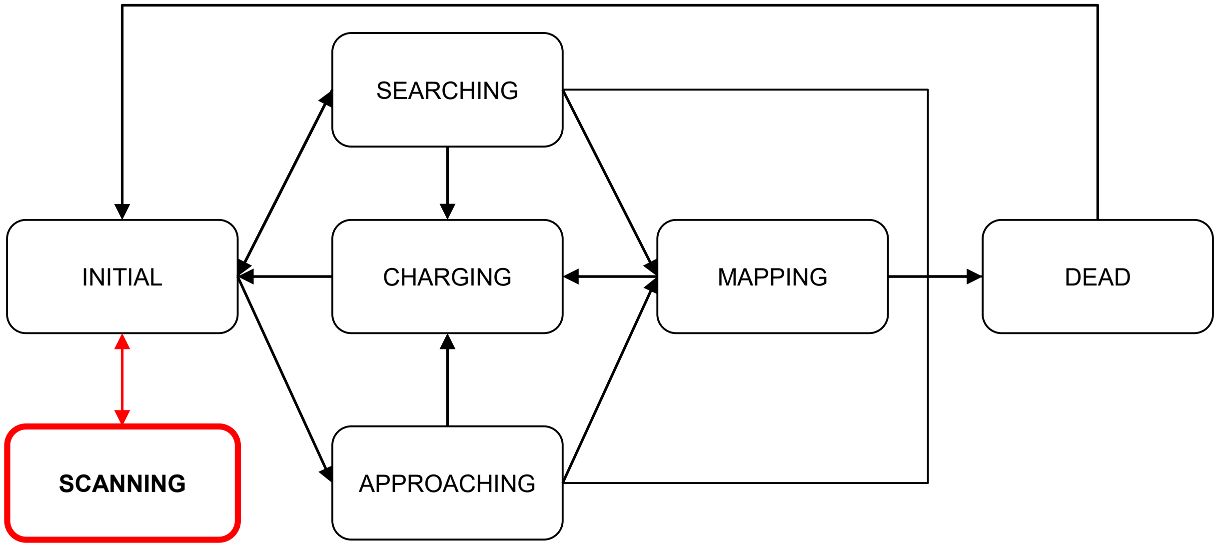
- Upon the beginning of the scenario, each and every drone makes an analysis of the current situation and decides the next action and the state



Algorithm - States

7 states

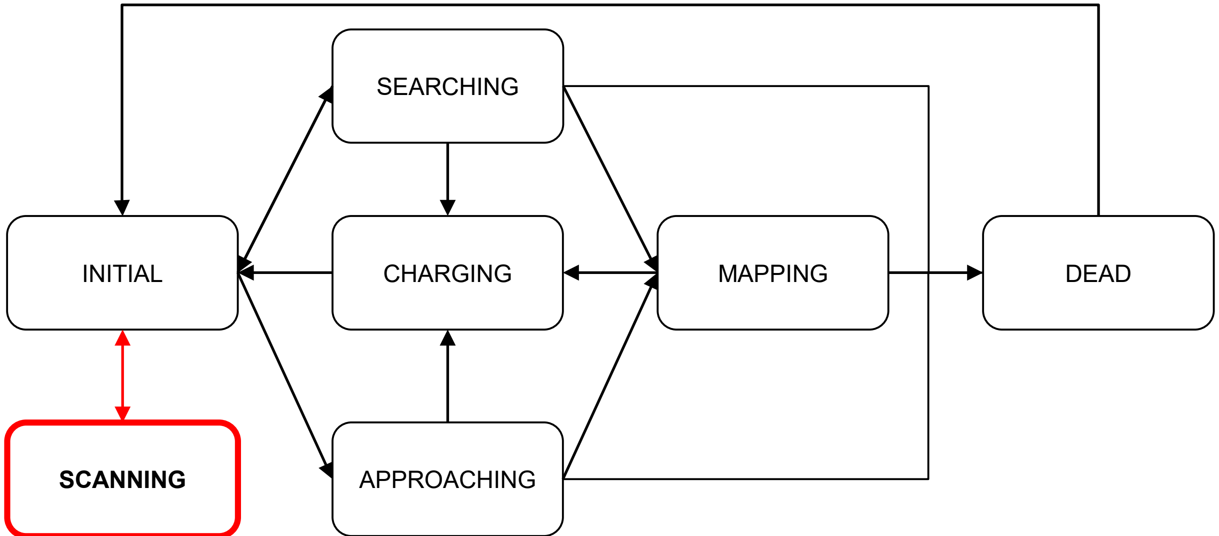
1. INITIAL
2. **SCANNING**
3. SEARCHING
4. APPROACHING
5. MAPPING
6. CHARGING
7. DEAD



Algorithm - States

SCANNING

- During the INITIAL state, one drone per recovery zone is randomly selected to switch to SCANNING state. The selected drone then scans the entire disaster area with its on-board sensors and makes an initial estimations of the fire zones.



Algorithm - States

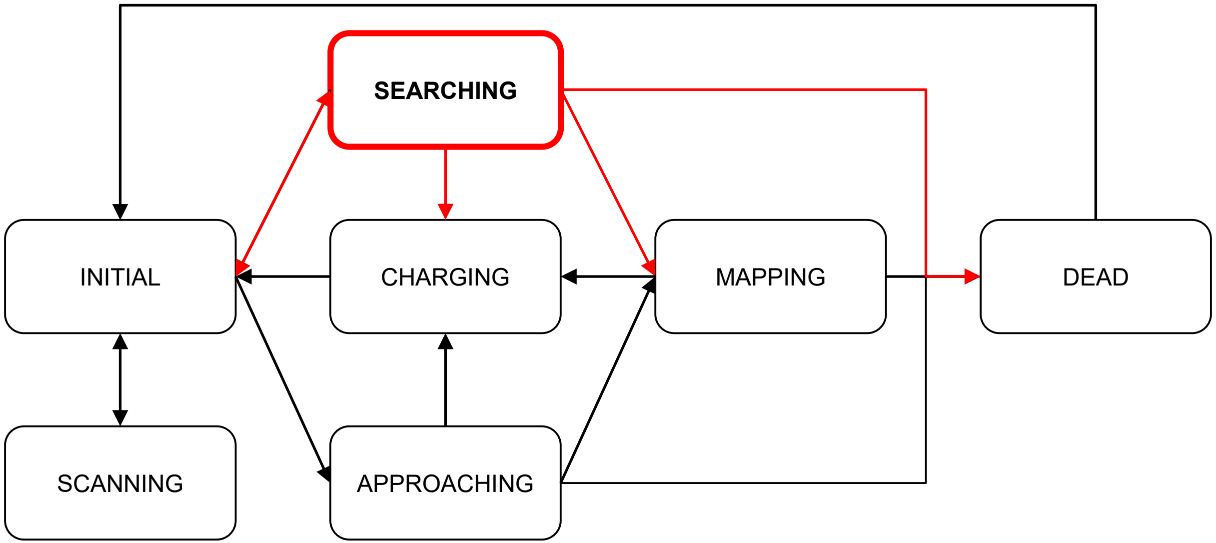
SCANN[redacted]

- Duri[redacted]witch to SCA[redacted]s on-board sens[redacted]

Algorithm - States

7 states

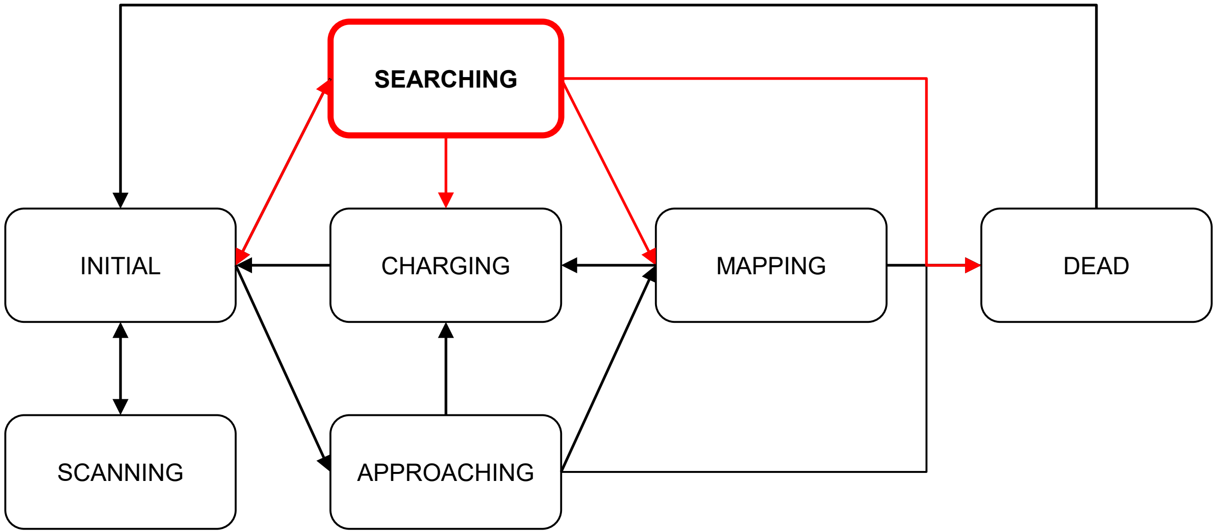
1. INITIAL
2. SCANNING
3. **SEARCHING**
4. APPROACHING
5. MAPPING
6. CHARGING
7. DEAD



Algorithm - States

SEARCHING

- Drones begin to explore a subsection of the entire area to detect and arrive at the tagged fire zone.



Algorithm - States

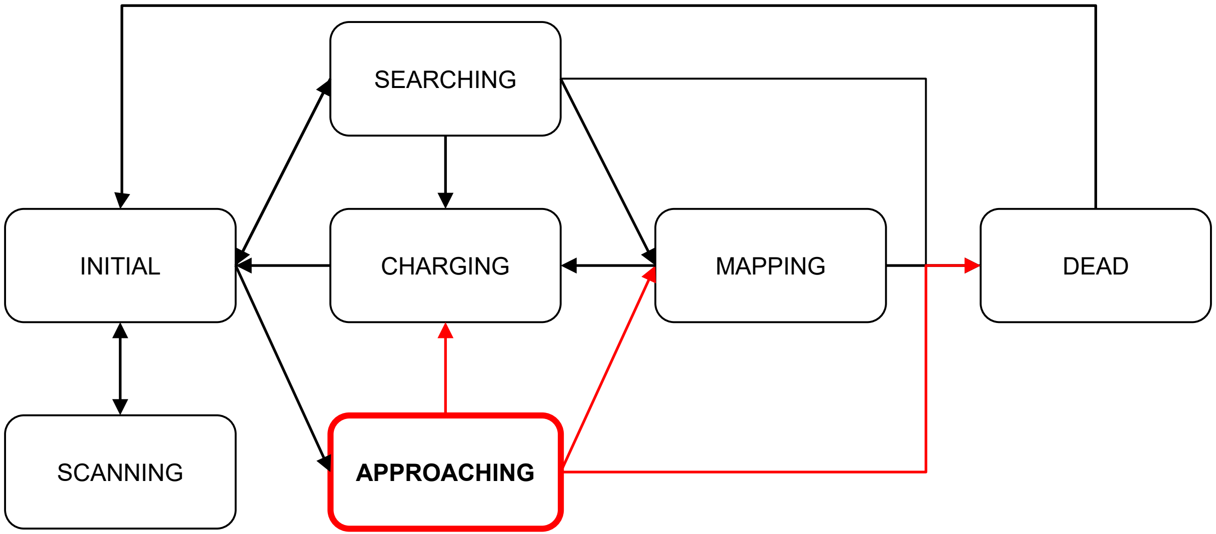
SEARC[redacted]

- Dro[redacted]agged fire [redacted]

Algorithm - States

7 states

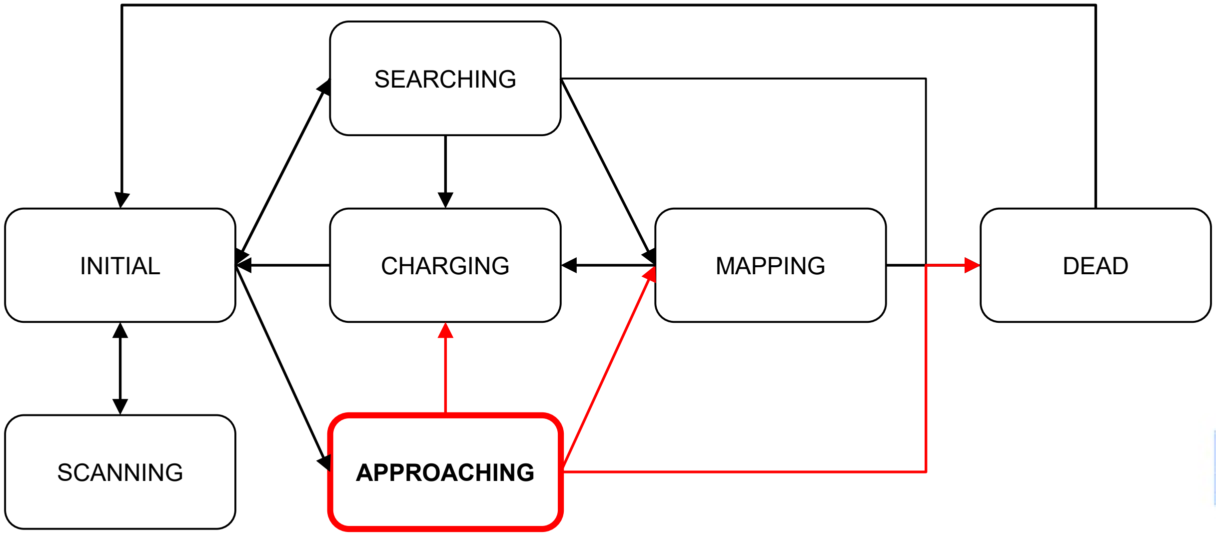
1. INITIAL
2. SCANNING
3. SEARCHING
4. **APPROACHING**
5. MAPPING
6. CHARGING
7. DEAD



Algorithm - States

APPROACHING

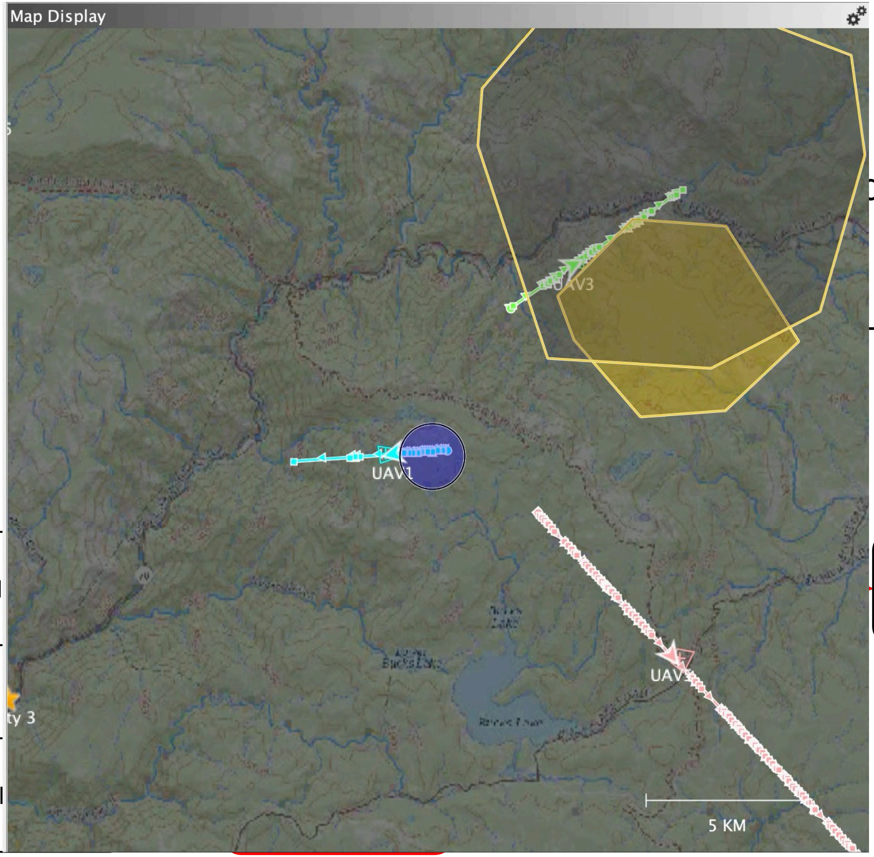
- Drones go to a found firezone to help figuring out the disaster area quickly



Algorithm - States

APPROACHING

● Drones go to a fou quickly



INI

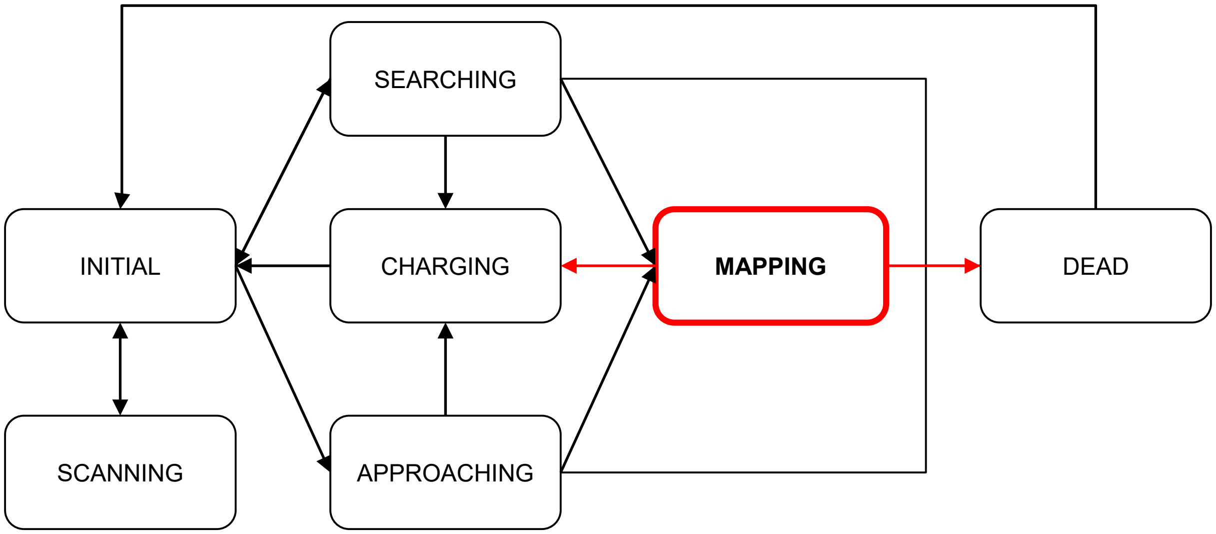
SCA

DEAD

Algorithm - States

7 states

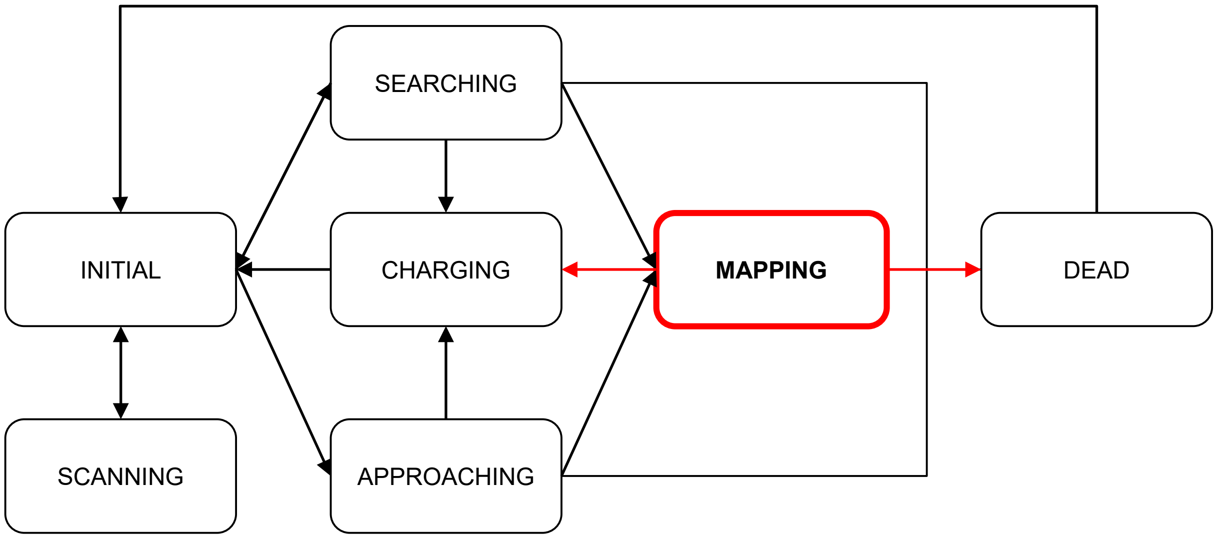
1. INITIAL
2. SCANNING
3. SEARCHING
4. APPROACHING
5. **MAPPING**
6. CHARGING
7. DEAD



Algorithm - States

MAPPING

- Drones engage in mapping the fire zone by tracking/tracing the boundary of the zone.

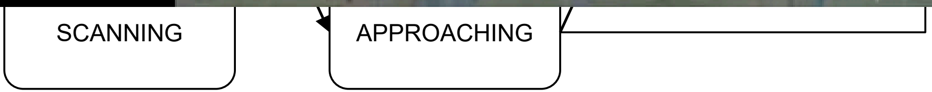


Algorithm - States

MAPPING

- Drones

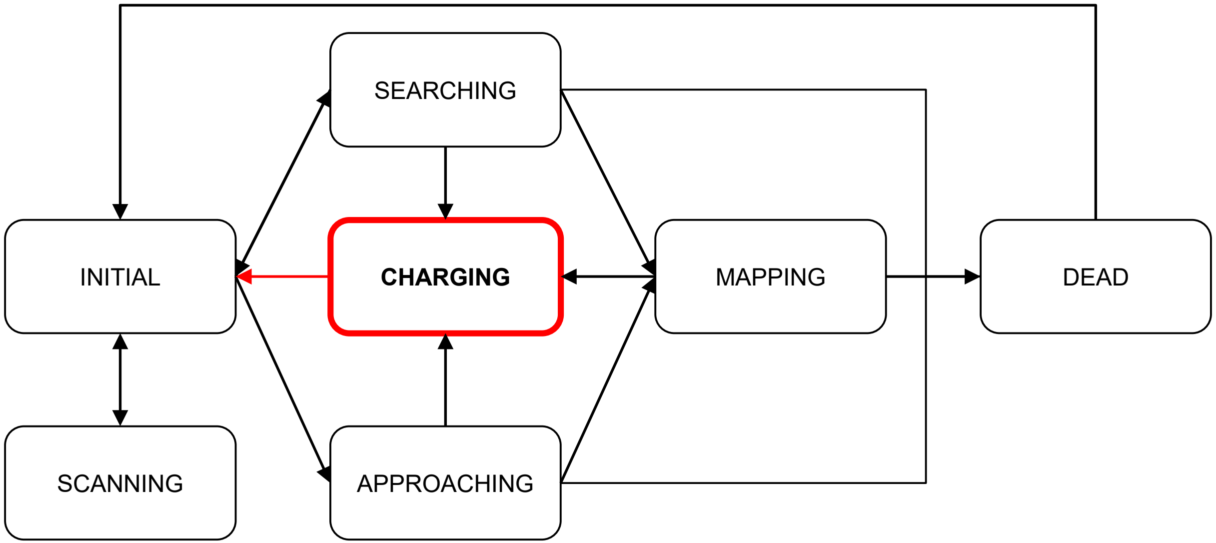
one.



Algorithm - States

7 states

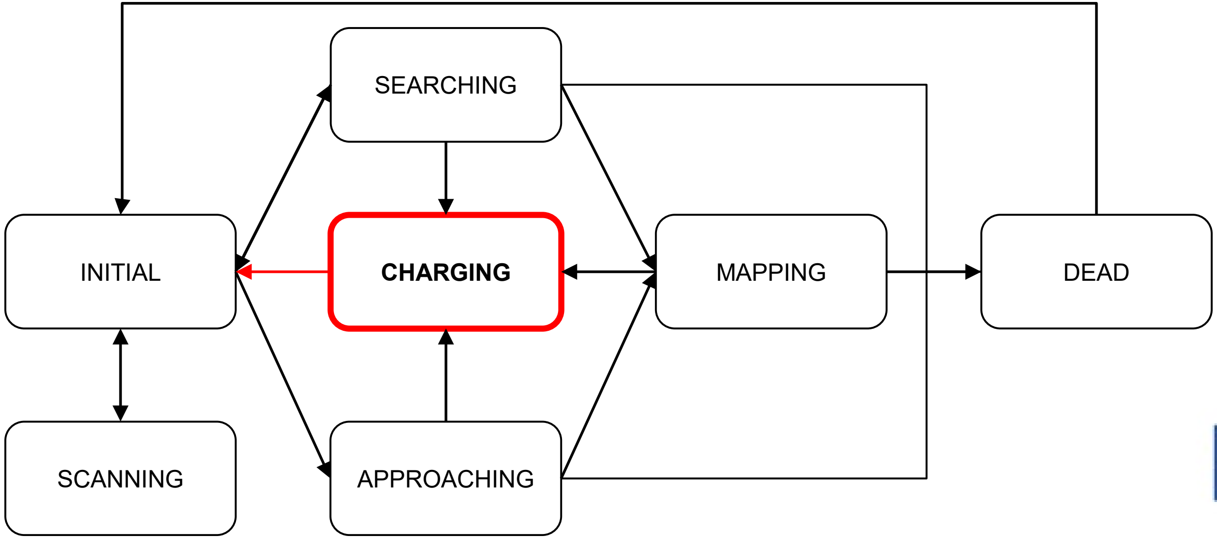
1. INITIAL
2. SCANNING
3. SEARCHING
4. APPROACHING
5. MAPPING
6. **CHARGING**
7. DEAD



Algorithm - States

CHARGING

- Drones fly to the designated recovery zones to recharge their batteries.



Algorithm - States

CHARGING

- Drones fl[redacted]

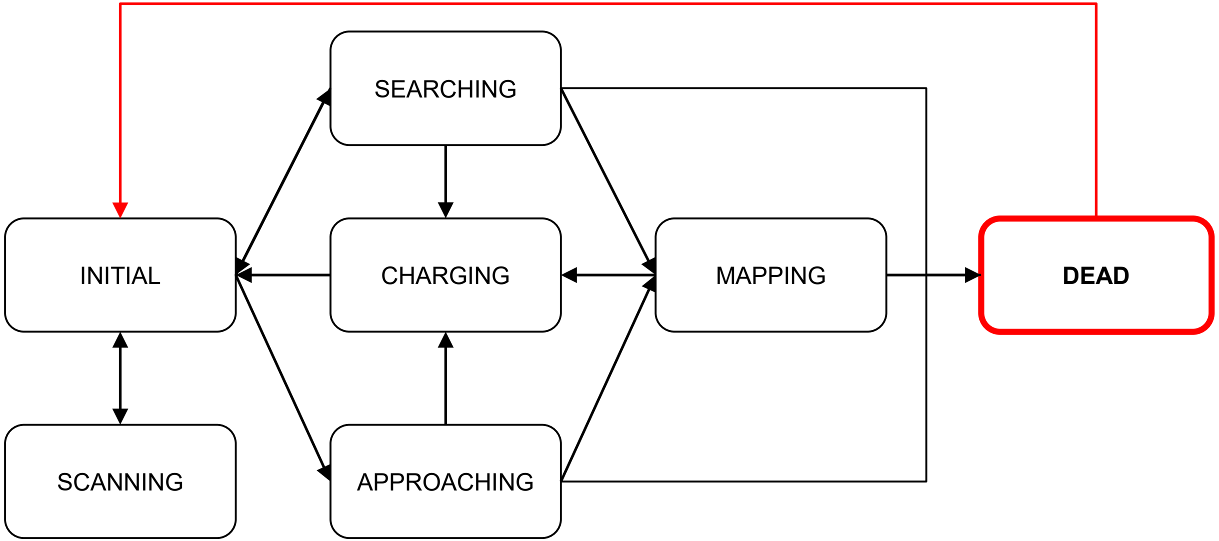
SCANNING

APPROACHING

Algorithm - States

7 states

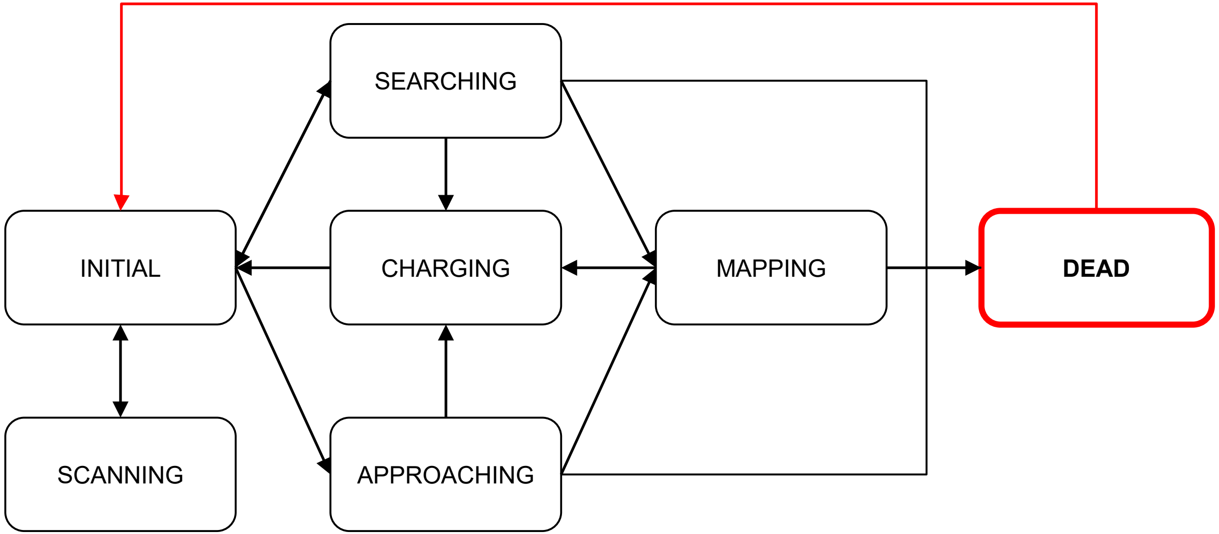
1. INITIAL
2. SCANNING
3. SEARCHING
4. APPROACHING
5. MAPPING
6. CHARGING
7. **DEAD**



Algorithm - States

DEAD

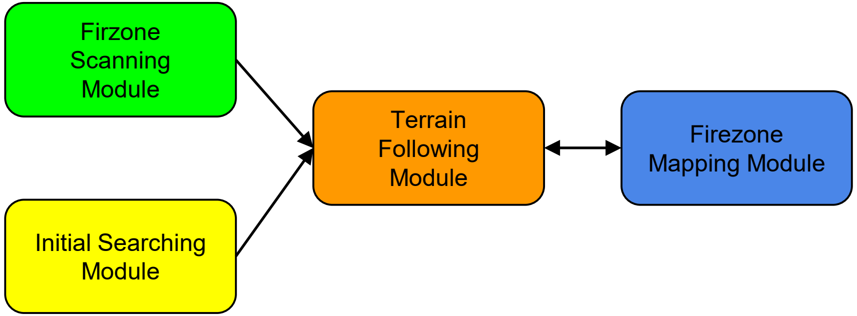
- Drones are destroyed or become inoperational due to explosion (by fire), crash (by terrain), depletion of the battery or an event of scenario.
- When drones are destroyed by scenario, new drones are created a few times later.



Algorithm - Modules

4 Modules

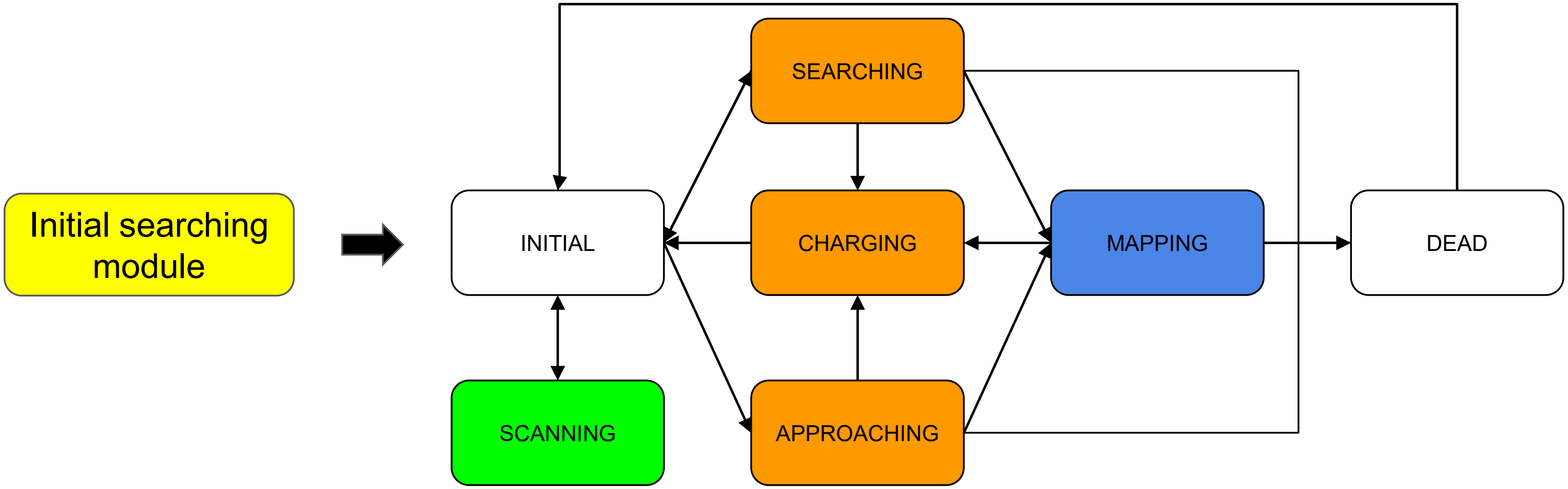
1. Firezone Scanning Module (FSM)
1. Initial Searching Module (ISM)
1. Terrain Following Module (TFM)
1. Firezone Mapping Module (FMM)



Algorithm - Modules

Pre-start

While running scenario



Algorithm - Modules

4 Modules

1. **Initial Searching Module (ISM)**

1. Firezone Scanning Module (FSM)

1. Terrain Following Module (TFM)

1. Firezone Mapping Module (FMM)

To cover the entire disaster area using **the available resources** (number of drones and battery lives) as **efficiently** and **fast** as possible.

Algorithm - Initial Searching Module (ISM)

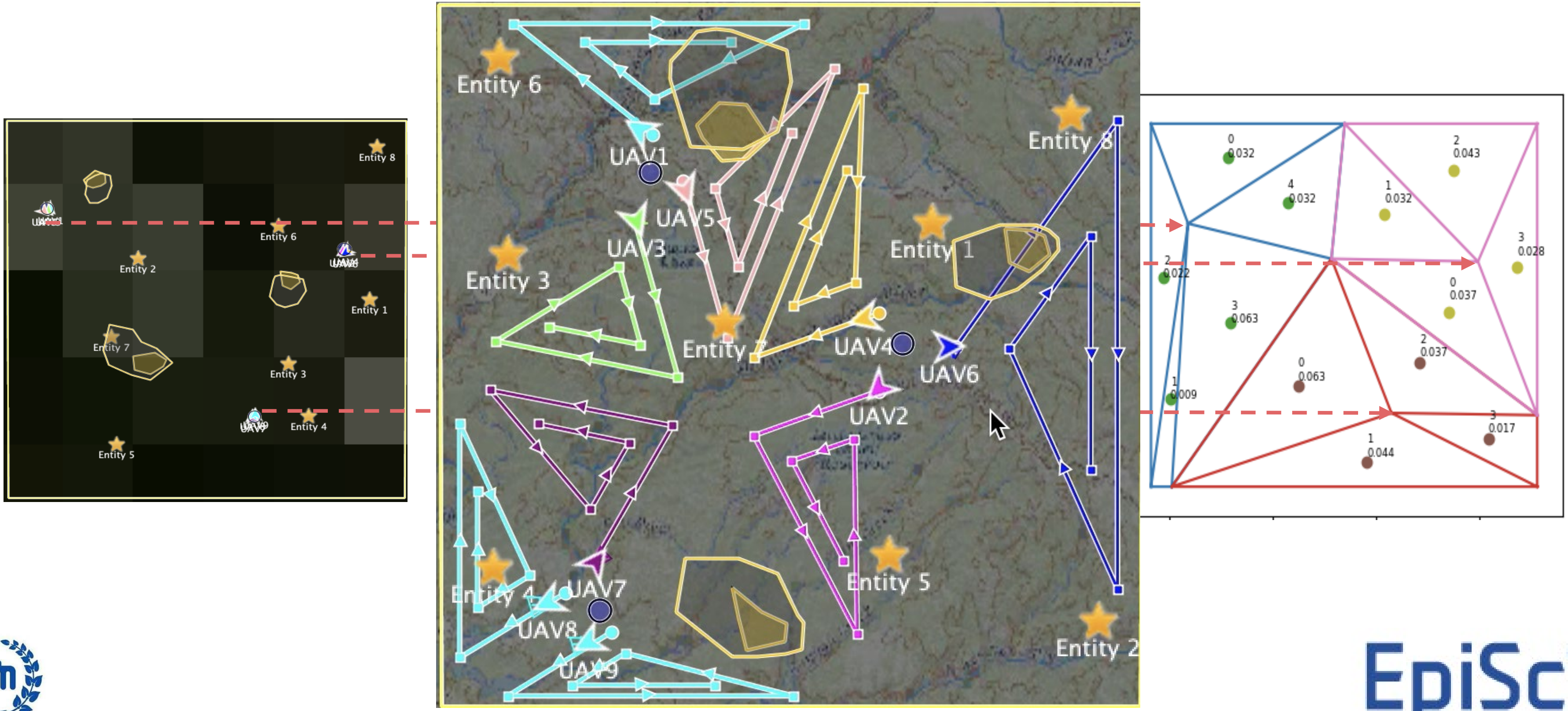
Using provided information from a scenario, ISM assigns each drone a part of the entire area to cover as wide as possible in whole scenario time.

1. When the scenario start, ISM collects the entire area's edges and the recovery zone centers as drone start points.

1. Using these information, the entire area is divided into smaller triangle areas by **Voronoi diagram**.

1. Each drone in 'INITIAL' state is assigned a triangle area in order of distance and switch to 'SEARCHING' state.

Algorithm - Initial Searching Module (ISM)



Algorithm - Modules

4 Modules

1. Initial Searching Module (ISM)

1. **Firezone Scanning Module (FSM)**

1. Terrain Following Module (TFM)

1. Firezone Mapping Module (FMM)

To cover the entire disaster area using **the available resources** (number of drones and battery lives) as **efficiently** and **fast** as possible.

Algorithm - Firezone Scanning Module (FSM)

Utilizing the onboard sensor, predict the area of likely fire zones.

1. During the ‘INITIAL’ state, one drone per recovery zone is randomly selected to switch to ‘SCANNING’ state.

1. The selected drones scan the entire disaster area with its onboard sensor

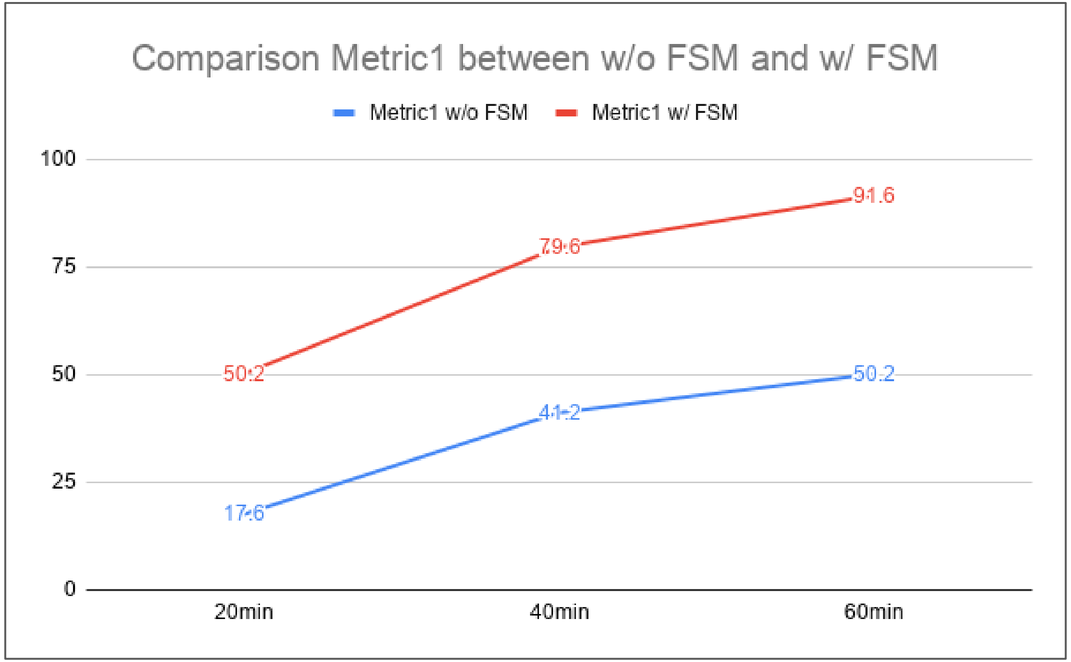
1. After scanning, the selected drones makes an initial estimations of the fire zones by sharing.

EpiSci

Algorithm - Firezone Scanning Module (FSM)

Algorithm - Firezone Scanning Module (FSM)

Metric 1 = Firezone detection ratio



Algorithm - Modules

4 Modules

1. Initial Searching Module (ISM)

1. Firezone Scanning Module (FSM)

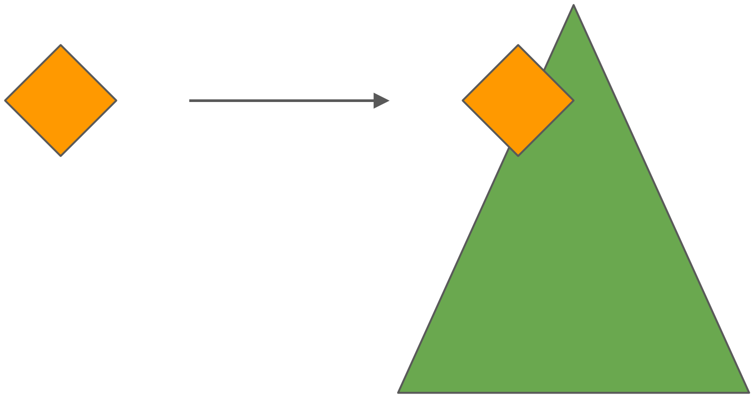
1. **Terrain Following Module (TFM)**

1. Firezone Mapping Module (FMM)

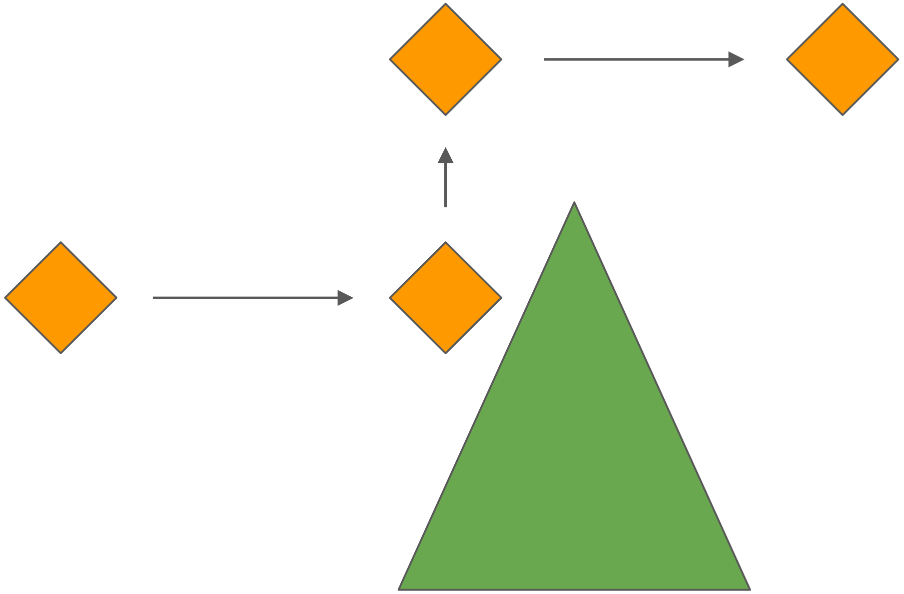
To **prevent itself from crash** due to **the challenging terrain conditions** such as steep and sudden ascending and descending slopes

EpiSci

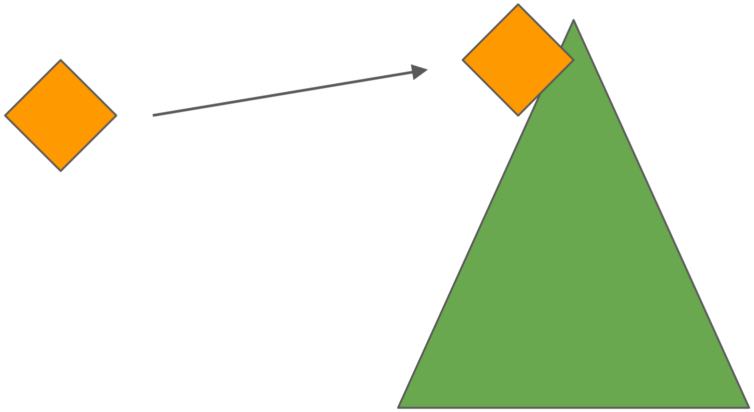
Algorithm - Terrain Following Module (TFM)



Algorithm - Terrain Following Module (TFM)



Algorithm - Terrain Following Module (TFM)



Algorithm - Terrain Following Module (TFM)

TFM is based on ‘Autonomous terrain-following for unmanned air vehicles’. According to the paper, there are a few requirements to use this module.

1. All altitude of path from start point to end point.

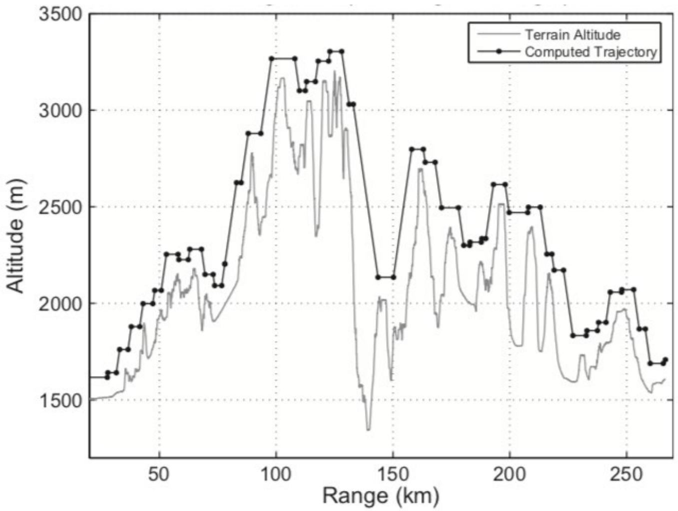
1. Drone’s fixed ascending and descending slopes

So, drones in states knowing where to go such as ‘Searching’, ‘Charging’, ‘Approaching’ use TFM.

Reference - ‘Autonomous terrain-following for unmanned air vehicles’ - Raza Samar,Abdur Rehman

Algorithm - Terrain Following Module (TFM)

TFM divides the drone's planned path into short segments and calculates the starting and ending points of the drone's ascending and descending as well as its slopes.



EpiSci

Algorithm - Terrain Following Module (TFM)

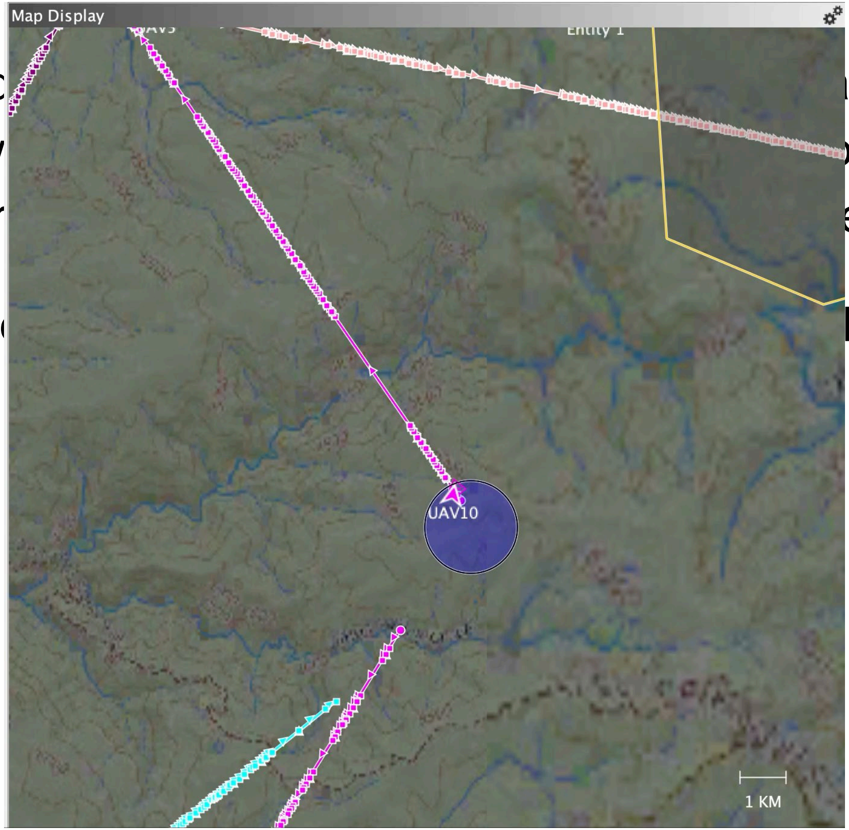
But drones have fixed slope to go up and down, so drones can’t follow all terrain exactly. Then there would be big gap between terrain and drones. Because of gap, drones can’t detect firezone and are destroyed by the firezone.

When the gap is bigger than onboard sensors range, drones hover to maintain the gap to threshold.

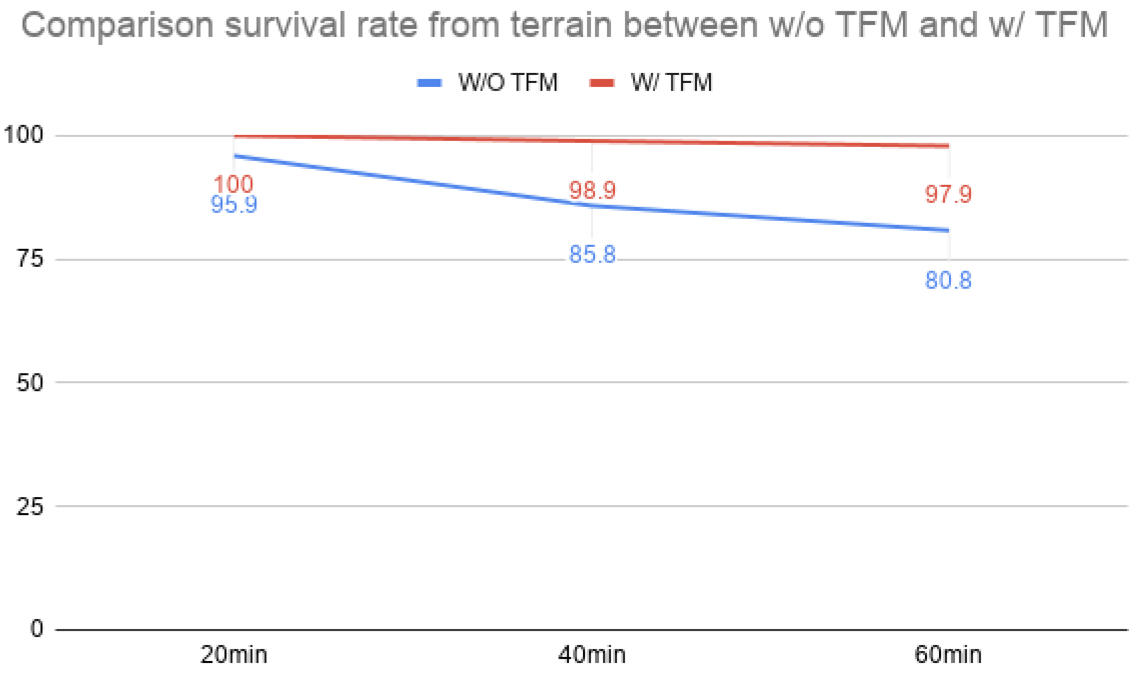
Algorithm - Terrain Following Module (TFM)

But drones have fixed … n't follow all terrain exactly. Then there w … ones. Because of gap, drones can't detect fir … e.

When the gap is bigg … hover to maintain the gap to ideal.



Algorithm - Terrain Following Module (TFM)



Algorithm - Modules

4 Modules

1. Initial Searching Module (ISM)

1. Firezone Scanning Module (FSM)

1. Terrain Following Module (TFM)

1. **Firezone Mapping Module (FMM)**

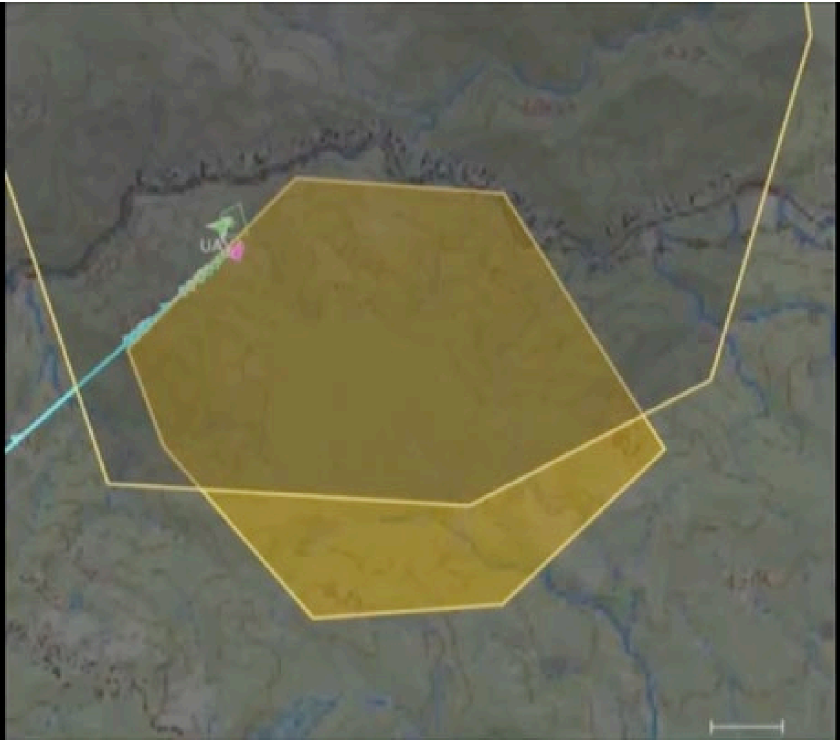
To **prevent itself from destroy** due to **the firezone** with approximating the current firezone area.

Algorithm - Firezone Mapping Module (FMM)

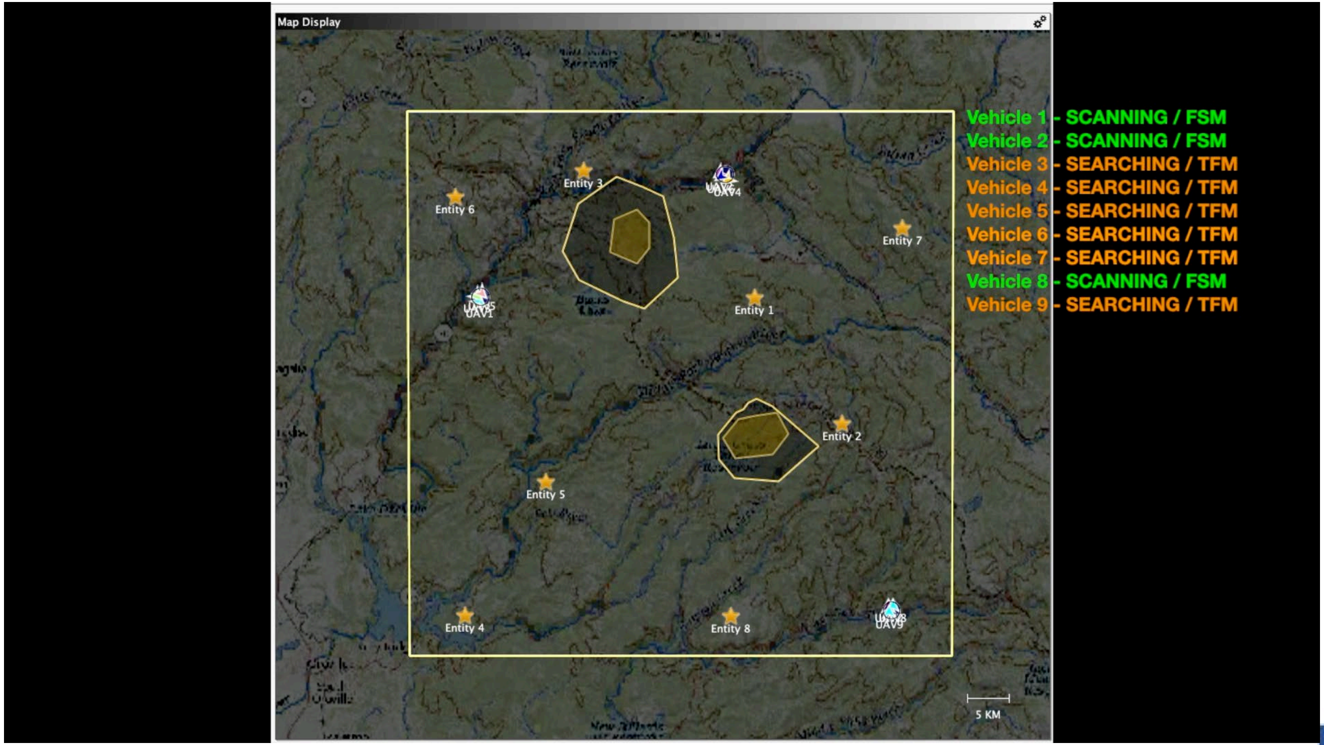
If a drone stays inside the zone over 5 seconds, it is destroyed by the fire.
Not to be destroyed by fire and estimate firezones as big as possible, drones in 'Mapping' use FMM.

1. Drone decides the direction of mapping based on the sensor's azimuth at the first detection. i.e. clockwise.
2. If drone detects firezone, drone then turns to outside of firezone.
3. If drone doesn't, drone then turns to inside of firezone.
4. Keep doing 2-3.

Algorithm - Firezone Mapping Module (FMM)



Example


Map Display
Vehicle 1 - SCANNING / FSM
Vehicle 2 - SCANNING / FSM
Vehicle 3 - SEARCHING / TFM
Vehicle 4 - SEARCHING / TFM
Vehicle 5 - SEARCHING / TFM
Vehicle 6 - SEARCHING / TFM
Vehicle 7 - SEARCHING / TFM
Vehicle 8 - SCANNING / FSM
Vehicle 9 - SEARCHING / TFM
Entity 1
Entity 2
Entity 3
Entity 4
Entity 5
Entity 6
Entity 7
Entity 8
UAV1
UAV4
UAV9
5 KM

Result

Metric

1. **Firezone detection ratio**
   a. Percentage of the firezones detected by the drones with no prior knowledge of their locations

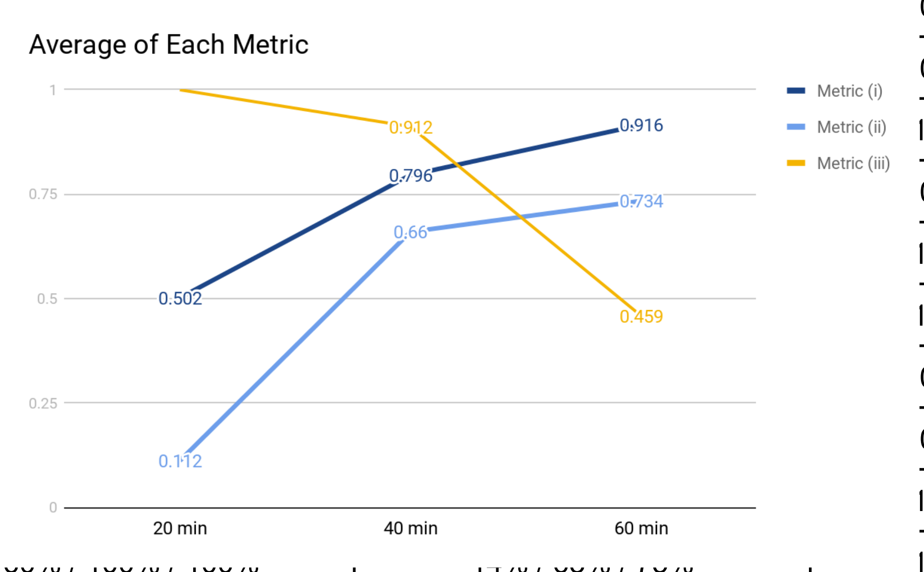
1. **Firezone mapping precision**
   a. Percentage of the firezones mapped by the drones under changing constantly due to dynamic weather conditions

1. **Drone mission completion ratio**
   a. The number of drones completing the entire scenario without being destroyed by fires or terrain.

EpiSci

Result

Scenario ID	Firezone Detection Ratio (i) 20min / 40min / 60min	Firezone Mapping Precision (ii) 20min / 40min / 60min	Mission Completion Ratio (iii) 20min / 40min / 60min
1	[illegible]	[illegible]	100% / 100% / 78%
2	[illegible]	[illegible]	100% / 100% / 56%
3	[illegible]	[illegible]	100% / 89% / 56%
4	[illegible]	[illegible]	100% / 100% / 33%
5	[illegible]	[illegible]	100% / 78% / 56%
6	[illegible]	[illegible]	100% / 78% / 44%
7	[illegible]	[illegible]	100% / 100% / 56%
8	[illegible]	[illegible]	100% / 100% / 67%
9	[illegible]	[illegible]	100% / 78% / 22%
10	[illegible]	[illegible]	100% / 89% / 44%
Average	**50.2% / 79.6% / 91.6%**	**11.2% / 66% / 73.4%**	**100% / 91.2% / 45.9%**



Summary

1. There are 7 states of drone and 4 modules to address the challenges.
    a. INITIAL, SCANNING, SEARCHING, APPROACHING, MAPPING, CHARGING, DEAD
    b. Initial Searching Module(ISM), Firezone Scanning Module(FSM), Terrain Following Module(TFM), Firezone Mapping Module(FMM)

1. After using FSM, drones can collect 37% more information about fire zone.

1. After using TFM, drone survival ratio from terrain is up about 17 percents.

Future work

1. Further reduce the remaining undetected area that needs to be searched.

1. Assign drones to zones more efficiently.

1. Enhance algorithms with remaining battery life constraints.

1. Upgrade Firezone Mapping Module by advanced algorithms such as reinforcement learning.

Q & A