



# **iJRASET**

International Journal For Research in  
Applied Science and Engineering Technology



---

# **INTERNATIONAL JOURNAL FOR RESEARCH**

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

---

**Volume: 14**

**Issue: IX**

**Month of publication:**

**September 2026**

**DOI:** <https://doi.org/10.22214/ijraset.2026.84907>

**[www.ijraset.com](http://www.ijraset.com)**

**Call:**  **08813907089**

**E-mail ID:** [ijraset@gmail.com](mailto:ijraset@gmail.com)

# AI/ML Powered Precision Reforestation using Drone with Hydrogel-Coated Seed Pods

Ayan Bera

Student, Milpitas High School (Innovation Campus), 1331 E. Calaveras Blvd., Milpitas, CA 95035, USA

**Abstract:** Wildfire-affected landscapes can be difficult to restore because damaged terrain may be remote, steep, hazardous, and spatially difficult to access. This paper presents a low-cost prototype that integrates a quadcopter drone, onboard/near-edge computer vision, and a servo-controlled seed dispenser for targeted reforestation. The system was developed through eight iterative prototypes spanning flight stabilization, camera integration, seed-dispenser geometry, machine-learning classification, and hydrogel seed-pod testing. A balanced image dataset of 1,520 forest images (760 burned and 760 green) was labeled and divided into 70% training, 15% validation, and 15% test subsets. Color/texture features and a support vector machine (SVM) classifier produced 93.0% test accuracy, with 105/114 green and 107/114 burned test images correctly classified. The final electromechanical prototype demonstrated image-triggered seed release over a brown/burned target. In a separate 10-day simulated degraded-soil experiment, hydrogel-coated seeds reached 90% germination and 6.5 cm mean height, compared with 60% germination and 3.8 cm for uncoated controls. These results establish a proof of concept for coupling real-time terrain classification directly to precision seed deployment.

**Keywords:** AI/ML, computer vision, drone, wildfire-affected landscape recovery, precision reforestation, support vector machine, hydrogel seed coating, autonomous seed dispenser.

## I. INTRODUCTION

High-severity wildfire can leave large areas with reduced green vegetation, degraded soil conditions, erosion risk, and difficult access. Post-fire reforestation therefore requires not only rapid deployment but also careful placement at microsites capable of supporting re-establishment. Recent restoration literature has similarly cautioned that aerial seeding alone is insufficient, and that improved precision is needed to concentrate seeds in favorable locations [1]. The present study was conceived as a detection-to-action system rather than a uniform aerial seeder. The prototype uses aerial imagery to distinguish healthy green vegetation from burned or barren terrain and links that classification to a servo-actuated dispenser. The design objective is to release seeds only when the visual system identifies a restoration target, thereby reducing unnecessary seeding in healthy areas while allowing access to terrain that may be unsafe or inefficient for manual crews. The present study originated from observation of a local wildfire and its persistent, burned landscape. The engineering system is designed and developed as a progression from a basic camera-equipped quadcopter drone to a stabilized, guarded platform with a custom 3D-printed dispenser, image-based classification, and moisture-retaining seed pods. The presentation describes the novelty as the integration of real-time AI-triggered deployment with a compact modular drone rather than pre-mapped uniform seeding. The design was motivated by post-wildfire landscapes that can remain barren, charred, and difficult to access long after the active fire. The present study therefore targets a specific engineering gap between broad-area observation and physical restoration: converting low-altitude visual sensing into an immediate, localized seed-release decision. Its distinguishing design concept is the integration of real-time burned-versus-green classification, servo-controlled dispensing, and moisture-retaining hydrogel-coated seeds in one compact aerial platform.

### A. Comparative Design Context

| Feature / Factor     | Manual Reforestation                    | Helicopter-Based Reforestation            | Satellite Monitoring Systems           | AI Drone System                      |
|----------------------|-----------------------------------------|-------------------------------------------|----------------------------------------|--------------------------------------|
| Cost Efficiency      | High labor/time demand                  | Very expensive: fuel, pilots, maintenance | Moderate-high data/infrastructure cost | Low-cost, scalable deployment goal   |
| Precision of Seeding | High placement precision; limited scale | Low for bulk seed dropping                | — (monitoring only)                    | High-precision targeting using AI/ML |
| Real-Time            | Human judgment; slower                  | Human-dependent                           | Delayed by                             | Real-time terrain detection          |

|                           |                                     |                                            |                                   |                                               |
|---------------------------|-------------------------------------|--------------------------------------------|-----------------------------------|-----------------------------------------------|
| Decision Making           | response                            | decisions                                  | acquisition/processing            | and trigger                                   |
| Accessibility             | Limited in steep/hazardous terrain  | Remote access; weather/terrain constraints | Remote sensing only               | Access to hazardous/hard-to-reach areas       |
| Seed Wastage              | Low-moderate; controlled placement  | High with non-targeted distribution        | — (monitoring only)               | Reduced by targeted deployment                |
| Labor Requirement         | Very high                           | High: crew, pilots, logistics              | Moderate: data-analysis personnel | Low operational labor goal                    |
| Environmental Impact      | Low direct equipment impact         | Higher fuel-related emissions              | Remote-sensing infrastructure     | Electric-drone platform; low direct emissions |
| Scalability               | Limited by manual deployment rate   | Limited by cost/resources                  | Broad-area monitoring             | Potentially scalable with drone swarms        |
| Terrain Analysis          | Visual/manual inspection            | Manual/visual estimation                   | Broad-area; less ground detail    | AI/ML burned-vs-green recognition             |
| Response Time             | Slow for large areas                | Deployment/operation delay                 | Delayed data updates              | Rapid deployment + real-time response         |
| Post-Wildfire Suitability | Worker exposure in unstable terrain | Operational risk/inefficiency              | Monitoring support                | Designed for post-wildfire restoration        |
| Automation Level          | Low                                 | Low                                        | Moderate, data-driven             | High: automated detection + seeding trigger   |

Table I. Qualitative design comparison used during concept development.

Table I summarizes the qualitative comparison used during concept development. The comparison is a design-level assessment from the present-study that highlights the intended advantages of an AI-guided electric drone for localized sensing and targeted deployment, while satellite systems are treated primarily as monitoring tools rather than seed-delivery platforms.

## II. SYSTEM DESIGN AND DEVELOPMENT

### A. System Architecture

The system architecture consists of five functional blocks: (1) quadcopter drone and flight controller; (2) camera module; (3) terrain-classification software; (4) servo-driven seed dispenser; and (5) hydrogel-coated seed pods as shown in Fig. 1. During operation, the camera acquires terrain imagery. The classification stage determines whether the viewed region is healthy/green or burned/degraded. A burned-area decision triggers the actuator, which rotates or opens the dispenser aperture to release a seed pod. The physical prototype therefore closes the loop between detection and mechanical action. The operational sequence is camera capture → AI burned/green classification → decision → seed release only for a restoration target → mission continuation, creating a closed detection-to-action loop.

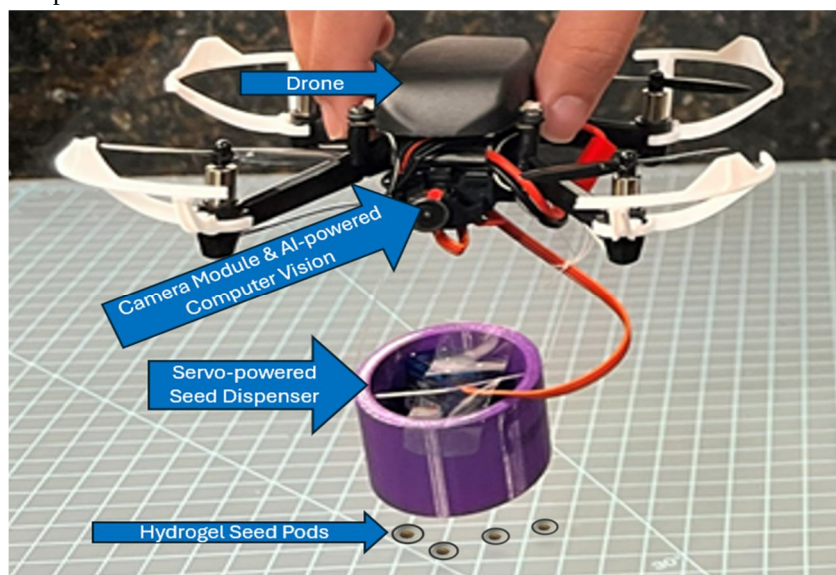


Fig. 1. Final prototype showing drone, camera/AI vision module, servo-powered seed dispenser, and hydrogel seed pods.

### B. Iterative Prototyping

Eight prototypes were used to reduce risk incrementally. Early work established the camera and microcontroller mounting and verified battery voltage above the arming threshold. After an unstable initial flight, propeller guards and protective canopies were 3D printed. Subsequent accelerometer and magnetometer calibration corrected lateral sway and heading drift, improving hover stability and positioning. The seed-deployment mechanism then became the principal mechanical challenge. Initial concepts considered a servo-driven gate or rotating disc aligned with a dispenser aperture. Prototype 5 demonstrated that the servo could operate while attached to the flying drone, but the dispenser fit was too tight for unrestricted motion. The housing dimensions and aperture location were therefore revised. By Prototype 6, the servo was customized to the dispenser, and a retaining pin was added to prevent actuator movement caused by continuous rotation. Three iterations focused specifically on height, width, pin geometry, and hole position before smooth operation was obtained.

## III. COMPUTER-VISION METHODOLOGY

### A. Dataset Preparation

The image-recognition study used 1,520 publicly available forest images obtained through Kaggle [2]: 760 labeled burned forest and 760 labeled green forest. Label Studio [3] was used to organize the two classes. The dataset was divided into 70% training, 15% validation, and 15% testing, corresponding to 1,064, 228, and 228 images, respectively. The balanced class distribution reduced class-frequency bias in the binary classification experiment.

### B. Baseline and Machine-Learning Pipeline

An initial color-thresholding baseline separated green vegetation and burned regions using predefined RGB/HSV ranges. This method provided fast segmentation but was sensitive to illumination changes and mixed terrain. The present study therefore progressed to a machine-learning classifier using visual color and texture information. Feature extraction and model evaluation were performed in a Jupyter Notebook [4]; scikit-learn [5] was used for modeling and confusion-matrix analysis, with visualization through Matplotlib [6] and seaborn [7]. Dataset-loading and annotation-format errors were corrected by standardizing paths, filenames, and preprocessing. The development record also documents PyTorch [8] within the image-recognition pipeline, while the reported final binary classifier was the SVM evaluated at 93% accuracy. A support vector machine was selected for the reported final classification experiment. For binary classes, the SVM seeks a decision boundary of the form  $f(x)=w^Tx+b$ , with the sign of  $f(x)$  determining the predicted class while maximizing separation between classes in feature space. Here  $x$  is the input feature vector for an image,  $w$  is the weight vector learned by the SVM during training, and  $b$  is the bias/intercept term learned during training. In this proof-of-concept implementation, the extracted visual feature vector encoded the color/texture differences between healthy green vegetation and charred/brown burned terrain.

### C. Test Metrics

The 228-image test set contained 114 images per class. The confusion matrix shows 105 green images correctly classified as green and 9 misclassified as burned; 107 burned images were correctly classified as burned and 7 misclassified as green as shown in Fig. 2. Overall accuracy was  $(105+107)/228 = 93.0\%$ . Class-specific recall was 92.1% for green and 93.9% for burned. These results support the feasibility of using lightweight visual classification as the decision stage for targeted deployment, while not yet establishing robustness under field-scale variation.

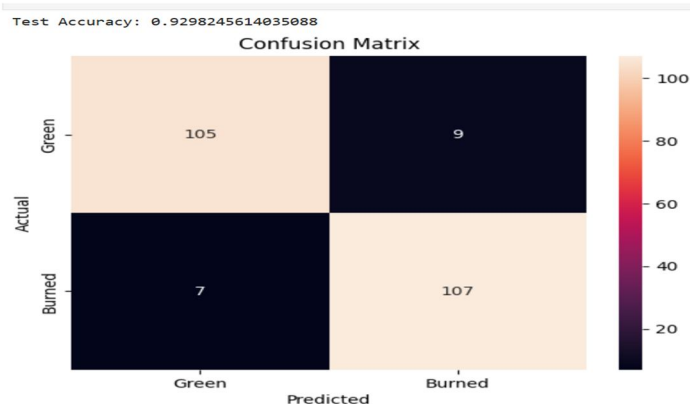


Fig. 2. Confusion matrix for the burned-versus-green SVM test set. Test accuracy = 93.0%.

The present study also compared satellite imagery with low-altitude drone imagery. The development log notes that satellite images were less suitable for the intended local, micro-scale monitoring because of revisiting limitations, spatial resolution, and cloud cover, whereas the drone could control viewing position, altitude, and angle. This observation motivated retaining the drone camera as the operational sensing source.

#### IV. PRECISION DISPENSING AND SEED-POD EXPERIMENT

##### A. Detection-Triggered Seed Deployment

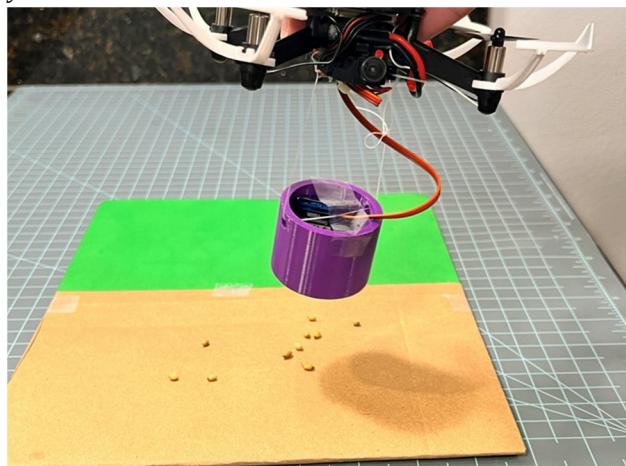


Fig. 3. Integrated seed-release test over a brown target representing burned terrain.

The central integration test linked visual recognition to actuation. During Prototype 6 testing, the drone/camera/dispenser assembly was positioned over contrasting terrain targets. When a brown region representing burned forest was recognized, the dispenser released seeds as shown in Fig. 3. This demonstrated the intended control concept: visual classification provides the trigger for physical deployment rather than following a fixed uniform-drop schedule. This test should be interpreted as a functional prototype demonstration, not as a quantified field-precision trial.

##### B. Hydrogel Seed-Pod Design

A biodegradable seed-pod concept is used in which a seed is coated by a moisture-retaining hydrogel/soil matrix. The purpose is to create a local microenvironment that supports hydration and early establishment in degraded soil. Prior research shows that hydrogel and biopolymer seed coatings can improve water-stress tolerance, but coating performance depends strongly on material formulation, and environmental conditions [9]–[11]. Accordingly, the seed-pod experiment in the present study was designed as a small proof-of-concept comparison rather than a universal claim about hydrogel coatings. Two groups of the same seed type were prepared, each containing 10 seeds. Group A received the hydrogel coating; Group B remained uncoated as the control. Both groups were planted in nutrient-poor, charred soil intended to simulate post-wildfire conditions. Germination and early growth were recorded on different days through Day 10.

| Day | Group    | Seeds Germinated (out of 10) | Germination % | Avg Height (cm) | Avg # of Leaves | Survival Count | Notes             |
|-----|----------|------------------------------|---------------|-----------------|-----------------|----------------|-------------------|
| 1   | Hydrogel | 0                            | 0%            | 0               | 0               | 10             | No visible change |
| 1   | Uncoated | 0                            | 0%            | 0               | 0               | 10             | No visible change |
| 3   | Hydrogel | 4                            | 40%           | 1.2             | 1               | 10             | Early sprouting   |
| 3   | Uncoated | 2                            | 20%           | 0.8             | 1               | 9              | Slower growth     |
| 5   | Hydrogel | 7                            | 70%           | 2.5             | 2               | 10             | Strong sprouts    |
| 5   | Uncoated | 4                            | 40%           | 1.6             | 1               | 8              | Some drying       |
| 7   | Hydrogel | 9                            | 90%           | 4               | 3               | 9              | Healthy growth    |
| 7   | Uncoated | 5                            | 50%           | 2.3             | 2               | 7              | Weak stems        |
| 10  | Hydrogel | 9                            | 90%           | 6.5             | 4               | 9              | Stable growth     |
| 10  | Uncoated | 6                            | 60%           | 3.8             | 3               | 6              | Some wilting      |

Table II. Germination and growth measurements from the simulated degraded-soil experiment.

## V. RESULTS AND DISCUSSION

### A. Classification Performance

The SVM correctly classified 212 of 228 test images, yielding 93.0% accuracy. The near-balanced correct counts for green (105/114) and burned (107/114) indicate that the reported accuracy was not produced by favoring one class. The classifier demonstrates feasibility of the concept and does not construe as a field-ready ecological decision system. Lighting, shadows, ash, dry grass, exposed soil, seasonal browning, and mixed pixels can create visual overlap between the two categories. Future work should therefore test independent drone-captured datasets and report precision, and performance across different burn severities and vegetation types.

### B. Electromechanical Integration

The electromechanical work demonstrated a complete prototype chain: stabilized flight, camera operation, servo actuation, revised dispenser geometry, and seed release following burned-area recognition. The iterative redesign, a practical engineering process is important because the dispenser initially constrained servo motion; later dimensional changes and a retaining pin corrected the interference and actuator movement.

### C. Hydrogel Seed-Pod Results

By Day 10, 9 of 10 hydrogel-coated seeds had germinated compared with 6 of 10 uncoated seeds as shown in Table II. Mean seedling height was 6.5 cm for the hydrogel group versus 3.8 cm for the control. Survival counts were 9 and 6, respectively. The difference appeared early: at Day 3, germination was 40% for hydrogel-coated seeds and 20% for controls. At the end of Day 10, average number of leaves is hydrogel group is 4 that is higher than 3 leaves in control. More stable growth is observed in hydrogel group than in control.

The direction of the present study result is consistent with studies showing that water-retaining seed coatings can support germination under water stress [9], [10]. However, recent controlled work also shows that hydrogel coatings can delay germination when coating mechanics or oxygen transport are unfavorable [11]. This literature is important for interpreting the present prototype: hydrogel chemistry, thickness, porosity, seed species, soil moisture, and gas exchange need to be optimized rather than assuming that any hydrogel formulation will improve establishment.

### D. Relation to Drone-Reforestation Research

Peer-reviewed restoration research increasingly supports precision as a key requirement for aerial seeding. Castro et al. argued that restoration success depends on microsite suitability and called for more precise drone seeding [1]. Recent UAV work has demonstrated lightweight precision seed-dropping mechanisms [12], while field studies of drone direct seeding show both operational promise and strong dependence on seed treatment and post-emergence survival [13]. The present study contributes a proof of concept that specifically couples visual burned-area recognition to the release decision, rather than treating sensing and seeding as separate operations.

From an application perspective, the present analysis identifies forestry agencies, land-management organizations, disaster-response groups, and restoration programs as potential users of a future validated system. The intended environmental value is faster access to difficult terrain, reduced non-target seed release, and support for post-fire ecosystem recovery. The remaining prospective benefits can include carbon sequestration, biodiversity recovery, cost reduction, and landscape-scale ecological outcomes.

## VI. LIMITATIONS, FUTURE WORK AND CONCLUSION

### A. Limitations and Future Work

The present study is concept and feasibility validation of a prototype using AI-Guided drone for reforestation with hydrogel-coated seed pods. First, the image dataset used publicly available burned and green forest imagery; the final classifier can be retrained and independently tested on geotagged imagery collected by the actual drone under variable altitude, illumination, season, smoke/haze, and mixed terrain.

Second, deployment performance should be quantified with repeated trials measuring trigger latency, seed-drop rate, horizontal drop error, missed releases, and sensitivity to wind and altitude. Flight endurance and payload tradeoffs should be measured before scaling to coordinated drone-swarm operation. Future swarm studies could divide large restoration areas among multiple drones, share georeferenced burn and planting-suitability maps, coordinate seed-pod payloads and coverage, and evaluate inter-drone communication, collision avoidance, task allocation, fault tolerance, and return-to-base behavior.

Third, the seed-pod study requires larger replicated samples, native species appropriate to the restoration site, multiple hydrogel formulations, and longer observation of emergence and survival. Recent hydrogel literature suggests explicitly balancing moisture retention with oxygen permeability [11]. The present study also proposes future biomimetic seed pods inspired by self-burying *Erodium* seeds [14] to improve seed-soil contact. For larger restoration areas, future work should evaluate coordinated drone swarms in which the landscape is partitioned into georeferenced sectors and multiple drone swarm share coverage status and target maps.

Finally, field deployment should be designed with ecological expertise and regulatory compliance. A burned area is not automatically a suitable planting site; natural regeneration, species composition, soil condition, climate suitability, and land-management objectives must guide restoration decisions. The AI trigger should therefore evolve from a simple burned-versus-green classifier into a decision-support layer informed by restoration ecology.

## B. Conclusion

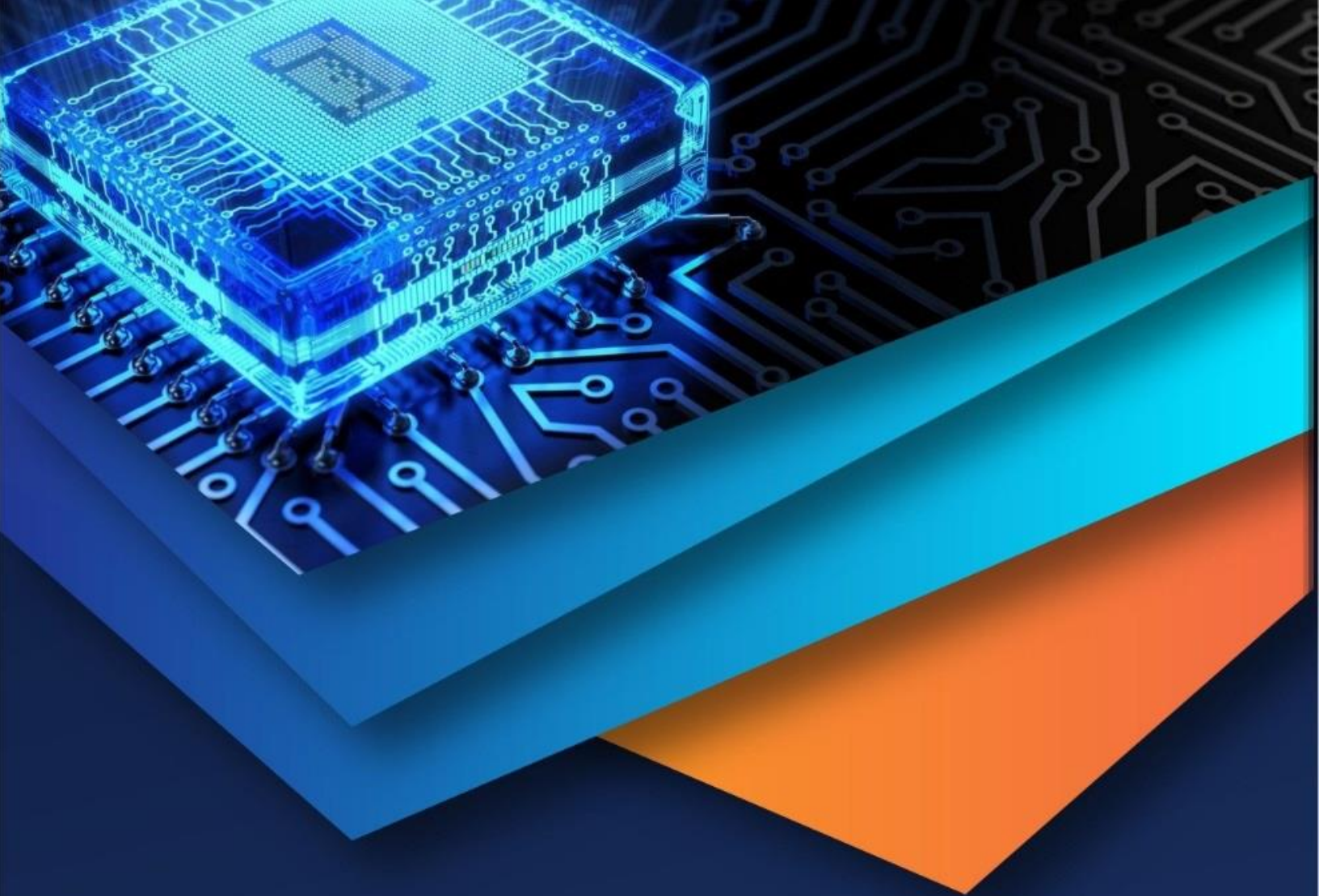
The present study demonstrates an integrated approach to precision reforestation in which aerial sensing directly controls seed deployment. Across eight prototypes, the present study progressed from a camera-equipped quadcopter to a stabilized platform with a custom servo dispenser, an SVM burned/green classifier, and hydrogel seed pods. The reported classifier achieved 93.0% accuracy on a balanced 228-image test set. The integrated prototype released seeds when a burned/brown target was recognized, demonstrating the intended detection-to-action loop. In the small simulated degraded-soil experiment, hydrogel-coated seeds showed 90% germination and 6.5 cm mean height at Day 10, compared with 60% and 3.8 cm for uncoated controls. These results establish a proof of technical concept and feasibility for coupling real-time terrain classification directly to precision seed deployment of hydrogel-coated seed pods for AI-guided drone reforestation.

## VII. ACKNOWLEDGMENT

The author acknowledges technical feedback on the servo mechanism from aerospace scientist Dr. Aditya Gupte and on the sensors and CAD from his school teacher Mr. Paul Okoye .

## REFERENCES

- [1] J. Castro, F. Morales-Rueda, D. Alcaraz-Segura, and S. Tabik, "Forest restoration is more than firing seeds from a drone," *Restoration Ecology*, vol. 31, no. 1, Art. no. e13736, 2023, doi: 10.1111/rec.13736.
- [2] Kaggle, "Datasets," online dataset platform, accessed May. 2026.
- [3] M. Tkachenko, M. Malyuk, A. Holmanyuk, and N. Liubimov, "Label Studio: Data labeling software," open-source software, 2020–2025.
- [4] T. Kluyver, B. Ragan-Kelley, F. Pérez, B. Granger, M. Bussonnier, J. Frederic, K. Kelley, J. Hamrick, J. Grout, S. Corlay, P. Ivanov, D. Avila, S. Abdalla, C. Willing, and Jupyter Development Team, "Jupyter Notebooks—a publishing format for reproducible computational workflows," in *Positioning and Power in Academic Publishing: Players, Agents and Agendas*, F. Loizides and B. Schmidt, Eds. Amsterdam, The Netherlands: IOS Press, 2016, pp. 87–90, doi: 10.3233/978-1-61499-649-1-87.
- [5] F. Pedregosa, G. Varoquaux, A. Gramfort, V. Michel, B. Thirion, O. Grisel, M. Blondel, P. Prettenhofer, R. Weiss, V. Dubourg, J. Vanderplas, A. Passos, D. Cournapeau, M. Brucher, M. Perrot, and É. Duchesnay, "Scikit-learn: Machine Learning in Python," *Journal of Machine Learning Research*, vol. 12, no. 85, pp. 2825–2830, 2011.
- [6] J. D. Hunter, "Matplotlib: A 2D Graphics Environment," *Computing in Science & Engineering*, vol. 9, no. 3, pp. 90–95, 2007, doi: 10.1109/MCSE.2007.55.
- [7] M. L. Waskom, "seaborn: statistical data visualization," *Journal of Open Source Software*, vol. 6, no. 60, p. 3021, 2021, doi: 10.21105/joss.03021.
- [8] A. Paszke, S. Gross, F. Massa, A. Lerer, J. Bradbury, G. Chanan, T. Killeen, Z. Lin, N. Gimelshein, L. Antiga, A. Desmaison, A. Köpf, E. Yang, Z. DeVito, M. Raison, A. Tejani, S. Chilamkurthy, B. Steiner, L. Fang, J. Bai, and S. Chintala, "PyTorch: An Imperative Style, High-Performance Deep Learning Library," in *Advances in Neural Information Processing Systems 32*, 2019, pp. 8024–8035.
- [9] A. T. Zvinavashe, J. Laurent, M. Mhada, H. Sun, H. M. E. Fouda, D. Kim, S. Mouhib, L. Kouisni, and B. Marelli, "Programmable design of seed coating function induces water-stress tolerance in semi-arid regions," *Nature Food*, vol. 2, no. 7, pp. 485–493, 2021, doi: 10.1038/s43016-021-00315-8.
- [10] L.-Q. Su, J.-G. Li, H. Xue, and X.-F. Wang, "Super absorbent polymer seed coatings promote seed germination and seedling growth of *Caragana korshinskii* in drought," *Journal of Zhejiang University-SCIENCE B*, vol. 18, no. 8, pp. 696–706, 2017, doi: 10.1631/jzus.B1600350.
- [11] T. M. Phillips, J. Green, A. Sanz-Saez, and J.-F. Louf, "Physical effects of hydrogel coatings on seed germination," *Soft Matter*, vol. 22, pp. 645–656, 2026, doi: 10.1039/D5SM00932D.
- [12] Q. R. Lee, H. Hesse, K. Naruangsri, W. Takaew, S. Elliott, and D. Bhatia, "UAV-Based Precision Seed Dropping for Automated Reforestation," *Journal of Field Robotics*, Art. no. e70344, 2026, doi: 10.1002/rob.70344.
- [13] Í. F. Campanharo, R. R. Rodrigues, P. H. S. Brancalion, J. P. B. Santos, G. P. Z. Bringas, and P. G. Molin, "Assessing drone-based direct seeding with bare and encapsulated seeds for enriching degraded tropical forest fragments," *Ecological Engineering*, vol. 233, Art. no. 108146, 2026, doi: 10.1016/j.ecoleng.2026.108146.
- [14] D. Luo, A. Maheshwari, A. Danieleescu, J. Li, Y. Yang, Y. Tao, L. Sun, D. K. Patel, G. Wang, S. Yang, T. Zhang, and L. Yao, "Autonomous self-burying seed carriers for aerial seeding," *Nature*, vol. 614, no. 7948, pp. 463–470, 2023, doi: 10.1038/s41586-022-05656-3.



10.22214/IJRASET



45.98



IMPACT FACTOR:  
7.129



IMPACT FACTOR:  
7.429



# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089  (24\*7 Support on Whatsapp)