ARI

Aerial Rescue Intelligence

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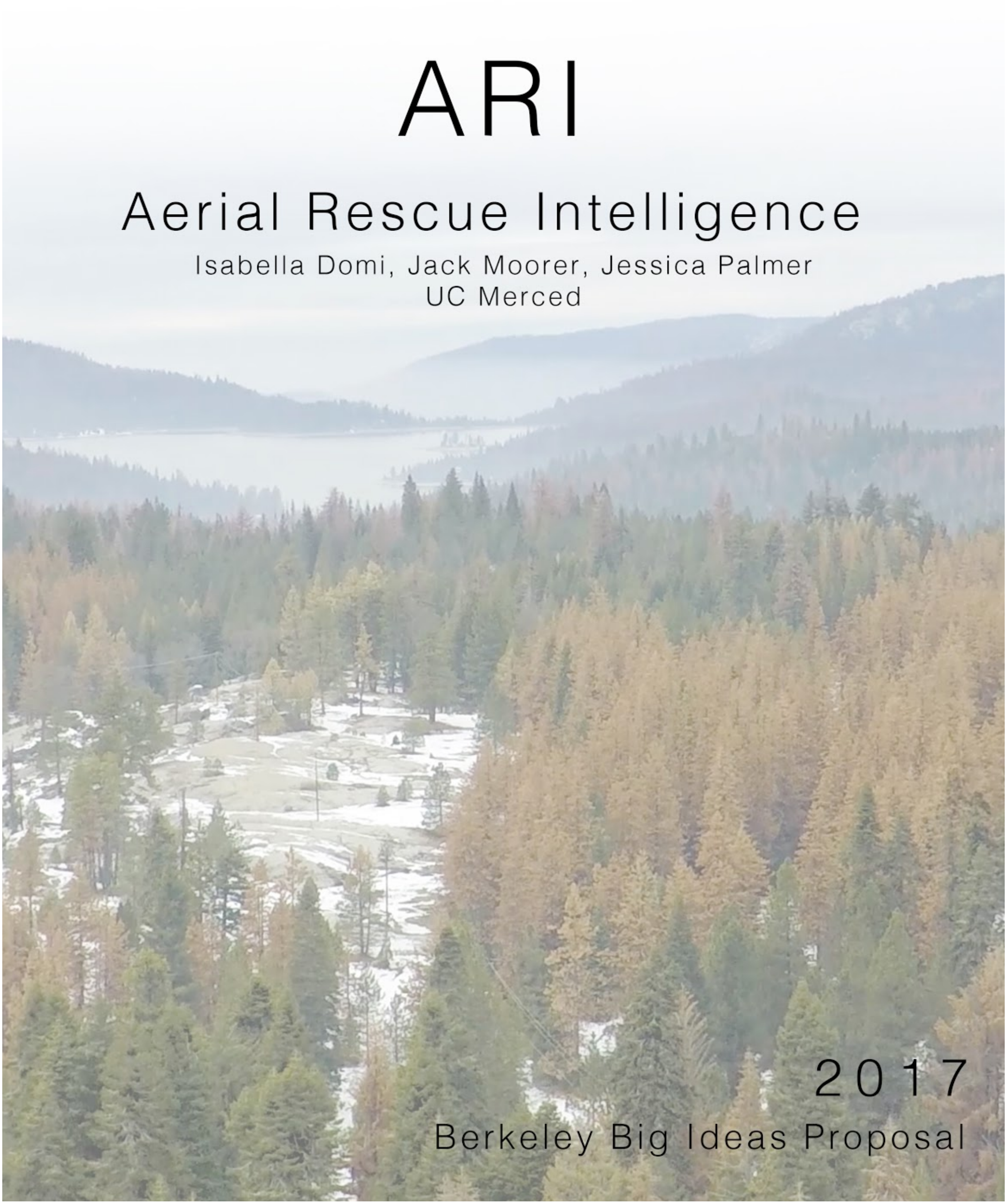


2017

Berkeley Big Ideas Proposal

Contents

1. Problem Statement

As part of the National Park Service, search and rescue teams are crucial for large parks with high amounts of tourist traffic. These search and rescue (SAR) teams are responsible for attending to injured, ill, and lost individuals without charging the affected persons with the cost of the service. One of the most developed SAR teams in the US is located in Yosemite National Park, where SAR rangers and volunteers are on duty 24 hours a day, 365 days a year.[1] To put the number of searches into perspective, a total of 2,650 incidences were recorded throughout the NPS in 2014.[2] Some of the highest number of incidences of National Parks are shown in table 1, where Yosemite totaled 181 incidents in 2014. Of course the most challenging job of SAR is searching for lost or deceased individuals. The process for wilderness search and rescue includes the processes: Locate, Access, Stabilize, and Transport. Locating is the most difficult of the four processes, as "in order to find a lost subject the responder must overlap the subject in both time and space".[3] For large search areas, such as Yosemite Valley, the issue of overlapping space and time becomes impossibly challenging due to the large area and small number of responders. In addition, after 51 hours of searching without finding the subject, the chances of surviving decreases at an alarming rate.[3] Generally, the same search methods have been used by SAR for wilderness searches, which includes having responders walking over large areas of land and, in more serious cases, using trained eyes to search the ground from a helicopter.[4] In fact, the helicopter used by Yosemite Search and Rescue (YOSAR) is not owned by SAR, it is borrowed by the fire department. Various search methods have been created and tested over the years to help increase the chance of finding missing persons using these two methods, such as Probability of Detection and Area which analyze the subject's chances of being found based on factors like lost person behavior and the type of activity the subject was participating in.[3,5] All of these search methods for locating a missing person have been in place for years, but in an age of advanced technology, why are we still using pen-and-paper techniques when the lives of people are at stake?

The answer is funding. Search and rescue departments throughout the NPS are very lacking in funding (the conservation of the park brings in more revenue than saving people). However, the cost of SAR missions has shown to be quite expensive and comes out of the NPS's pocket. The cost breakdown of SAR services at the top National Parks are shown in table 2, with Yosemite being the costliest at $1,228,238 in 2005 alone. For all of the National Parks, "personnel costs accounted for 49.8% of the total SAR costs from 1992 to 2007, and aircraft costs accounted for 49.7% of the total cost".[6] In terms of actual cost for 2005, the total cost for SAR was $4.9 million, with personnel costing $2.3 million and aircraft costing $2.1 million.[6] Clearly, the NPS is putting a lot of money into SAR operations, and therefore any new development that has the potential to lower this cost would be beneficial.

These issues of locating missing persons and budgeting have been taken into account to design a system that solves these problems while ensuring to not disrupt the SAR responders current search methods, but instead improving them. We have designed a product that is low cost, easy to use and integrate, and made to fit the current workflow of search and rescue methods used in the NPS. ARI (Aerial Research Intelligence) is a small unmanned aerial system that can autonomously search the area around an initial planning point (IPP) and quickly detect people using machine learning. Using RGB and thermal video data, ARI is able to determine the images and GPS locations of detected persons using a trained neural network. Data collected from the program is then put into an ArcGIS map, which can be accessed by all SAR personnel on a smartphone or tablet so that they can immediately go out to the locations where a person was detected and make notes regarding the results of the search. Currently, all SAR missions in Yosemite are recorded in detail using ArcGIS, so using this mapping feature will be second nature to the SAR team. With today's technology, we are capable of greatly decreasing the search time while increasing the probability of finding missing persons as well as creating a low-cost solution that can fit into any park's protocol and budget.

Table 1. Search and rescue incidents for national parks in 2014.[6]

National Park	*SAR incidents (2014)*
Grand Canyon National Park	324
Lake Mead National Recreation Area	217
Yosemite National Park	181
Great Smoky Mountains National Park	104
Sequoia & Kings National Parks	93
Assateague Island National Seashore	91
Zion National Park	80
Rocky Mountain National Park	70
Point Reyes NS	62

Table 2. National Park Service units with the highest search and rescue costs, 2005.[6]

National Park Service Unit	*SAR costs*	*%Total NPS SAR cost*
Yosemite National Park (California)	$1 228 238	25%
Sequoia and Kings Canyon National Parks (Colorado)	$476 159	10%
Rocky Mountain National Park (Colorado)	$416 260	8%
Grand Canyon National Park (Colorado)	$400 629	8%
Denali National Park and Preserve (Alaska)	$348 565	7%
Yellowstone National Park (Wyoming)	$280 757	6%
Mount Rainier National Park (Washington)	$236 606	5%
Zion National Park (Utah)	$139 869	3%
Great Smoky Mountains National Park (Tennessee)	$132 943	3%
Wrangell-St. Elias National Park and Preserve (Alaska)	$117 238	2%

2. Existing Solutions

In serious cases, the YOSAR team will use the fire department's helicopter to search for people from an aerial view. For this method, the team on board the helicopter is trained to identify people from the helicopter.[1] Since humans cannot keep attentive for extended periods of time, searching from a helicopter is not the most efficient way to find people from an aerial view. On top of being inefficient for search purposes, it is also costly. In a search in the Grand Teton National Park for two missing persons in 2011, the SAR team had to lease a helicopter costing $33,000, with the total cost of the search totaling to an appalling at $115,000.[7] Note that, as mentioned previously, the missing (or deceased) person is not charged for these services. It was also stated in a report on SAR in Yosemite that "whereas helicopters have certainly revolutionized SAR and have become the vehicle of choice for many SAR services, they have important limitations, including weather, daylight, visibility, cost of operation, and danger to the personnel".[1]

The first National Park to implement drones for SAR purposes is the Grand Canyon, initiating drone use in September 2016. According to Brandon Torres, the National SAR Coordinator with the Grand Canyon UAS program, the SAR team has had great success in using 3DR Solos to search for people and vehicles that have fallen off the edge of cliffs either due to suicides or accidents.[8] All operations thus far have been manual line-of-sight flights (where the drone is always visible to the pilot in the sky), and the park has a total of 9 certified drone pilots. However, due to searching low (around 800 feet deep) in the canyon, it is difficult to spot the drone and so pilots use FPV (first person view) goggles to see the drone's perspective while flying. After flights, the SAR team looks through all image/video data taken from the Solo to hopefully find the missing person or vehicle. However, since this implementation is new it still has various issues, for example people searching through large amounts of data will inherently make mistakes. Also, using a thermal sensor to detect people is nearly impossible in areas that become very hot during the day like the Grand Canyon, however, flying at night might solve this issue and show clear heat signatures of the missing person via the thermal camera.

Following suit, the National Park system of California has purchased about 250 3DR Solos in September of 2016 to implement in uses such as SAR, vegetation, wildlife, 3D modeling, multispectral imaging, and LIDAR.[9] The NPS also has agreements with the FAA to fly drones for these specific purposes, and must request COA's (certificate of waiver or authorization) for flying out of line-of-sight. As reported by Bradley Koeckeritz, Division Chief of UAS for the U.S. Department of the Interior, setting up ground control stations and getting rangers trained to be drone pilots has been quite easy to do. Contributing to this easy implementation, the DOI has an official sUAS training session for NPS rangers.[10] Since the adoption of drones for the NPS is still so new, methods of drone integration in SAR are still being worked out. It was also noted that the DOI owns FLIR thermal sensors for the drones, but has not yet used them for SAR missions. Although the National Park system is inexperienced with using drones in SAR, they do own a large quantity of 3DR Solos and are willing to push this into further development. Having the correct platform in stock already, ARI would just need to be included in the ground control station used for SAR missions.

3. Proposed Innovation

3.1. How it Works

Our sUAS is unique in that it uses a trained neural network to detect people from a video feed, giving efficient and instantaneous results during the search. However, for the final product, the neural network will be trained using Amazon Web Service (AWS) Machine Learning, which allows for easy remote predictions of data using an API. The built-in API capabilities allow the user to obtain data from the neural network without having the computer hardware needed to run it. The network is trained from video and image data collected from aerial imagery containing people (positive images, figure 1) and non-people (negative images, figure 2). To further increase accuracy, other data sets not containing aerial images of people were also used to train the data set. In deep learning applications such as this, the more data the system has to train on, the more accurate the results. Therefore, all data collected from SAR missions using this UAS would be put into the neural network to continue training so that the accuracy of the predictions is always increasing.

Figure 1. Positive images (images with people).

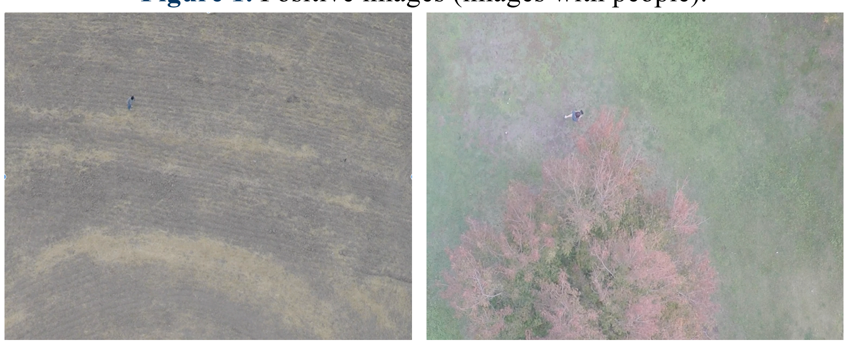


Figure 2. Negative images (images without people).

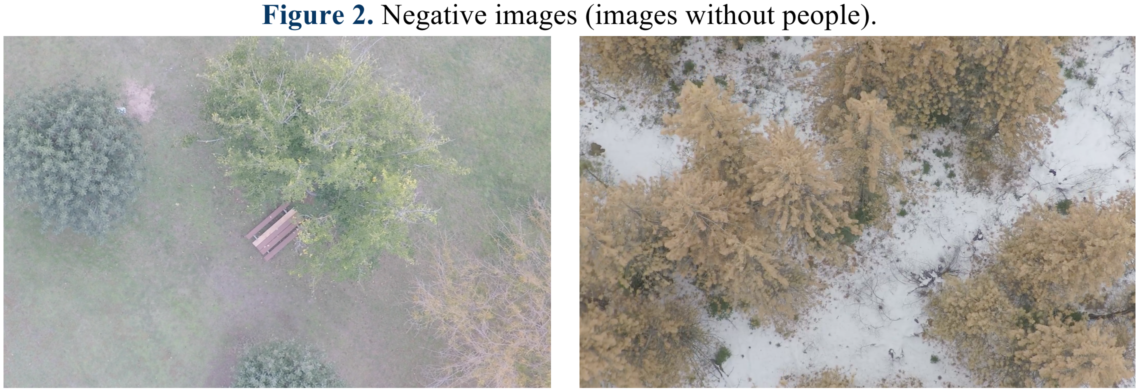
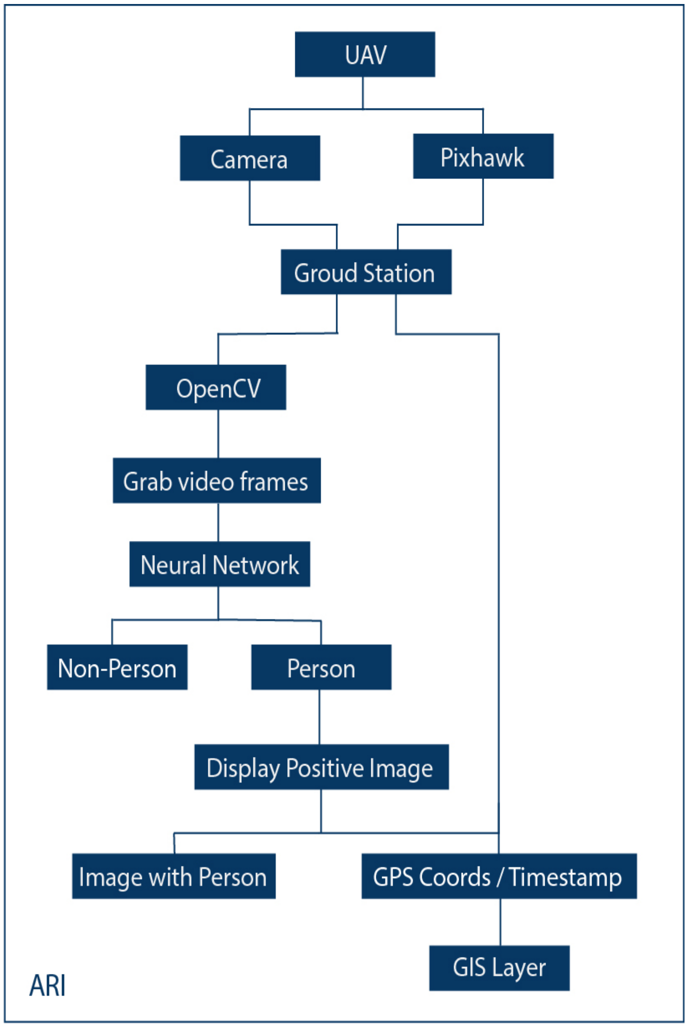


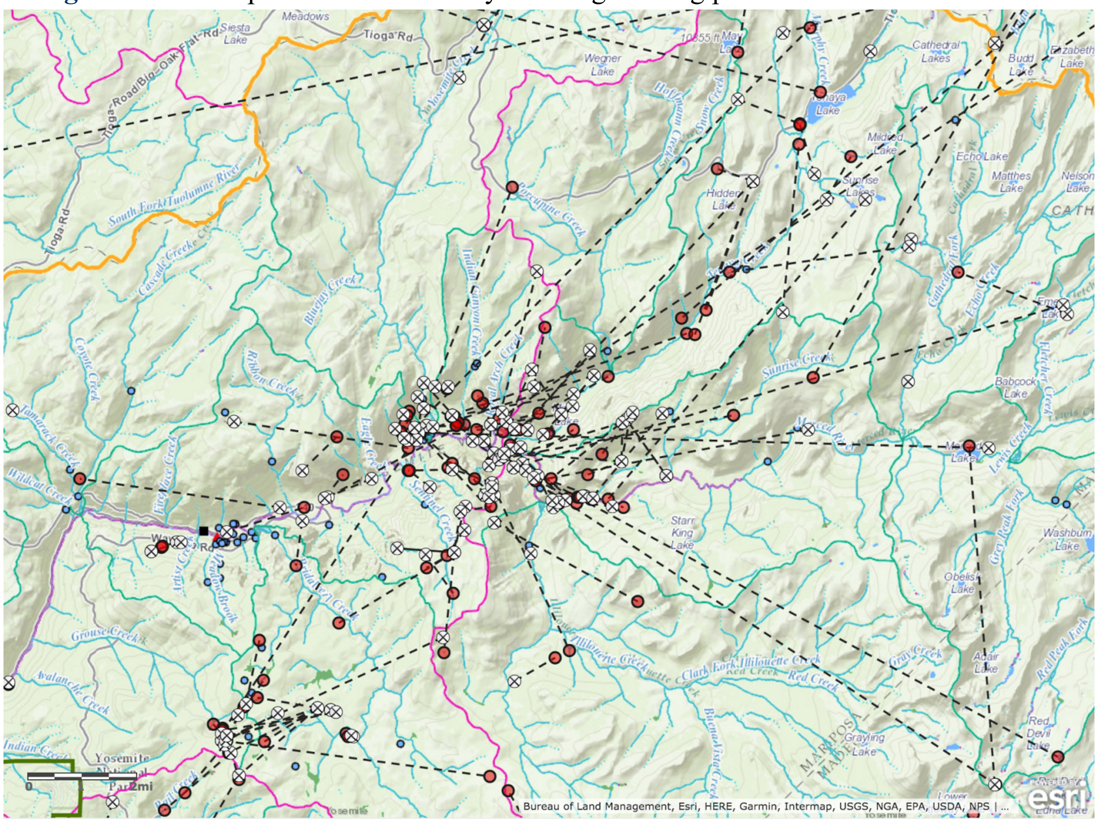
Figure 3. ARI program flow chart.



The complete system workflow, shown in figure 3, would involve a UAV and ground control station. The UAV platform will be the 3DR Solo, a small and easy to operate quadcopter that the NPS is already using for SAR missions; therefore, our system would be easy to implement on this already existing platform for National Parks.[9] The 3DR solo's battery life is approximately 20 minutes; although short, it is plenty of time to efficiently scan the near area. Extra batteries will be available in the case that a larger search area is appropriate. A smartphone or tablet will be connected to the Solo to perform autonomous flight paths using the 3DR app. For searches conducted during the day, an RGB camera will be used as well as a FLIR thermal sensor. Both the RGB camera and thermal sensor will record video and be processed through the neural network API post flight. Having two forms of imagery increases accuracy; in some cases, the RGB camera will see a person better, and in other cases the thermal will be preferred. For example, missions at nightfall and during the night will utilize the thermal sensor to detect the heat signatures of people. With current thermal sensors, it is possible for the drone pilot to fly at night using the live thermal video feed.

After the flight is completed, ARI will connect to the Solo's Wi-Fi and take GPS data from the Pixhawk flight controller of the Solo. Video recordings from the microSD cards of the cameras will then be put into the ground control station computer, where ARI will split the video into frames and cut up each image frame into smaller images in order to obtain more accurate classifications. These smaller images are then run through the neural network API to detect people. Once all image data is processed, the program will display all positive images found along with their respective GPS location and percent accuracy from the neural network. This positive image data is then transferred to a GIS (geological information system) layer, where a point on the map indicates the location at which the positive image was found, and a color system indicates how accurate the neural network's prediction was. For example, the percent accuracy could be displayed in terms of color (red is highly accurate at 90-100%, yellow is moderate at 70-89%). An example of a GIS layer from YOSAR is shown in figure 5, where the red points are where located people are found and the white points are the IPP. As Yosemite SAR is already using GIS maps to collect data, this would be a simple way to integrate ARI without disrupting YOSAR's current methodology. We will also be using the ArcGIS mobile app Collector, which allows ARI to show results of the neural network via smartphone or tablet. By adding this feature, the SAR team can head out to locations where the missing person was found shortly after the flight is conducted and record notes on the GIS map of the locations visited.

Figure 5. GIS map of Yosemite Valley showing missing person data from 2000-2011.[11]



3.2. Intended Use

After discussing the project details with John Dill, one of the first members of the Yosemite Search and Rescue (YOSAR) team, and Paul Doherty, a previous UC Merced PhD graduate that has worked with YOSAR on SAR methodology, the exact uses for our drone system was modified to best help the search and rescue team's needs.[5,12] The intended use of this system is now to perform a quick search surrounding an initial planning point (IPP) or targeted area. When beginning a search, the SAR team will decide upon an IPP based on factors such as where the person was last seen.[13] The targeted area is related to another guess on where the person is based on their activity; e.g. a climber would be on a cliffside, a hiker would be on or near a trail. At the IPP or target area, a pilot from the SAR team can deploy the drone and either fly manually to get a view of the area, or set up an autonomous search radius to survey. Another use would be getting an aerial view of a deceased person that fell in a hard to reach area, or for searching an area that helicopters would be limited in.

3.3. Logistics

All SAR rangers are required to have a pilot's license, and it would therefore be possible to have some rangers receive a drone pilot's license.[9] National Parks in California, such as the Grand Canyon, are currently using drones for SAR and already have certified drone pilots. The drone pilot license is easy to obtain for rangers that already have airspace knowledge; it is currently $150 and requires a 60 question exam on airspace and drone regulations.[14] Since FAA drone regulation is relatively new, most National Parks have a ban on drone use. However the Department of the Interior added a regulation that, as of August 2014, allows for "administrative use of unmanned aircraft as approved in writing by the ADVRP for such purposes as...search and rescue operations, fire operations, and law enforcement [by] NPS personnel as operators or crew [and] cooperators such as government agencies and universities that conduct unmanned aircraft operations for the NPS".[15] The National Parks have also acquired a separate COA (certificate of authorization) from the FAA allowing them to operate under these excluded purposes.[16]

3.4. Implementation and Challenges

The first year of development would involve more research such as taking more data imagery to train the neural network, getting the program running with real time video from the drone, and test searches to see how the system performs. Further research would involve talking to more SAR teams about their search methods and how they could see a drone being implemented in their process. It would also be possible to visit the SAR team in the Grand Canyon to see how they have successfully brought drones into SAR, as well as how they can improve in the use of UAS in SAR. Throughout the entire course of the year, test data will be taken in order to continuously increase the accuracy of the neural network; this includes taking data in varying terrain including land in Yosemite. Before testing the entire system, the program needs to be completed and modified to fulfill the expectations of the system. This includes processing the video feed from both the RGB camera and thermal sensors and displaying the found person image frame on screen with GPS location and time stamp. In addition, the data collected from a mission would be used to create a GIS map layer and create points where the positive images are found (images containing the detected person). Once the program is fully functioning, tests will be conducted by performing searches of a person hidden in a nearby location. Through these tests, modifications will then be made to fix any issues and improve the system. Other testing would involve flying at different altitudes to determine the optimal altitude for data collection.

From our previous research with using a neural net to detect people, we understand that the neural network is not completely reliable, especially in its early stages of training. We did receive a large number of predictions that detected people in image data with no person, however this is just a result of the data set not being large enough. Another challenge is the terrain; some terrain, like heavy tree coverage, will be extremely difficult to detect people. However, this is one instance where the thermal imagery takes over to view heat signatures through difficult vegetation. Previously, authorization to fly UAVs in National Parks and State Parks was an issue, but within the last year various parks are obtaining COAs that allow drone usage for specific purposes like search and rescue. In terms of hardware, the limited battery life of the Solo and difficulty flying in strong weather conditions can also pose to be a challenge. The battery life is not much of a challenge, as a new battery can be quickly swapped and the mission can continue where it left off. For serious weather conditions, however, flights will most likely not be conducted.

3.5. Future Development

Although ARI is designed to search for missing people for SAR applications, the concept of the product can be used for a multitude of applications. Within National and State Parks, a ARI could be trained to detect wildlife for research purposes, and possibly be able to count the number of desired animals in a given region. It could also be applied to the Law Enforcement department for security purposes and detecting illegal drugs and wanted persons. For pure animal research purposes outside parks, ARI could be especially helpful for detecting or counting ocean animals.

4. Implementation Timeline

The initial plan for ARI as a business will be to hire a larger team to work on software development. During June through December, the team will perfect the image processing code using OpenCV, set the program up to AWS and Amazon's Machine Learning Service, and be able to input the GPS and accuracy data into ArcGIS. The team will also make sure image data from missions is sent back through the neural network to train it further.

We will also initially be purchasing the 3DR Solo, RGB camera, and FLIR Vue Pro thermal sensor for purposes of development in this early stage. Since this hardware is already owned in large quantities by the DOI, we will need to make sure ARI is made to work with the given platform. The hardware is also crucial in collecting data and ensuring that the program can process the video and GPS data correctly. Throughout the course of the first year of work, data will be collected in order to increase the accuracy of the neural network.

Beginning January 2018, we plan to integrate the hardware and software in order to perform test flights. From January up until June, test flights will be conducted in order to find errors in the system so that we can effectively make improvements. These test flights will be performed in various terrain including Yosemite National Park, as we have permission to test the system with YOSAR once it is running. Once the flight process is near perfected, instructional documentation on how to operate the system and integrate it into a SAR program will be written for users.

By next June of 2016, we would like the system to be used and tested by the Yosemite Search and Rescue team, and possibly other SAR teams, to obtain feedback to further improve the system. By this point in time, we plan to partner with Esri to maximize our use of their system.

5. Budget

We will be using the 3DR Solo as our drone platform seeing that the National Park system of California currently own 250 of them, therefore it will be simple to implement our program on the already existing platform. The Solo holds a maximum payload of 420g, which allows us to have a GoPro (83g) and FLIR Vue Pro thermal sensor (113.4g) together on the drone. The GoPro Hero4 Black is capable of shooting up to 4K video; higher quality will translate to higher accuracy for the neural net.[17] A 3.97 mm non-distorted lens from Peau Productions will be fitted to the GoPro so that the images are not distorted from the fish-eye shape of the original GoPro lens. The FLIR Vue Pro is made specifically for sUAS applications, and can have up to 640 x 512 resolution with a 19mm lens; in the thermal sensor world, this is very high quality.[18] All mentioned hardware is shown in figures 6-9 below, followed by table 3 breaking down the cost of each product.

Figure 6. 3DR Solo quadcopter.

Figure 7. FLIR Vue Pro (thermal sensor).

Figure 8. Gopro Hero 4 Black (RGB camera).

Figure 9. 3.97mm non-distorted lens.

Table 3. Cost breakdown of hardware.

Product	Cost
3DR Solo	$392
GoPro Hero4 Black	$350
FLIR Vue Pro	$3,500
3.97mm lens	$140
Total Cost	*$4382*

In terms of software, we will be using Amazon Web Services (AWS) for storing the neural network and image data. We will also be utilizing Amazon's Machine Learning service, so that the ARI can easily connect to the API of the neural net. AWS Glacier will be used for the storage and backup of all data collected from missions with ARI, which costs $0.005 per GB per month.[19] As for the Machine Learning service, it costs $0.42 per hour of model building and $0.10 per 1,000 predictions.[20] Batch predictions allow us to run a large amount of predictions at once and receive the results after all predictions are generated, and the results can then be accessed immediately after computation through the API. The cost of using AWS will be quite low for the beginning of product development, until a larger base of customers are using ARI for data storage and batch predictions.

6. Market and Revenue

According to Andrew Hower, Deputy Chief at the NPS, the NPS has over 400 park units with SAR capabilities.[21] This gives over 400 potential users of ARI throughout the National Park Service alone, which does not account for county Sheriff departments, and other areas that could benefit from the product. According to the National Department of State Park Directors, there were 10,234 state parks in 2014.[22] Additionally, from the California Department of Parks and Recreation, all State Park rangers are required to have knowledge of search and rescue methods.[23] This opens up our market to both National and State Park SAR departments for search and rescue missions.

As the first year is to be utilized for research and development, we do not expect revenue for this time period. However, the Yosemite Search and Rescue team as well as the Department of the Interior have shown interest in the system, so it would be viable to have them be the first customers in the following year. Since the National Parks in California already own the drones, cameras, and thermal sensors that our system requires, we would only be selling a license for the program for each SAR team. As a cost estimate, assuming half of the parks in the US purchase a year license of ARI for $500, we would be making $260,000 in that year. Alternatively, we could potentially have a yearly contract with the DOI so that they can distribute the licenses to the respective SAR teams throughout the National Parks.

7. Measuring Success

The provided timeline for the first year of integration will guide as a way to track the progress of ARI's development. Given that we have been working on ARI since September of 2016, another year of research, development, and testing is more than reasonable to achieve a full product. Once ARI is up and running for SAR missions, we can measure success based on how many missing persons we are able to detect.

8. Team Members

Isabella Domi, Team Lead
Mechanical Engineering and Physics, UC Merced

Licensed sUAS pilot who is capable of collecting data and test flying UAVs. Also has contributed to product development and the data processing programming. Has experience with group engineering projects from working on the SpaceX Hyperloop pod competition, and experience working with UAVs at UC Merced's MESA (Mechatronics, Embedded Systems and Automation) Lab.

Jack Moorer, Program Developer
Applied Mathematics and Actuarial Sciences, UC Berkeley

Has experience in python, Java, HTML, R, and CSS and has contributed to the data processing programming of the system as well as GIS integration.

Jessica Palmer, Data Collector and Policy Advisor
Mechanical Engineering, UC Merced

Licensed sUAS pilot who has contributed to data collection and ensuring that the UAVs are fixed and in good condition to fly. Has experience working with UAVs from working at the MESA Lab.

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