Utilizing Survival Behavior Models to Optimize Path Plotting for Multi-Unmanned Aerial Vehicle (UAV) Swarms in Search and Rescue (SAR)

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"How can we implement an algorithm that takes into account different factors in SAR missions and apply them to multi-UAV systems?"

The goal of our project was to develop an algorithm that would decrease the overall time of finding lost targets in SAR operations by incorporating survival behavior models along with optimized path plotting. We did this by creating a probability map of where the targets are mostly likely to be located and creating an algorithm which searches areas of high probabilities over lower ones, resulting in a decrease of search time. We chose drones to implement our algorithm because they are more efficient than humans and have fewer limitations, and can be equipped with useful technology.

Introduction

Search and Rescue (SAR) operations are important investigative missions that are used in scenarios where an individual goes missing.

- Close to 80,000 individuals in SAR operations with 2,659 fatalities and 24,388 injured in a 15 year period (Heggie, et al., 2009).
- National Park Service reports a 16% increase in the last decade.
- The NPS also reported increasing SAR missions, from 1403 to 1470 from the first half of 2018 to first half of 2021 (Sonken, 2021).
- Time is vital in search and rescue: missing people have high survival rates if found within the first day; survival rates drop to almost zero 50 hours after target is declared missing (Adams et al., 2007).
- SAR missions with drones show a quicker time-to-locate; however, the mission without drones was more successful in terms of finding the target if the drone lacked a proper algorithm or strategy (Eyerman et al, 2018).

Survival Behavior Models

SAR behaviors can be modeled to see how the targets have dispersed within a certain time. Results from experiments on the effect of terrain on movement of a lost person show that the methods to search an area are highly dependent on the landscape of that area (Hashimoto et al., 2022). However, the strategies of the person were not previously considered, but they can now be taken into account with survivability behavior models. Lost individuals tend to stick to geographic paths of least resistance, like trails or rivers going downhill (Phillips et al., 2014, pp. 168-169).

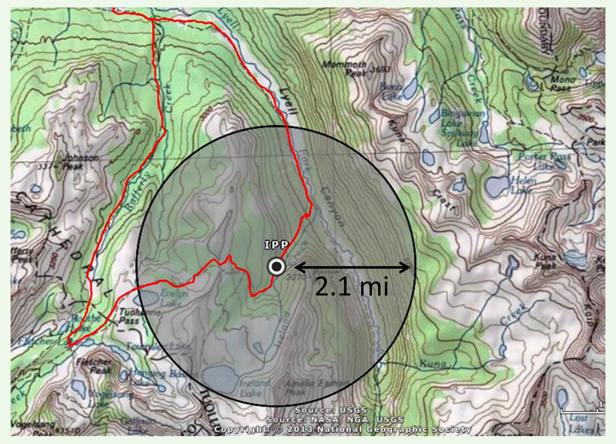

Figure 1: 75% of missing runners are located within 2.1 miles of the initial planning point (IPP). (Phillips et al., 2014)

Probability Maps

In order to utilize the information provided by survival behavior models to search the area in a logical way, we created probability maps to differentiate between high probability areas and low probability areas. These probability maps are given to the UAVs for improved searching. The map is divided into square units the size of the camera coverage from the drone and each identified high probability segment is marked with slowly lowering probabilities as a gradient from the border.

1. Getting the Trail Information:
   a. National Park Service (NPS) API that returns the longitude and latitude coordinates of all trails in a select region defined by the coordinates of the lower left corner and upper right corner.

Figure 2: ArcGIS renders NPS API*

2. Locate Rivers:
   a. Google Maps' API returns a satellite image of the search region. This was passed into a machine learning model created by Verma, et al. which identifies rivers given a satellite image.

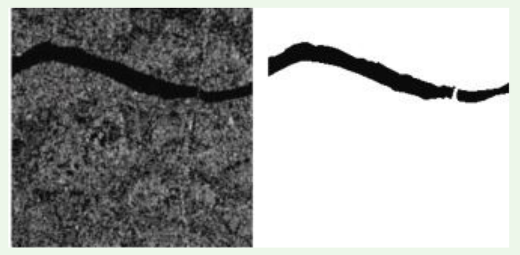

Figure 3: Get River Location (Verma, et al., 2021)

3. Other given information:
   a. We may be provided other information and can adjust our probability map accordingly. For example, we manually inputted the areas of lower ground as areas of high probability

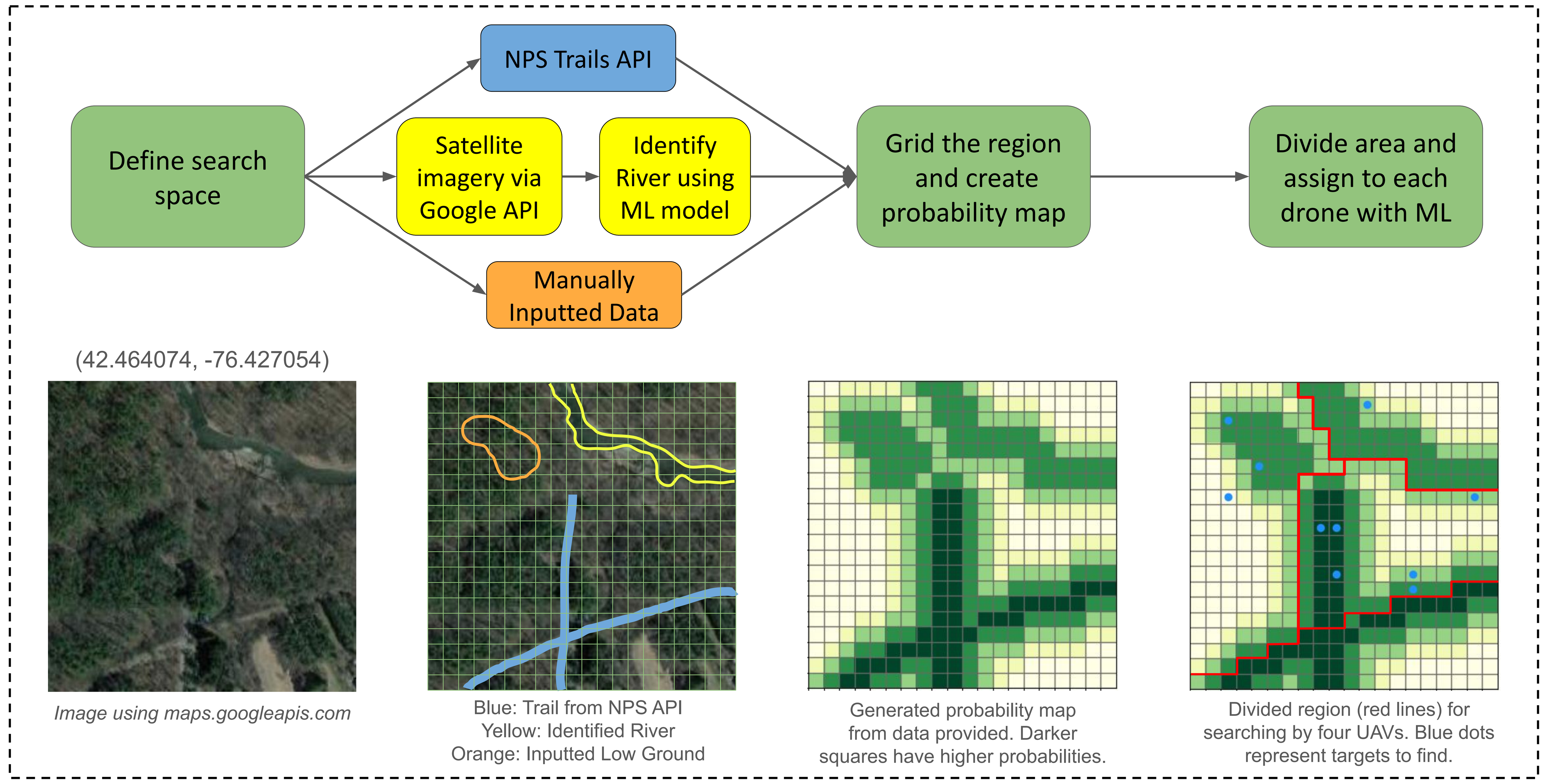

Figure 4: Preprocessing System Flow Diagram*

Results

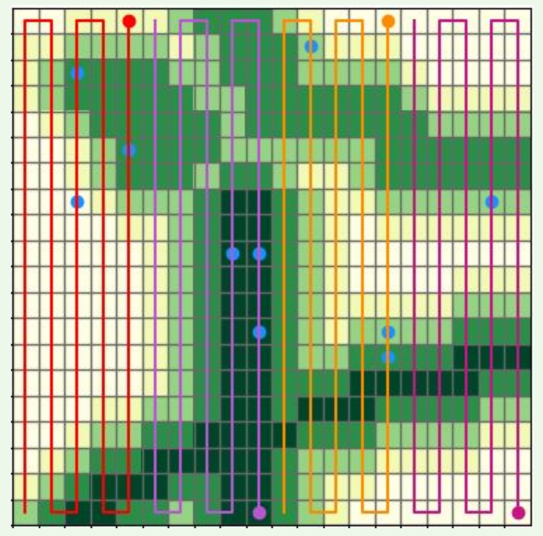

Figure 5: Control Path (Basic Brute Force Procedure)*

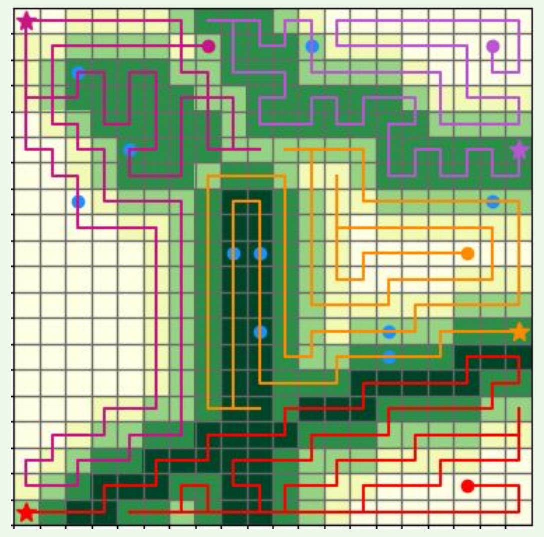

Figure 6: Our algorithm using the probability map*

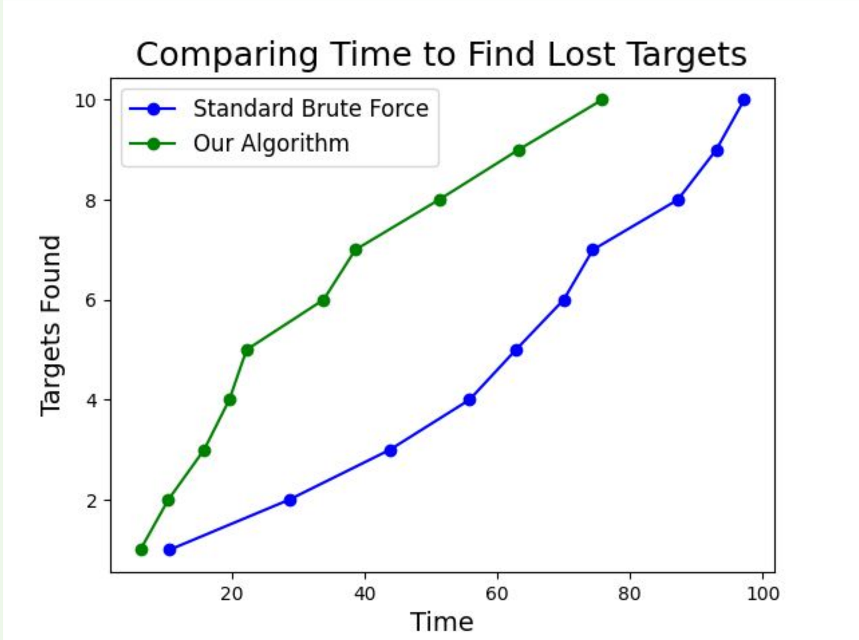

Figure 7: Graph Visualizing our Algorithm Against the Basic Brute Force Search*

Table 1: Raw Data for Standard Algorithm against Our Algorithm*
t = 1 unit of time

Target	Standard (t)	Ours (t)
1	10.6	6.2
2	28.6	10.4
3	43.8	15.8
4	55.8	19.6
5	62.8	22.2
6	70.0	33.8
7	74.4	38.6
8	87.2	51.2
9	93.0	63.2
10	97.2	75.8
AVG	**62.34**	**33.68**

We ran multiple trials, following the same path each time with new pseudo-randomly generated targets. Each trial contained 10 targets. The averaged values for the trials are shown in the table and graph above. It was found that on average, the standard algorithm takes 62.34 units of time to find the lost person, while only taking 33.68 units of time with our algorithm. This is a **46% percent decrease in the operation time**, almost halving the length of the standard operation.

Multi-UAV Swarms

Multi-UAV swarms are more effective than single-UAV systems based on factors such as survivability, scalability, speed, autonomy, radar, and communication. With a multi-UAV system, it is important to segment the area so that there is no overlap. To split the search region among the drones, we follow a variation of a standard practice, segmenting the region based on physical landmarks which were also regions of high probabilities (Phillips et al., 2014).

Path Plotting

Standard procedures don't take into account the probability map and follow a basic brute force procedure for the drone operation. This brute force method serves as our control operation and comparison.

To improve on this, we used our probability map to determine where the drone should go. This problem is a variation on the Traveling Salesman Problem (NP-Hard), so while it is impractical to find the most efficient path, we are looking for a path more efficient than existing solutions. One method is naively visiting the regions in order from high to low probabilities, irrespective of distance; however, this is illogical and leads to high search times due to repeated searching and unnecessary travelling. Our algorithm continues to generally visit areas of high probability over lower ones, but takes distance into account by preferring closer regions over units farther away.

$$p_{new} = \frac{pr_n}{pr_n + (1-p)(1-r_p)}$$

P : former unit probability
p_{new}: new probability
r_n: false negative rate
r_p: false positive rate

Equation 1. Probability updating equation for the probability map

Conclusion

In order to speed up SAR operations, we used an algorithm that factored in the psychology of a target as well as the geography of the environment. With these variables, we were able to show a decrease in the search time, indicating an increase in SAR efficiency. Our research was limited by the inability to test on physical drones, but showed promising results to improve SAR operations in the future. We are working on testing our algorithm using flight simulators and integrating it with Facebook's Detectron2 residual networks (ResNet), a state of the art image classification machine learning model for SAR.

Figure 8: Search and Rescue Drone from DJI (Singh, 2022)

References

Adams, A. L., Schmidt, T. A., Newgard, C. D., Federiuk, C. S., Christie, M., Scorvo, S., & DeFreest, M. (2007). Search is a time-critical event: When search and rescue missions may become futile. *Wilderness & Environmental Medicine*, *18*(2), 95-101.

Eyerman, J., Crispino, G., Zamarro, A., & Durscher, R. (2018). *Drone efficacy study (DES): Evaluating the impact of drones for locating lost persons in search and rescue events*. Brussels, Belgium: DJI and European Emergency Number Association.

Hashimoto, A., Heintzman, L., Koester, R., & Abaid, N. (2022). An agent-based model reveals lost person behavior based on data from wilderness search and rescue. *Scientific Reports*, *12*(1), Article 5873.

Heggie, T. W., & Amundson, M. E. (2009). Dead men walking: Search and rescue in US national parks [Abstract]. *Wilderness & Environmental Medicine*, *20*(3), 244-249.

Phillips, K., Longden, M. J., Vandergraff, B., Smith, W. R., Weber, D. C., McIntosh, S. E., & Wheeler, A. R., III. (2014). Wilderness search strategy and tactics. *Wilderness & Environmental Medicine*, *25*(2), 166-176.

Singh, I. (2022). DroneDeploy flight automation app now supports DJI Air 2S drone [Updated].

Sonken, L. (2021, August). *Search-and-rescue missions growing in national park system*. National Parks Traveler.

Verma, U., Chauhan, A., M.M, M. P., & Pai, R. (2021). DeepRivWidth: deep learning based semantic segmentation approach for river identification and width measurement in SAR images of coastal karnataka. *Computers & Geosciences*, 154, 104805.

* All images generated by student researchers