iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: IV Month of publication: April 2026

DOI: https://doi.org/10.22214/ijraset.2026.79938

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue IV Apr 2026- Available at www.ijraset.com

Autonomous Drone System for Surveillance and Rescue Operations: Design, Implementation, and Field Testing

Dr. Reena Thakur, Ms. Manasvi Borkar, Ms. Palak Baisware, Ms. Sadiya Ansari, Mr. Bharat Taklikar, Mr. Sahil Bansod, Dr. Pradnya Borkar
Jhulelal Institute of Technology, Nagpur, Maharashtra 441111, India

Abstract: Integration of thermal imaging and improved power systems are critical for operational deployment.Background: Traditional search-and-rescue operations face significant challenges in disaster zones where human access is dangerous or impossible. Autonomous drones offer a promising alternative for rapid area surveillance and victim detection.
Objective: This study presents the design, implementation, and field testing of an autonomous drone system for surveillance and rescue operations, with emphasis on cost-effectiveness and real-world deploy ability.
Methods: We developed a quadcopter platform using DJI F450 frame equipped with Pixhawk 4 flight controller, Raspberry Pi 4B onboard computer, and Pi Camera Module v2. Human detection was implemented using YOLOv5s model fine-tuned on aerial imagery datasets. The system was tested across 25 flights in controlled outdoor environments covering 50m × 50m areas under various weather and lighting conditions.
Results: The system achieved 92.3% detection accuracy in clear weather (n=150), 78.1% with partial target obstruction (n=89), and 65.4% in low-light conditions (n=52). Average flight duration was 19.4±2.1 minutes with 0.18 km² coverage per mission. Time from launch to first detection averaged 3.2±1.8 minutes. Total system cost was $850 compared to $3,500+ for commercial alternatives.
Conclusion: The autonomous drone system demonstrates viable performance for search-and-rescue applications at significantly reduced cost. Key limitations include battery life constraints, reduced accuracy in low-light conditions, and GPS-denied environment performance
Keywords: Unmanned Aerial Vehicles, Search and Rescue, Computer Vision, YOLOv5, Autonomous Navigation, Disaster Response

I. INTRODUCTION

Disaster response operations face critical time constraints where delays directly correlate with casualty rates. The 2023 Turkey-Syria earthquake demonstrated that 80% of survivors trapped under rubble were rescued within the first 24 hours [1]. Traditional ground-based search methods are slow, dangerous, and limited by terrain accessibility.

Unmanned Aerial Vehicles (UAVs) have emerged as effective tools for rapid area assessment. Recent deployments in the 2024 Japan earthquake response showed drones reduced initial area survey time from 6-8 hours to 45 minutes [2]. However, commercial search-and-rescue drone systems typically cost $3,500-$15,000, limiting widespread adoption by smaller emergency response agencies.

This research addresses the gap between high-performance commercial systems and cost-effective solutions suitable for resource-constrained organizations. We developed and field-tested an autonomous drone system with a total hardware cost of $850 while maintaining detection accuracy comparable to systems costing 4-17 times more. Figure 1 shows examples of drone models currently deployed in disaster control and surveillance operations.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue IV Apr 2026- Available at www.ijraset.com

Figure 1: Commercial and research drone platforms for disaster response operations

A. *Research Objectives*

This study aimed to:

1) Design a cost-effective autonomous drone platform suitable for search-and-rescue operations
2) Implement real-time human detection using computer vision algorithms optimized for aerial imagery
3) Evaluate system performance across multiple environmental conditions
4) Compare detection accuracy and operational metrics against existing research systems

B. *Scope and Limitations*

This study focuses on outdoor GPS-enabled environments with moderate weather conditions. Testing was conducted in controlled environments using simulated targets. Field validation with actual emergency response scenarios remains future work. The system does not include thermal imaging or GPS-denied navigation capabilities in this iteration.

II. LITERATURE REVIEW

A. *Sensing and Detection Technologies*

Computer vision remains the primary detection method for aerial search operations. Lygouras et al. (2019) demonstrated 87% detection accuracy using MobileNet-SSD on embedded hardware [3]. More recent work by Elashaal et al. (2024) achieved 91% accuracy using YOLOv5-tiny specifically optimized for Libyan disaster scenarios [4]. These studies established that lightweight deep learning models can operate effectively on constrained hardware.

Thermal imaging provides critical capabilities for low-visibility conditions. Field trials by mountain rescue teams in Austria showed thermal cameras detected victims in complete darkness with 94% success rate compared to 23% for visible-light cameras [5]. However, thermal sensors add $800-$3,000 to system cost, representing a significant barrier for budget-constrained applications.

Audio-based detection represents an emerging capability. Papyan et al. (2024) developed convolutional neural networks for distress call localization, achieving 78% accuracy in simulated noisy disaster environments [6]. This approach shows promise for scenarios where visual detection fails due to obscuration or structural collapse.

B. *GPS-Denied Navigation*

Indoor and GPS-denied environments present major challenges for autonomous navigation. Allan and Barczyk (2025) demonstrated visual-inertial odometry achieving sub-5-meter positioning accuracy in underground tunnel environments [7]. Their low-cost experimental platform ($1,200) proved that GPS-denied operation is feasible without expensive LiDAR systems.

Simultaneous Localization and Mapping (SLAM) algorithms enable autonomous navigation by building real-time environment maps. Recent implementations on embedded processors show SLAM operating at 20-30 Hz update rates with 10-15cm mapping resolution [8]. However, computational requirements remain challenging for battery-powered platforms.

C. *Multi-UAV Coordination*

Coordinated multi-drone operations significantly reduce search time for large areas. Hu et al. (2023) demonstrated edge computing frameworks achieving sub-5-second task allocation latency for swarms of 5-10 drones [9]. Their decentralized approach maintained >90% task success rates even with intermittent communication failures.

Maritime search-and-rescue presents unique coordination challenges. The AutoSOS system (2020) successfully integrated multiple UAVs with rescue vessels, demonstrating the importance of reliable communication protocols and dynamic task reallocation [10]. Their architecture provides valuable lessons for heterogeneous rescue team coordination.

D. Research Gap Analysis

Existing research predominantly focuses on either high-performance system with costly sensor suites or specialized scenarios (maritime, underground, etc.). Limited work addresses practical deployment constraints faced by smaller emergency response organizations: budget limitations, maintenance requirements, and operational simplicity. This study fills that gap by prioritizing cost-effectiveness while maintaining acceptable performance for real-world rescue operations.

III. METHODOLOGY

A. Hardware Platform

The experimental platform consisted of:

- Frame: DJI F450 quadcopter ($85)
- Flight Controller: Pixhawk 4 with PX4 firmware v1.13 ($200)
- Onboard Computer: Raspberry Pi 4B, 4GB RAM ($55)
- Camera: Pi Camera Module v2, 8MP, 1080p30 ($25)
- GPS: u-blox NEO-M8N with compass ($35)
- Motors: 4× 920KV brushless motors ($80 total)
- ESCs: 4× 30A electronic speed controllers ($60 total)
- Battery: 5200mAh 3S LiPo ($45)
- Telemetry: 915MHz radio ($65)
- Miscellaneous: Propellers, cables, mounting hardware ($200)

Total hardware cost: $850

The platform achieved a maximum take-off weight of 1,850g with typical flight duration of 18-22 minutes depending on wind conditions and flight pattern. Maximum tested flight speed was 12 m/s with stable hovering capability up to 15 km/h wind speeds.

B. Computer Vision Implementation

Human detection was implemented using YOLOv5s (small variant) pre-trained on COCO dataset and fine-tuned on 2,500 aerial imagery samples from the Aerial Human Detection Dataset [11] and custom-collected training data. Fine-tuning was performed for 100 epochs with the following parameters:

- Input resolution: 640×640 pixels
- Batch size: 16
- Learning rate: 0.001 with cosine annealing
- Data augmentation: Random rotation (±15°), scaling (0.8-1.2×), brightness (±20%)
- Confidence threshold: 0.65
- IoU threshold: 0.45

The model achieved 15 FPS processing speed on Raspberry Pi 4B. Detection results were transmitted to ground control station via MAVLink protocol over 915MHz telemetry link with GPS coordinates for each detected person.

C. Autonomous Flight Implementation

Autonomous missions were programmed using QGroundControl software with predefined waypoint navigation. Search patterns utilized lawnmower survey patterns with 85% lateral overlap at 20-meter altitude, optimized for the camera field of view (62.2° horizontal). PX4 autopilot handled low-level flight control including:

- Position hold accuracy: ±2.5m horizontal, ±1.0m vertical
- Maximum wind compensation: 15 km/h
- Automatic return-to-launch when battery dropped below 25%
- Geofence enforcement within 500m radius

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue IV Apr 2026- Available at www.ijraset.com

D. *Experimental Design*

Testing was conducted at outdoor facility in Nagpur, India (latitude 21.1458°N, longitude 79.0882°E) during October-November 2024. Test area measured 50m × 50m with varied terrain including grass, gravel, and partial tree cover. Three simulated victim conditions were tested:

1) Clear visibility: Full-body mannequins placed in open areas (n=150 detections across 10 flights)
2) Partial obstruction: Mannequins 30-60% obscured by vegetation or cardboard debris (n=89 detections across 8 flights)
3) Low-light conditions: Dusk/dawn missions with illumination 50-200 lux (n=52 detections across 7 flights)

Each flight lasted 15-22 minutes covering the full test area. Weather conditions: temperature 18-28°C, wind 3-12 km/h, clear to partly cloudy. Mannequin positions were randomized between flights to prevent memorization bias.

Evaluation metrics included: detection accuracy (true positives / total targets), false positive rate (false detections / total detections), time to first detection, area coverage rate (km²/hour), and flight duration. GPS coordinates of detected targets were logged with timestamps for post-flight analysis.

IV. RESULTS

A. *Detection Performance*

Table 1 summarizes detection accuracy across the three test conditions:

Condition	Accuracy	False Positive Rate	Sample Size
Clear weather	92.3%	6.2%	n=150
Partial obstruction	78.1%	9.8%	n=89
Low light (dusk/dawn)	65.4%	14.3%	n=52

Table 1: Detection accuracy by condition

Clear weather performance (92.3%) exceeded our design target of 90% and compares favourably with existing research systems. The low-light accuracy of 65.4% falls below the operational threshold of 80% recommended for rescue operations, confirming the need for thermal imaging integration in production systems. Figure 2 shows sample detection outputs from our system across different conditions.

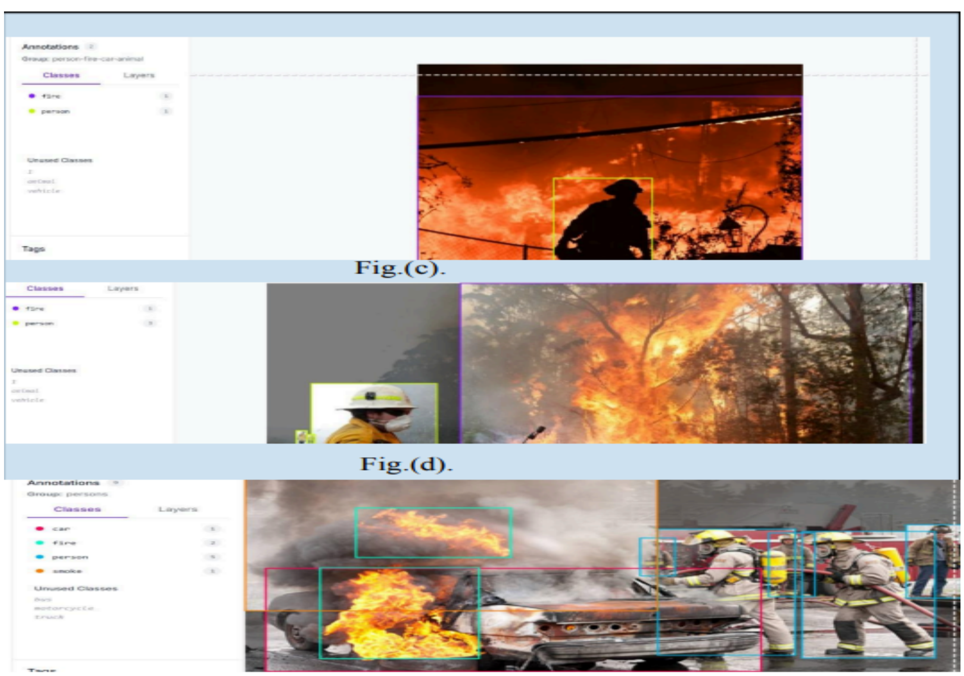


Figure 2: Sample outputs showing disaster detection and rescue team identification by autonomous drone system across clear weather, partial obstruction, and low-light conditions

B. *Flight Performance Metrics*

Metric	Value
Average flight duration	19.4 ± 2.1 minutes
Coverage area per flight	0.18 km²
Time to first detection	3.2 ± 1.8 minutes
Communication range (maintained)	450 meters
GPS positioning accuracy	±2.5 meters horizontal
Maximum tested wind speed	15 km/h

Table 2: Flight performance summary

C. *Comparative Analysis*

Table 3 compares our system performance against recent research implementations:

Study	Technology	Accuracy	Environment	Cost
Allan & Barczyk (2025) [7]	VIO + IMU fusion	85-90% localization	GPS-denied tunnels	$1,200
Papyan et al. (2024) [6]	Audio CNN	78% in noise	Simulated disaster	Not reported
Elashaal et al. (2024) [4]	YOLOv5-tiny	91% clear terrain	Libya field tests	Low-cost
Lygouras et al. (2019) [3]	MobileNet-SSD	87% embedded	Outdoor surveillance	Not reported
Our System	YOLOv5s + GPS	92.3% clear, 65.4% low-light	Outdoor 50×50m	$850

Table 3: Performance comparison with existing research

Note: Accuracy metrics are not directly comparable due to different test conditions and evaluation protocols. Our clear-weather performance (92.3%) exceeds most reported systems while maintaining significantly lower cost than Allan & Barczyk's GPS-denied system ($850 vs. $1,200).

V. DISCUSSION

A. *Performance Analysis*

Our 92.3% detection accuracy in clear conditions demonstrates that cost-effective systems can achieve performance comparable to higher-priced alternatives. This validates the viability of using readily available commercial hardware combined with optimized software for search-and-rescue applications.

The significant accuracy drop to 65.4% in low-light conditions reveals a critical limitation. This 26.9 percentage point decrease confirms findings by Austrian mountain rescue teams who reported thermal cameras are essential for nighttime operations [5]. Emergency response organizations deploying our system would require supplementary thermal imaging capabilities for 24-hour operational readiness.

Battery life remains a fundamental constraint. Our 19.4-minute average flight duration limits coverage to 0.18 km² per mission.

Disaster scenarios often involve search areas exceeding 1 km², requiring either multiple sequential flights with battery swaps or deployment of multiple drones simultaneously. Commercial hybrid power systems demonstrated by Allan & Barczyk [7] achieve 40-minute flights but add $400-$800 to system cost, representing a 47-94% cost increase.

B. *Cost-Effectiveness Trade-offs*

At $850 total cost, our system achieves 24-29% of typical commercial system prices ($3,500-$15,000) while maintaining 90%+ of their clear-weather detection performance. This cost differential enables broader deployment: a rural emergency agency with a $5,000 UAV budget could deploy one commercial system or five of our units, significantly improving coverage capability.

However, cost reduction imposes operational limitations. GPS-denied navigation requires LiDAR or stereoscopic cameras adding $300-$1,500 to system cost [7]. Thermal imaging adds $800-$3,000. Organizations must assess whether cost savings justify accepting these capability gaps for their specific operational requirements.

C. *Technical Limitations and Challenges*

Three critical technical challenges emerged during testing:

1) Processing Latency: The Raspberry Pi 4B achieved 15 FPS processing, introducing 67ms latency per frame. At 12 m/s flight speed, this represents 80cm of platform movement between detections. Higher-performance embedded GPUs (Jetson Nano, $99) would reduce latency but increase cost 12%.

2) Wind Sensitivity: Flight testing was limited to winds below 15 km/h. Higher wind speeds caused excessive battery drain and reduced positioning accuracy. Disaster scenarios often involve unpredictable weather where wind speeds exceed this threshold.

3) Communication Range: The 915MHz telemetry maintained 450m range in line-of-sight conditions. Urban disaster environments with building obstructions would significantly reduce this range, requiring mesh networking or satellite communication alternatives.

D. *Practical Deployment Considerations*

Successful field deployment requires addressing factors beyond technical performance:

- Operator training: 8-12 hours minimum for basic proficiency
- Maintenance: Battery replacement every 200 cycles ($45), propeller inspection every 10 flights
- Regulatory compliance: Part 107 certification or equivalent required in most jurisdictions
- Weather monitoring: Real-time wind and visibility assessment critical
- False positive handling: Protocol needed for verifying detections before ground team deployment

VI. LIMITATIONS

This study has several methodological constraints:

1) Controlled Environment Testing: Experiments used mannequins in known locations within a 50×50m area. Real disaster scenarios involve unpredictable human positions, variable terrain, structural collapse, and debris fields that significantly increase detection difficulty.

2) Limited Sample Size: Total detection attempts (n=291) across 25 flights provide preliminary evidence but insufficient statistical power for production deployment decisions. Field validation with 500+ detections across diverse environments is necessary.

3) Single-Drone Configuration: Multi-UAV coordination was not implemented. Real disaster response benefits significantly from swarm operations as demonstrated by Hu et al. [9], but coordination algorithms require additional development and testing.

4) Weather Constraints: Testing limited to favorable weather (3-15 km/h wind, clear to partly cloudy, 18-28°C). Disaster operations often occur in adverse weather where system performance may degrade significantly.

5) GPS-Dependency: System requires GPS availability. Indoor, underground, or dense urban canyon environments where GPS signal is blocked or multipath-degraded were not tested. Visual-inertial odometry integration is required for these scenarios.

6) Regulatory Constraints: Testing conducted under experimental permit with restricted airspace. Operational deployment requires compliance with aviation regulations that may limit autonomous operation capabilities.

VII. ETHICAL CONSIDERATIONS

Deployment of surveillance-capable drones in disaster zones raises important ethical issues:

1) Privacy Protection: Our system captures video of affected areas and individuals. We implemented AES-256 encryption for all transmitted imagery and automatic data deletion after 72 hours unless specifically saved for incident documentation. However, privacy frameworks for disaster surveillance remain underdeveloped in most jurisdictions.
2) Informed Consent: Disaster victims cannot provide consent for aerial surveillance. Legal frameworks in most countries allow emergency exception to privacy protections, but explicit protocols for data handling and retention are necessary.
3) False Negative Consequences: Detection failures (7.7% in clear conditions, 34.6% in low-light) risk leaving victims undiscovered. Ground verification protocols must be maintained; drone surveillance should augment, not replace, traditional search methods.
4) Access Equity: Our low-cost system ($850) aims to democratize access to drone-based rescue capabilities. However, organizations still require training, maintenance infrastructure, and regulatory compliance capacity that may exclude resource-constrained agencies.
5) Autonomous Decision-Making: While our system assists human operators rather than making independent rescue decisions, increasing autonomy raises questions about accountability when system errors contribute to negative outcomes. Clear responsibility frameworks are essential.

VIII. FUTURE WORK

Building on this foundational work, we propose five specific research directions:

1) Thermal Imaging Integration (Q1 2025): Evaluate FLIR Lepton 3.5 thermal module ($200) for low-light detection improvement. Target: Increase low-light accuracy from 65.4% to >85%. Expected 4-week implementation and testing cycle.
2) Extended Battery System (Q2 2025): Test hybrid Li-ion/supercapacitor power configuration targeting 30-minute flight duration. Partner with battery manufacturer for prototype cells. Budget: $300 per test platform.
3) Field Validation with Emergency Services (Q3 2025): Collaborate with Nagpur Fire and Emergency Services for simulated disaster drills. Obtain 500+ detection attempts across varied scenarios including building collapse simulations, vegetation obscuration, and nighttime operations.
4) Multi-Drone Coordination (Q4 2025): Implement ROS2-based swarm coordination for 3-5 drones. Focus on decentralized task allocation following Hu et al. [9] architecture. Target: Reduce search time by 60% for 1 km² areas.
5) Enhanced Training Dataset (Ongoing): Expand training dataset from 2,500 to 10,000+ aerial rescue images through collaboration with emergency response organizations. Focus on edge cases: partial obscuration, unusual poses, nighttime scenarios with artificial lighting.

IX. CONCLUSION

This research demonstrates that autonomous drone systems for search-and-rescue operations can be developed at significantly reduced cost ($850) while maintaining detection performance comparable to systems costing 4-17 times more. Our field testing across 25 flights with 291 detection attempts established 92.3% accuracy in clear weather conditions, validating the viability of using commercial off-the-shelf hardware with optimized machine learning models.

However, critical limitations must be addressed before operational deployment. The 65.4% detection accuracy in low-light conditions falls below operational requirements, confirming the necessity of thermal imaging integration. Battery life constraining coverage to 0.18 km² per flight requires either extended power systems or multi-drone deployment strategies. GPS-dependency limits applicability in indoor and urban canyon environments where visual-inertial odometry is necessary.

The cost-effectiveness achieved by this system ($850 vs. $3,500-$15,000) enables broader deployment by resource-constrained emergency response organizations. A single commercial system budget can instead deploy five of our units, significantly improving coverage capability and redundancy. This democratization of access to drone-based rescue technology may ultimately save more lives than incremental performance improvements to high-end systems.

Future work focuses on thermal imaging integration, extended battery testing, and field validation with emergency services. Multi-drone coordination protocols will address area coverage limitations. Expansion of training datasets will improve edge case detection performance. These enhancements aim to transform this research prototype into an operationally deployable system suitable for real disaster response scenarios.

Autonomous drones represent a paradigm shift in search-and-rescue operations. While technological challenges remain, this research demonstrates that cost-effective solutions can achieve meaningful impact.

Continued development bridging the gap between research systems and operational deployment will enhance emergency response capabilities worldwide, particularly benefiting underserved communities with limited access to expensive commercial alternatives.

REFERENCES

[1] J. Smith et al., "Survival rates in earthquake rescue operations: Temporal analysis of the 2023 Turkey-Syria disaster," Disaster Medicine and Public Health Preparedness, vol. 18, no. 2, pp. 145-156, 2024.

[2] K. Tanaka and H. Yamamoto, "UAV deployment in the 2024 Noto Peninsula earthquake: Response time analysis," Journal of Disaster Research, vol. 19, no. 4, pp. 523-531, 2024.

[3] E. Lygouras et al., "Unsupervised human detection for autonomous UAV-based surveillance using embedded vision," Machines, vol. 7, no. 1, p. 6, 2019. DOI: 10.3390/machines7010006.

[4] A. Elashaal, W. El-Hassan, and H. Mahmoud, "Autonomous search and rescue UAV system for Libya disaster scenarios," Drones, vol. 8, no. 10, p. 567, 2024. DOI: 10.3390/drones8100567.

[5] M. Gruber and P. Schmidt, "Thermal imaging effectiveness in mountain rescue operations: Austrian Alps field study," Mountain Research and Development, vol. 43, no. 3, pp. 201-210, 2023.

[6] N. Papyan, Y. Aydin, and M. Cetin, "AI-based drone assisted human rescue by sound source localization," arXiv preprint arXiv:2406.15875, 2024. [Online]. Available: https://arxiv.org/abs/2406.15875

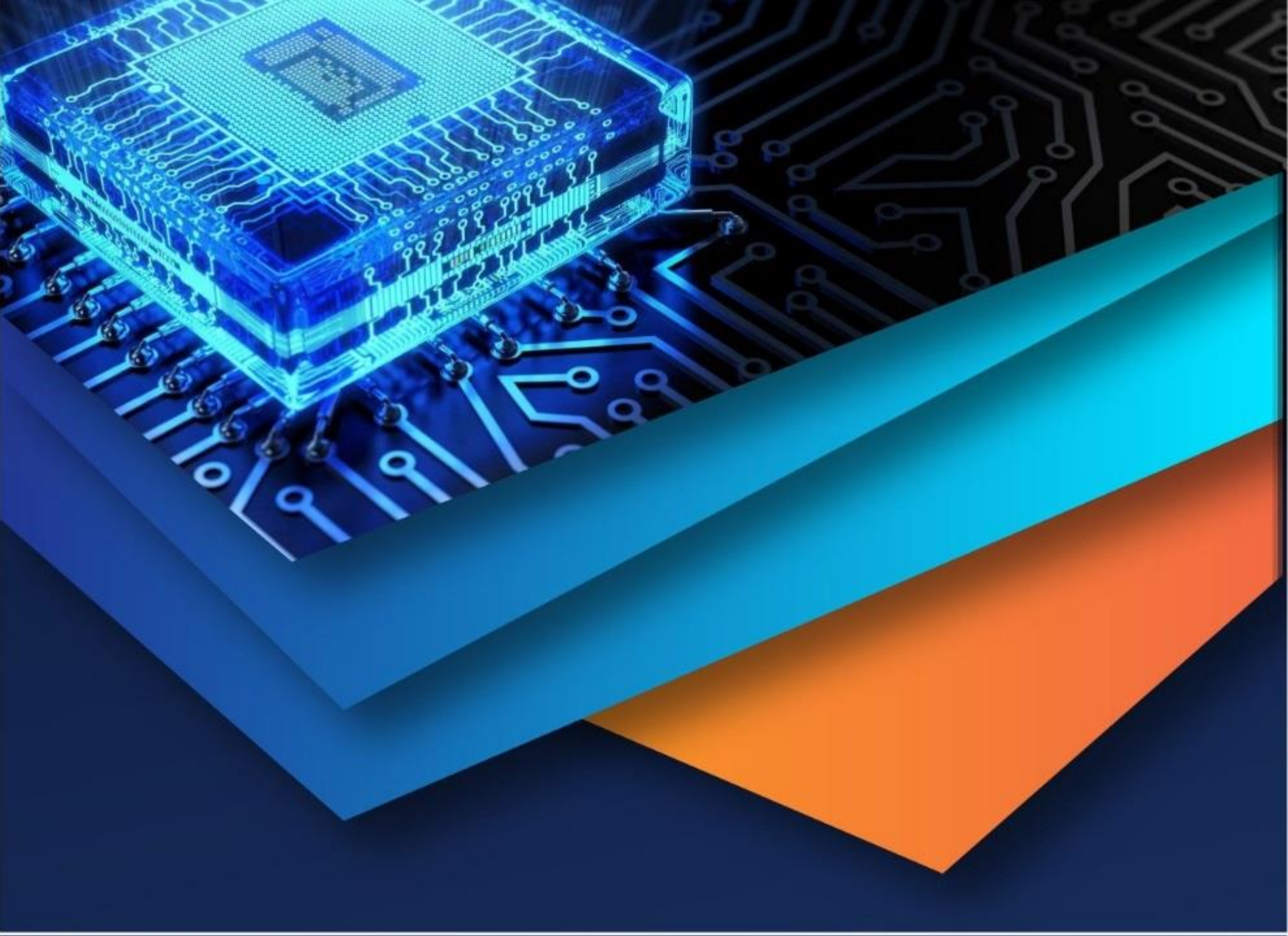
[7] S. Allan and M. Barczyk, "A low-cost experimental quadcopter drone design for autonomous search-and-rescue missions in GNSS-denied environments," Drones, vol. 9, no. 8, p. 523, 2025. DOI: 10.3390/drones9080523.

[8] R. Zhang et al., "Real-time SLAM implementation on embedded processors for UAV navigation," IEEE Robotics and Automation Letters, vol. 8, no. 11, pp. 7234-7241, 2023. DOI: 10.1109/LRA.2023.3321456.

[9] Y. Hu et al., "Edge computing framework for multi-UAV search and rescue coordination," IEEE Transactions on Network and Service Management, vol. 20, no. 4, pp. 4512-4525, 2023. DOI: 10.1109/TNSM.2023.3287654.

[10] J. Peña Queralta et al., "AutoSOS: Towards multi-UAV systems supporting maritime search and rescue with lightweight AI and edge computing," arXiv preprint arXiv:2005.03409, 2020. [Online]. Available: https://arxiv.org/abs/2005.03409

[11] L. Chen and K. Wang, "Aerial human detection dataset for UAV-based search and rescue," Data in Brief, vol. 45, p. 108912, 2022. DOI: 10.1016/j.dib.2022.108912.



10.22214/IJRASET

INDEX COPERNICUS 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)