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A Drone-Based AI Solution for Smart Park Management

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ABSTRACT: San Diego's Black Mountain Open Space (BM) Park struggles with the severe challenges of wildfire and vegetation management because of its largely inaccessible 2,350-acre terrain and rugged environment. This project proposes a drone-based, Artificial Intelligence (AI), and Geographic Information System (GIS) integrated system to address these challenges. The system applies high-resolution drone imagery analyzed by AI algorithms to identify dry plants, seedlings, and fire-prone zones automatically. It uses GIS to interpret the imagery and produce 2D and 3D terrain mapping for further analysis, which will enable park rangers to preempt fire-prone areas and monitor dry plants, seedlings, and invasive species. The system can also be used in real-time video detection to aid decision-making and improve response time. The results showed that the Drone-AI-GIS integrated system is capable of scanning massive areas at least five times faster than manual labor while also providing actionable information in real-time for the park ranger to act, and that the system can be easily adapted to other parks or scaled to a much larger application area.

KEYWORDS: Environmental Science, AI Technology, Wildfire Mitigation, Vegetation Management, Drone Imaging.

Introduction

Drone imagery and AI have been leveraged for vegetation and fire risk monitoring.[1-4] For example, Turner et al. utilized drones equipped with multispectral cameras to monitor the health and distribution of vegetation in environments that are challenging to access using traditional methods;[1] Zhang et al. showed that AI models are highly able to automatically detect fire-prone zones in real-time by incorporating surrounding environmental factors such as wind, humidity, vegetation status, and can help predict and identify fire outbreaks with high accuracy.[2] However, even though those studies show the advantages of drone technology and AI respectively, what is lacking in the currently available research is a fully integrated system that combines the power of drones, AI, and GIS for smart park management that is capable of 3D GIS mapping, real time video detection, AI driven fire risk mitigation, detailed GPS logging and future automation. By integrating those technologies, this proposal will not only improve short-term operational efficiency but also ensure long-term sustainability in park management, allowing for better monitoring of the health of plants and more effective mitigation of wildfire risks.

BM Park's over 2,350 acres of rugged land have been facing severe challenges in vegetation management and wildfire risk mitigation due to its dense vegetation and highly diversified terrain. Currently, park rangers and volunteers are forced to rely on manual methods to monitor the vast majority of the park to identify the areas that require planting, watering, or attention for wildfire risks. However, these manual methods are time-consuming, labor-intensive, and often unsafe, especially in the vast majority of the unwalkable areas. On top of these challenges, BM Park is classified as a Very High-Risk Fire Zone by Cal Fire,[5] and thus there is an urgent need for fire risk monitoring.

Given these challenges, traditional methods of vegetation management and fire risk mitigation are no longer feasible. Manual monitoring done by park rangers and volunteers cannot keep up with the rapidly growing needs of the park, the complexity, and the diversified terrains. The current approach is to walk through the park's massive terrain and rugged terrains, check plant health status, identify invasive species, dry plants, and locate areas of stressed plants and seedlings' health. This approach is not only highly labor-intensive but also dangerous, especially when dealing with vast areas, steep slopes, and vegetation-dense areas and invasive species.

Aware of the inefficiency of the manual approach and given the rising challenges, I decided to develop a technical solution to address these rapidly growing problems. In this project, I propose a drone-based, Artificial Intelligence (AI), and Geographic Information System (GIS) integrated system to address the challenges of both vegetation management and wildfire risk monitoring at BM Park. This integrated system utilizes high-resolution drone imagery, GIS technology to map out terrain, and AI-based analysis to automate the detection of dry plants, invasive species, and fire-prone zones.

Methods and Procedure

Traditional manual monitoring methods suffer from inefficiencies and safety concerns. A new system was designed to address those limitations while also enhancing the overall effectiveness of park management. The methods used to address the objective include Drone design, AI model design, and the use of GIS for 2D and 3D terrain mapping.

Initial Planning and Setup:

The first phase involved an initial survey of the park to determine areas with severe vegetation issues and wildfire-prone risk zones. Based on the results, certain regions of the park were

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chosen for detailed study. Specific areas were selected based on the presence of dry plants, seedlings, and high-risk fire zones. Drone model and camera specifications were selected by considering the terrain and vegetation within the park.

Drone and System Setup:

The drone system was designed and assembled, including four brushless motors and propellers, a Pixhawk flight controller, a transmitter, and a GPS module. A high-resolution camera was added to capture images and videos. The total system cost was approximately $700. The frame and most of the parts were purchased as a kit from the Holybro store and Amazon. Some modifications were made to the foot stand and camera mounting system to ensure stability and reduce vibration. The drone system was programmed and calibrated to enable stable flight and image capturing of the park (Figure 1). All necessary flight planning and control software were installed to enable seamless operation of the drone. System calibration was carried out to keep the drone stable in the air and make sure the data I got was useful.

(a) (b)

Figure 1: (a) Electrical diagram of the drone system, including four propellers, a flight controller, a transmitter, a GPS, and a camera. (b) Complete system after assembly. This drone system enabled stable flight and image capturing of the park.

Flight Planning:

The project was conducted under the FAA's recreational drone flight rules. I completed the TRUST (The recreational UAS Safety Test) certification and received approval from local park authorities before flying the drone. The mission planner software was set up to allow seamless autonomous flights based on the specific flight path required to scan the park regions. Test flights were conducted to determine drone flight quality and performance during the missions. The flight results were analyzed, and necessary adjustments were made to improve flight performance.

Data Collection:

After configuring the flight path and optimizing the flight parameters, the drone was deployed to capture images and videos of vegetation and fire-prone regions of the park. To ensure the image quality, all flights were conducted in clear weather with wind speeds under 10 mph. Field test confirmed that the drone system is capable of continuously capturing images and videos along the pre-programmed flight path.

(Figure 2). Images of the park regions were captured during the flight missions, and the georeferenced GPS information was recorded for each image location. The raw data were pre-processed to ensure the images were properly aligned and of good quality for the next phase of analysis. It was also ensured that the drone flight covered all targeted areas by capturing overlapping images during the flight to ensure full coverage and no gaps or missing data in the images. This provided comprehensive data for image analysis using AI and GIS.

(a) (b)

Figure 2: (a) Pre-programmed drone flight path for scanning. (b) Drone in flight. Field test confirmed the drone system's capability of continuously capturing images and videos along the pre-programmed flight path.

Data Processing and Analysis:

After finishing the drone flights, I checked all the photos for clarity. Then WebODM 6 was used to make 3D terrain models. It gave us a more direct view of the plants' condition and showed the places that may be in danger of fire. Next, I marked the photos with precision by identifying dry plants, small seedlings, and fire-prone sections. This labeled dataset was then used to train the YOLO model.

AI Model Training and Deployment:

YOLO[7] (You Only Look Once) is a deep learning object detection model known for its real-time performance. In this study, the YOLO model was trained with those labeled pictures, so the model learned how to see dry plants, seedlings, and high-risk fire zones. After training, I compared the AI-detected results with data from field surveys to check accuracy. Additional training images and training cycles were added to improve detection accuracy.

Automated Detection and Analysis:

When the model was ready, I used it on the drone photos and videos. It could detect dry plants, seedlings, and possible fire zones by itself, and give useful information for park workers. Each detection was cut out as a small photo, and the GPS location was also saved, so rangers can find the spot and check or remove the risks later.

Final Mapping and Reporting:

Finally, I put all the data into GIS software to make 2D and 3D maps of the park. The maps showed where the plants are dry and where the fire risk is higher. Rangers can use these maps to inspect the whole park and decide what action to take. All the maps were integrated with GPS coordinates recorded by the drone. The 3D map gave a clearer view, so it helped rangers to make better choices for managing plants and preventing wildfires.

System Testing and Validation:

To test how well the system works, I flew the drones in different places in BM Park. The images were processed with the

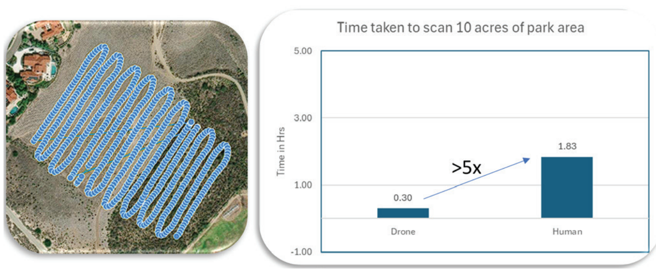
AI model and GIS, and then compared with manual survey data. The system proved capable of detecting fire risk areas, dry vegetation, and seedlings while its 2D/3D mapping function enhanced the speed and efficiency of monitoring operations.

Results and Discussion

System Efficiency Test:

To evaluate the system's performance, I conducted a test over a 10-acre area of the park. The drone flight speed was reduced to 5mph to ensure high-quality video and images. I recorded the time it took for the drone to complete the scan and compared it with the estimated time a person would need to walk the same area while searching for dry vegetation or fire hazards.

Our results indicate a tremendous improvement in efficiency. The drone took only 18 minutes (0.30 hours) to scan the 10-acre area, while a human needed 110 minutes (1.83 hours) to do the same, or a sixth of the time, as shown in Figure 3. When scanning the entire 2,350-acre BM Park is considered, the drone system could reduce the scanning time from roughly 430 hours by a human to only 70.5 hours without even factoring in the 1,554-foot elevation and unpredictable terrain (Figure 4). The drastic reduction in scanning time solo demonstrates the efficiency of the drone system in performing large-scale vegetation management and wildfire risk mitigation tasks, which were previously time-prohibitive.



(a) (b)

Figure 3: Comparison of the time taken to scan 10 acres of park area. The drone-based system drastically improved the efficiency of park monitoring tasks, reducing the scanning time by at least five times compared with manual surveys.

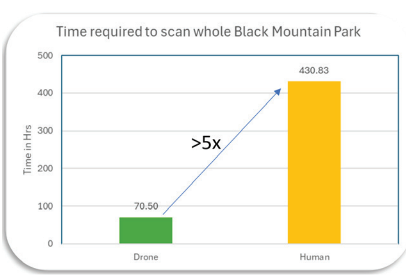


Figure 4: Comparison of the time required to scan the entire BM Park. The drone-based system can reduce the time needed to scan the whole BM Park area by more than five times compared with manual surveys.

Full Coverage and Hard-to-Reach Areas:

One of the most significant advantages of the drone-based system is its ability to scan previously unscannable, hard-to-reach places. This is because traditional methods of manually identifying fire risk areas, dry plants, and other vegetation management issues are limited by terrain and human capability, especially in areas with steep inclines and dense vegetation. In contrast, our drone is not limited by these obstacles and can easily scan most hard-to-reach areas. The ability to scan hard-to-reach areas ensures previously unidentified critical fire risk zones, dry plant patches, and other vegetation management issues can be identified without exposing rangers and volunteers to danger.

Additionally, another advantage is that drone-based methods provide a continuous and uninterrupted stream of data and analysis that can be used to monitor large areas. Drones can cover vast areas and can be programmed to operate autonomously during the entire flight, allowing for more flexibility and less human involvement.

Detailed and Accurate Data Collection:

In addition to drastic efficiency gains, the drone-based system provides park management with more detailed and accurate data. The high-res drone camera images and videos are processed with AI and GIS to produce detailed 2D and 3D terrain park maps, which are used to monitor vegetation health, distribution of dry plants/wildfire risk zones, seedlings' location, and other characteristics. These maps allow remote monitoring of the entire ecosystem's vegetation health and accurate identification of wildfire risk zones for timely mitigation.

More than 2,000 drone images were processed in this study. 2D and 3D terrain maps were created using WebODM and QGIS software, for rangers to monitor the ecosystem/ wildfire risks remotely and efficiently (Figure 5).

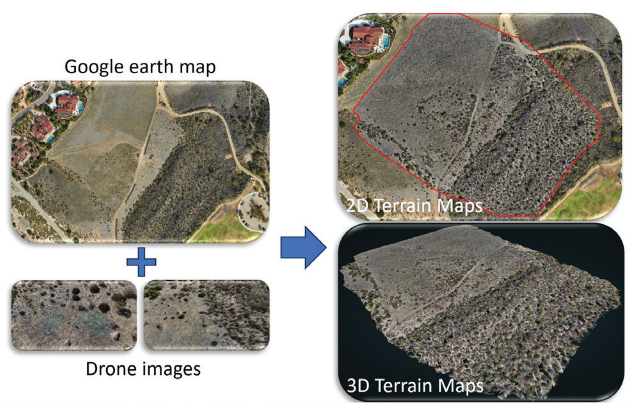


Figure 5: 2D and 3D Terrain Maps generated from drone images. 2D and 3D Terrain Maps were created from the drone images using WebODM.

In addition, the Difference Vegetation Index (DVI) model has also been applied to assess vegetation health (Figure 6), which further improves its capability to indicate areas that need further attention. The surface model was also produced to display the 3D view of the terrain, which can show the changes in elevation and other geographic features (Figure 7).

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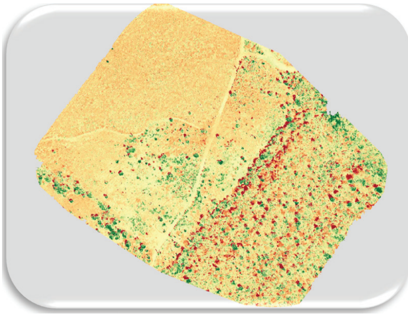

Figure 6: The Difference Vegetation Index (DVI) of plant health. The DVI model was created to show the vegetation health in the area studied.

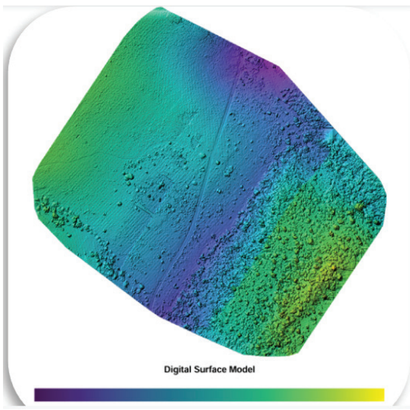

Figure 7: Terrain surface model. The model was created to show the changes in elevation of the area.

AI Model Training and Detection:

Central to the system is the trained YOLO AI model, employed for real-time object detection on drone images. This model was trained with a dataset of over 200 manually labelled drone images and optimized by utilizing different data augmentation and tuning the hyperparameters of the model to improve the accuracy of the model, as shown in Figure 8. The plot indicated consistent convergence of the model, supporting the model's robustness in detecting dry plants, seedlings, and fire-risk spots.

Despite a relatively small dataset, the model demonstrated 100% accuracy in the detection of fire-risk spots and seedlings. The accuracy demonstrates the efficacy of AI in determining the critical spots in need of attention in wildfire management and vegetation health.

The model also achieved over 80% accuracy in detecting dry spots. This may be attributed to the large variation in the look of plants due to the different plant and tree species in the park, which can be improved by collecting additional data and further training of the AI model.

The trained model was then used to examine the drone images to identify and mark the dry plants, seedlings, and the fire risk zone, as shown in Figure 9. A cropped image of each instance of the object was saved, along with the recording of each GPS coordinate for further review and analysis, as shown in Figure 10.

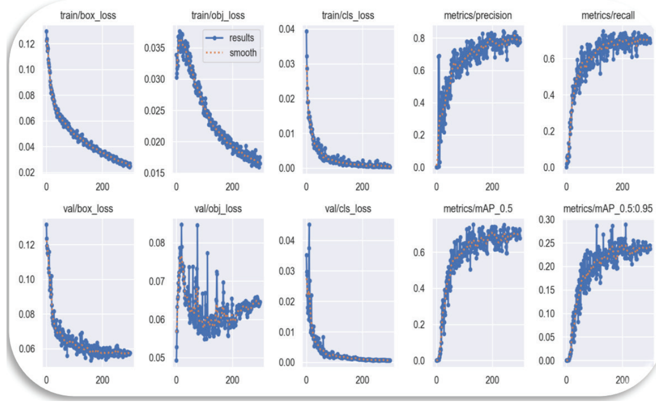

Figure 8: Yolo model training plots. The plot indicated consistent convergence of the model, supporting the model's robustness in detecting dry plants, seedlings, and fire-risk spots.

Figure 9: Yolo model detection examples of fire risk spots/dry plants/seedlings. The trained Yolo model identified and labeled dry plants, seedlings, and fire-risk spots in drone images.

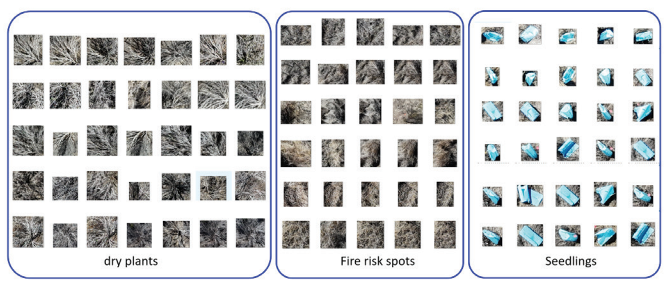

Figure 10: Cropped image examples of fire risk spots/dry plants/seedlings. The trained Yolo model generated cropped images of those detected objects in the images for further analysis.

Real-Time Video Detection and GIS Integration:

The drone system can also analyze live video and, when paired with GIS tools, gives rangers the information they need to respond quickly. Having this kind of real-time feedback is especially important for reducing wildfire risks, since it makes it possible to catch problematic areas early and step in before things get worse. The system also logs the GPS location of each spot, turning observations into clear action points for park rangers to follow up.

Conclusion

This pilot project showed that the drone monitoring system at BM Park functions as an effective tool for vegetation management and wildfire risk assessment. The combination of drone imagery with AI and GIS technology enables the park to handle land management tasks more efficiently while detecting dry vegetation and fire danger areas with enhanced precision.

The system delivers four main advantages in park management. First, the system enhances operational efficiency by more than five times when compared to traditional manual methods of park management. Park managers often face limited staffing and competing priorities, making it difficult to conduct regular in-person inspections across large areas. The system enables park rangers and volunteers to conduct rapid inspections and access challenging locations, which enhances their safety during operations.

In addition, the system enables real-time wildfire monitoring through its data collection capabilities, which helps identify fire-prone areas before they become dangerous. The system provides faster emergency responses through its automated monitoring system, which reduces the need for human intervention.

The system also enables precise detection of dry plants and seedlings, which leads to better resource management and enhanced vegetation care.

Furthermore, the system maintains the ability to expand its operations to bigger park areas. The addition of automated drones for watering and weed control in the future will enhance park management efficiency.

Overall, the system offers a functional solution to handle vegetation management and wildfire prevention needs for extensive or hard-to-reach park areas. With proper training, this system could also help identify illegal activities such as homeless encampments and dumping, as well as assess the condition of fencing and signage, concerns that are well-known in San Diego's open space parks.

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Author

Austin Zhang is a passionate hiker and biker at Black Mountain Open Space Park. He has always been deeply involved in environmental initiatives. Since 2024, he has worked alongside the nonprofit organization Friends of Los Peñasquitos Canyon Preserve, contributing to surveys and volunteer-led restoration projects. In addition, he coordinates student volunteers from the San Diego Sustainable Environmental Engineering (SEE) Club, DNH Youth Build Club, and the Youth Care Club (YCC) in these efforts. Together, they completed approximately 20 sessions, contributing over 700 volunteer hours towards nature restoration efforts.

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