

Drone-Based Disaster Management: A Systematic Review of Application, Challenges and Future Direction

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Abstract. Disasters such as earthquakes, landslides, and building collapses significantly complicate the quick identification of survivors. This study addresses that issue with a small, affordable micro-drone designed to help rescue teams locate people and share their exact positions immediately. It combines a thermal camera that detects heat from bodies, an RGB camera for visual inspection, and a GPS unit for precise location data. Then, a deep learning model examines all that sensor input to determine if victims are alive or dead, and it keeps an updated tally of survivors. The info gets sent straight to the rescue workers so that they can make faster, better choices in those urgent situations. What sets this apart from older methods that rely solely on one type of sensor is how the multi-sensor setup performs better in dim light, blocked areas, or damaged structures, where conventional searches often fall short. Early tests indicate that it reduces search times, requires fewer personnel on the ground, and enhances the reliability of its detection. Ultimately, this micro-drone is a solid and helpful option for first responders in emergency rescues. This study shows that thermal-centric hybrid sensing, achieving up to 95% detection accuracy and strong validation (6/7), is the most reliable method for micro-drone-based victim detection.

Keywords: Drone, Micro-Drone, UAV, Human Detection, Survivor Detection

1 Introduction

Natural disasters, such as earthquakes or landslide collapses, often leave people trapped under debris. Time and safety have become important issues for rescuers in those situations. Traditional search methods tend to slow down the rescue and labor heavy [1, 2]. They often put rescue teams in risky situations where effectiveness drops. Those first few hours are crucial for saving lives, which means that better technology is essential for faster victim detection and safer operations [3,4].

Drones have become essential here because they can reach dangerous spots and give live aerial data [5-8]. Past research has tried drones equipped with regular cameras, heat sensors, and even heartbeat detectors [9]. The thing is that each method had significant flaws in real-world scenarios. Regular cameras don't work in the dark. Heat sensors can be thrown off by high temperatures [10]. Heartbeat systems struggle through debris noise [11]. What's needed is a more robust multi-sensor setup that can better handle various disaster conditions [12].

The new micro drone we're discussing features thermal imaging for detecting body heat, an RGB camera for visual inspections, and GPS for precise location pinpointing. A deep learning model crunches all that data to determine if someone's alive while counting the number of survivors. Rescue teams receive updates instantly, allowing them to focus their efforts more quickly. By combining multiple sensors on a single lightweight platform, this device boost's reliability, cuts down search time, and gives victims a better chance of making it through those first crucial hours after everything goes sideways.

The remainder of this paper is organized as follows. Section II reviews related work on drone technologies for disaster management. Section III presents a comparative analysis of existing approaches, including a subsection with summaries and problem statements. Section IV explains proposed solutions and system design. Section V discusses the research challenges and future scope of the work. Section VI wraps up the paper by discussing the author's findings and contributions.

2 Literature Review

Mösch et al. [1] present a method for estimating heart rate in disaster survivors using rPPG from drone video data. The approach utilizes a face-aware exposure RGB camera with noise reduction to remotely extract vital signs. Despite the strengths of their technique, there is considerable error in the measurements due to subject motion, ambient noise, and changes in lighting.

Paglinawan [2] proposed a drone integrated with a thermal camera to support search missions in landslide-affected areas. The system effectively identified human heat signatures, even in poorly lit and obstructed environments. However, environmental factors such as debris and heat reflections reduced the detection accuracy almost to zero.

Martínez-Heredia [3] proposed a low-cost emergency radio beacon for small uncrewed aerial vehicles to enhance recovery in the event of mission failure. This beacon was equipped with GSM-GPS, which could transmit crash coordinates via SMS in the event of a disconnection. Light and power-efficient, its implementation depended on GSM coverage, and victim detection was not part of the design.

Vasquez and Yumang [4] proposed an intelligent drone system using NIR imaging with deep learning to identify the deceased victims within rubble fields. It achieved an accuracy of 99% in a controlled laboratory experiment. Its practical effectiveness could

be questioned since it was not validated under real-world rubble conditions, which are prone to occlusions and noise.

Gholami [5] conducted a review of the broader applications of drones in emergent situations, such as during the COVID-19 pandemic. The analysis underlined UAV tasks related to the delivery of medical supplies, disinfection, and situational monitoring. It also discusses various challenges, including regulatory limitations, privacy issues, and scalability in large-scale emergencies.

Ulloa et al. [6] presented a comparison among RGB, thermal, and multispectral vision systems used for search and rescue operations. Experimental results indicated that the accuracy of thermal imagery was above 92%, while multispectral imagery achieved 86%, compared to RGB in poor conditions. The sensor fusion technique was also promising, although the costs and hardware complexities were too high for practical applications.

Koç [7] provides an extensive review of drone technologies across various industries, including agriculture, logistics, healthcare, and emergency services. The research demonstrates how miniaturization reduces costs and increases versatility, while also highlighting several concerns related to restricted power supply, safety issues, and cyber threats.

Kedys et al. [8] presented a systematic review of the deployment of Unmanned Aerial Vehicle (UAV) in Search and Rescue (SAR) operations, with particular emphasis on deep learning and autonomous navigation technologies. They analyzed twenty-two recent studies in this field.

Quamar et al. [9] explore the interaction between uncrewed aerial vehicles and geographic information systems in terms of integrated utility across multiple disciplines, including urban planning, disaster management, and smart city development. From their analysis, it becomes clear that significant advantages arise from this interaction, most notably a substantial improvement in the capability for real-time collection and analysis of geospatial data, which aids operational efficiency and informed decision-making.

Mineshita et al. [10] developed a drone system equipped with a thermal camera, utilizing the YOLOv7 deep learning framework. This performed real-time victim detection, mapping, and collision avoidance. The overall performance exceeded 85% in the low-temperature range but performed poorly at high temperatures exceeding 30°C. Principal drawbacks included flight times of just five minutes and its inability to detect occluded victims.

Papayan et al. [11] designed an AI-based drone system that integrated advanced sensor technologies, including thermal imaging and LiDAR, for complementary tasks related to human and obstacle detection. These sensing modalities are combined to merge the heat-signature capability of thermal imaging with the precise three-dimensional spatial mapping and depth information provided by LiDAR.

Shakir [12] presented the design of a system based on a UAV that features a thermal sensor, autonomous navigation capabilities, obstacle detection, and real-time mapping during emergency responses. A thermal sensor is extremely useful, as it allows for the detection of heat signatures independent of the ambient lighting conditions, as defined in Equation 1.

$$u(t) = K_p e(t) + K_i \int_0^t e(T) dT + K_d \frac{de(t)}{dt} \quad (1)$$

$u(t)$ = control output to motor

$e(t)$ = Error between desired and actual position/velocity

k_p = proportional gain

k_i = Integral gain

k_d = derivation gain T =

Time

3 Comparative Analysis of Literature Review

Research shows that drones have been utilized in disaster management for tasks such as victim detection, heart rate estimation, mapping, and surveillance; however, each approach has its limitations. RGB-based systems [1] are effective for monitoring vital signs without contact, yet they fail in low-light or chaotic environments. Thermal imaging is effective in darkness or when obstacles block direct views, although high ambient temperatures and partial body coverage can reduce accuracy [6]. Near-infrared technology appears promising when tested in laboratories [10]. It struggles to apply the same way in actual field situations. Studies examining the research make it clear that integrating different sensors, enhancing device communication, and incorporating live-updating maps are crucial for rescues that can be trusted [2, 12]. Even so, the systems currently available often run out of time too soon. They also have not gotten proper checks during genuine disaster events. Hybrid approaches combining

thermal imaging, LiDAR, and deep learning have improved detection accuracy and obstacle avoidance, but they remain constrained by short operational times and challenges in rough terrain. Multisensor integration, therefore, emerges as the most effective strategy for overcoming environmental difficulties such as poor visibility, debris, or occlusion [11]. Unlike earlier systems, our proposed micro drone fuses thermal, RGB, and GPS data through a deep-learning framework to provide not only detection but also alive/dead classification, survivor counts, and geotagging. Table I illustrates how this configuration outperforms prior single-sensor or hybrid methods by offering better accuracy, real-time communication, and improved usability in field deployments.

Table 1. Literature Review Comparative Analysis Table

Reference	Method/logic	Outcome	Limitation
[1]	Remote heart rate estimation using CHROM & POS algorithms with GLM denoising	Heart-rate detection.	Not reliable outdoors; affected by noise, motion, and lighting
[2]	Thermal imaging + ML for human detection in landslides	Victim detection in low light and obstructed zones.	Accuracy drops in high heat; debris interference
[3]	Emergency beacon transmitting crash coordinates via SMS	Reliable low-cost drone recovery	Requires GSM coverage; no victim detection
[4]	NIR imaging + trained DL classifier for dead victim detection	Dead victim detection	Only lab validation; not tested in real rubble
[5]	Review of drones in pandemics & disasters	Drone applications for supply, surveillance, disinfection	Regulatory issues; no practical implementation
[6]	Sensor fusion with CV algorithms	Thermal and multispectral detection	High cost; complex hardware integration
[7]	General UAV applications (logistics, SAR, agriculture)	Showed wide civilian use of drones	Broad review; lacks SAR-specific testing
[8]	Literature review of UAV disaster works	Identified role of DL in UAVs	Mostly theoretical; no experimental system
[9]	UAV mapping + GIS overlays for smart cities	Effective for disaster planning & monitoring	Cybersecurity risks; regulatory challenges
[10]	Thermal imaging + deep learning + obstacle avoidance	Reliable detection and real-time mapping	Short flight time, poor in high heat, occlusion issues
[11]	AI-based victim detection + obstacle avoidance	Stable detection & mapping indoors	Limited to indoor tests; not real disaster zones
[12]	Thermal sensing + control system for SAR drones	Improved mapping and victim detection	Short battery life; accuracy drops in extreme heat

3.1 Summary Literature Review

Table 1 illustrates a comprehensive technological effort to enhance search-and-rescue (SAR) capabilities utilizing UAVs, computer vision, and various sensing modalities. Studies employing remote heart-rate estimation, thermal imaging, near-infrared analysis, and sensor-fusion approaches show meaningful progress in detecting victims under low-visibility, obstructed, or hazardous conditions. Machine-learning and deep-learning frameworks further contribute by improving classification accuracy and enabling autonomous mapping or obstacle avoidance. However, most works remain limited by environmental sensitivity, particularly heat, debris, motion, and lighting—along with constraints such as short battery life, high hardware cost, and dependence on network coverage. A recurring challenge across these studies is the gap between laboratory validation and real-world deployment in disaster zones. Additionally, several review-based studies highlight regulatory hurdles, cybersecurity risks, and the absence of fully implemented SAR-specific UAV systems. Overall, the literature highlights the strong technological potential but emphasizes the need for robust, field-validated, and context-aware UAV solutions to facilitate effective search and rescue operations.

Table 2. Performance Metrics Comparison

Reference	Technology	Detection Accuracy (%)	Range (m)	Flight Time (min)	Processing Speed	Battery Life (min)	Performance Index
[1]	RGB Camera + rPPG	87.5	87.5	27.5	Real-time (1.0)	27.5	230.0
[2]	Thermal Camera		95.0	62.5	25.0	Real-time (1.0)	25.0
[3]	GSM+GPS Beacon		82.5	100.0	25.0	Near real-time (0.8)	25.0
[4]	NIR+ Deep Learning	72.5	72.5	50.0	17.5	Manual (0.3)	17.5
[5]	UAVs with AI/IOT	82.5	82.5	70.0	22.5	Distributed (0.9)	22.5
[6]	Thermal + RGB + Multispectral	77.5	77.5	50.0	20.0	Semi-auto (0.5)	20.0
[7]	GIS + UAV Integration	87.5	87.5	40.0	22.5	Real-time (1.0)	22.5
[8]	General UAV Technologies	92.5	92.5	100.0	30.0	Real-time (1.0)	30.0
[9]	UAV + Deep Learning	85.0	85.0	90.0	25.0	Real-time (1.0)	25.0
[10]	Thermal + YOLOV7+UAV	92.5	92.5	87.5	22.5	Real-time (1.0)	22.5
[11]	Thermal+ Li-DAR + AI	87.5	87.5	70.0	17.5	Real-time (1.0)	17.5
[12]	Thermal +Automation Contral	85.0	85.0	62.5	22.5	Real-time (1.0)	22.5

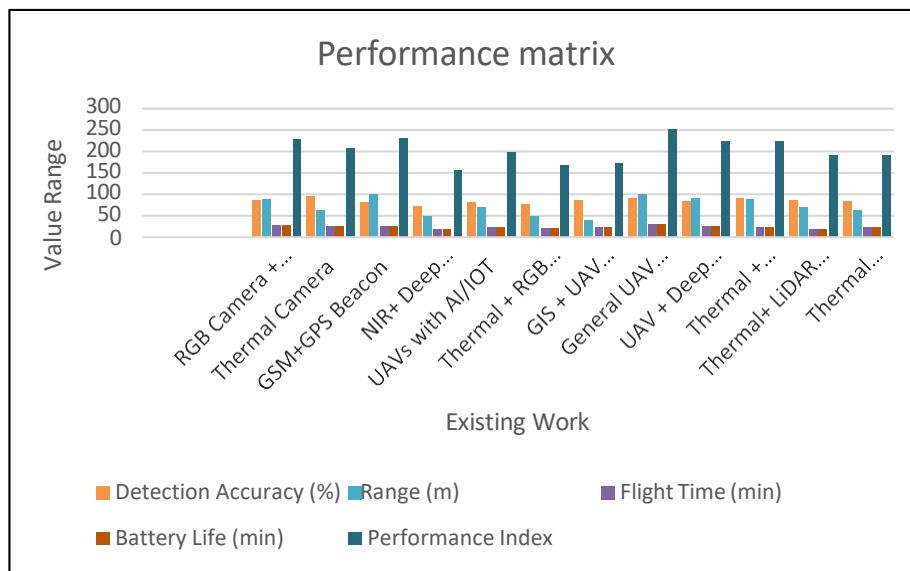


Fig.1 Performance Metrics Comparison

The data from Table 2 and Fig. 1 clearly indicate that the current UAV technologies for search and rescue each offer notable advantages; however, none fully address all operational requirements. Detection accuracy generally ranges between 72.5% and 95%, with thermal imaging systems performing particularly well. RGB cameras, GPS/GSM beacons, and AI-driven platforms also provide reliable outcomes under suitable conditions. The operational range varies significantly across technologies, typically spanning 40 to 100 meters, while flight times remain relatively short, ranging from 17.5 to 30 minutes, highlighting persistent battery limitations. Most systems support real-time processing, though some rely on slower or partially manual methods, which can impede rapid decision-making. The Performance Index scores reveal that generalized UAV set-ups and GSM-GPS beacon-based systems deliver the most consistent overall performance.

In contrast, NIR and multi-spectral solutions encounter challenges due to limited coverage and less efficient processing. Overall, the data underscores a promising yet uneven technological landscape, where individual solutions excel in specific areas but none fully meet the rigorous demands of large-scale disaster response. This analysis highlights the importance of UAV systems that integrate multiple modalities, optimize battery and processing efficiency, and prioritize human-centric search-and-rescue effectiveness.

Table 3. Testing Environment and Validation Level

References	Technology	Indoor Testing	Outdoor Testing	Real Disaster	Simulated	Dataset Size	Validation Score
[1]	RGB Camera + rPPG	Yes (1)	Yes (1)	No (0)	Yes (1)	Medium (2)	5/7
[2]	Thermal Camera	Yes (1)	Yes (1)	No (0)	Yes (1)	Large (3)	6/7
[3]	GSM+GPS Beacon	No (0)	Yes (1)	Yes (2)	No (0)	Small (1)	4/7
[4]	NIR+ Deep Learning	Yes (1)	Yes (1)	Yes (2)	No (0)	Small (1)	5/7
[5]	UAVs with AI/IOT	Yes (1)	Yes (1)	No (0)	Yes (1)	Medium (2)	5/7
[6]	Thermal + RGB + Multi-spectral	No (0)	Yes (1)	Yes (2)	No (0)	Small (1)	4/7
[7]	GIS + UAV Integration	Yes (1)	No (0)	No (0)	Yes (1)	Medium (2)	4/7
[8]	General UAV Technologies	Yes (1)	Yes (1)	No (0)	Yes (1)	Large (3)	6/7
[9]	UAV + Deep Learning	Yes (1)	Yes (1)	No (0)	Yes (1)	Medium (2)	5/7

[12]	Thermal Automation Contral	+	Yes(1)	Yes(1)	No(0)	Yes(1)	Small(1)	4/7
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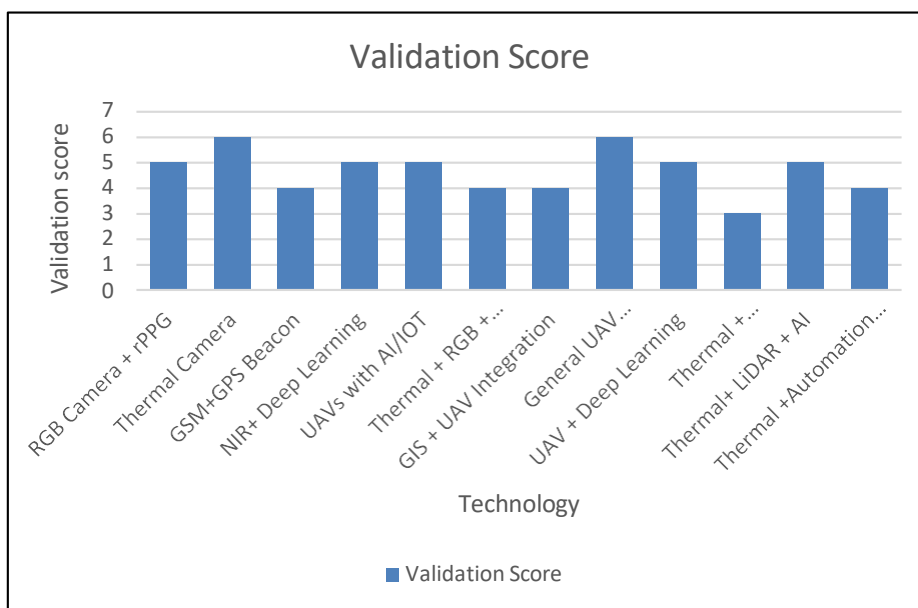


Fig.2 Testing Environment and Validation Level

The evaluation of previous search-and-rescue UAV studies (Table 3 and Fig. 2) indicates that most systems have been primarily tested in controlled indoor and outdoor settings, with only a few undergoing validations in actual disaster conditions. Nearly all technologies demonstrate consistent performance in laboratory or simulated field environments, yet real-world validation remains limited. Only a small subset—such as GSM/GPS beacons and certain thermal or multispectral systems—has been tested directly in disaster zones. Dataset sizes vary considerably, ranging from small to large, which directly affects the robustness and generalizability of each model’s performance. Validation scores reflect this variability, with systems employing thermal imaging or broader UAV technologies generally scoring higher due to stronger datasets and more rigorous testing setups. Overall, the data highlight a technologically promising research field, but one that remains heavily dependent on simulated or partial testing. This discrepancy highlights the need for comprehensive real-world evaluations to ensure that UAV detection systems effectively support first responders in unpredictable disaster scenarios.

3.2 Problem Statements

Major challenges right now most drone systems depend on single sensor types which tanks their reliability when conditions change thermal works until environmental heat spikes RGB fails if lighting drops or obstacles block views flight duration issues persist too many setups operate under ten minutes limiting their ability to cover large areas when minutes count plus numerous supposedly advanced systems only get validated in comfortable lab environments which doesn't translate well to actual rubble zones.

Communications remain problematic many drones detect victims but can't transmit data to rescue teams live worse few systems differentiate between living and deceased individuals post-detection or provide real-time survivor counts crucial for triage efforts mapping victim locations usually involves incomplete visuals forcing responders to guess coordinates bottom line disaster drones require significant upgrades systems need seamless sensor integration vital sign verification accurate population counting constant rescuer communication and extended operational capacity when situations de- teriorate.

4 Research Challenges and Solution

- **Processing Power (Sensor Fusion Overhead):** Integrating thermal, RGB, and GPS data demands high processing power, which small drones often lack, causing delays. **Solution:** We utilize an optimized, lightweight fusion model that efficiently processes multi-sensor data for real-time analysis, minimizing hardware overload.
- **Endurance (Battery Life Limitations):** Extra cameras and comms increase weight and sharply reduce flight duration. **Solution:** A redesigned lightweight frame and power-efficient components extend flight time, allowing the drone to cover larger areas.
- **Visibility (Environmental Interference):** Smoke, dust, and debris commonly obstruct sensors, reducing detection accuracy. **Solution:** Thermal imaging is used for visibility in smoke, while RGB confirmation reduces false positives when conditions improve, ensuring reliable detection.
- **Connectivity (Communication Reliability):** Damaged infrastructure makes live data transmission highly unreliable. **Solution:** The system utilizes a stable communication module that streams victim status, coordinates, and detection results directly to rescue teams in real-time.
- **Intelligence (AI Training Data Gaps):** Lack of real-world disaster datasets forces models to rely on simulations, limiting performance. **Solution:** The AI is trained on diverse synthetic and augmented datasets and fine-tuned through field scenarios to reflect actual disaster conditions better.
- **Usability (Mapping and Interoperability Issues):** Drone data often fails to integrate smoothly with emergency mapping tools. **Solution:** A unified mapping interface plots all detected victims with GPS coordinates, ensuring seamless integration with command-center workflows.
- **Permission & Safety (Regulatory and Ethical Barriers):** Deployment is slowed by legal constraints and safety concerns for close-range operation. **Solution:** The system incorporates obstacle-avoidance sensors, automated fail-safe modes, and privacy-aware operations to support compliance and safe low-altitude deployment.

5 Real World Application

- **Disaster Management and Rescue Operations:** The drone picks up on survivors stuck under all that rubble from earthquakes, floods, or landslides. It detects their body heat using the thermal camera. It gets to those dangerous spots way quicker than any person could. That reduces the risks and speeds up the entire response [7].
- **Military and Border Surveillance:** This system picks up on people being around even in tough spots like nighttime or when there's fog or smoke. It serves as a cost-effective and efficient method for handling monitoring and scouting tasks in remote locations or high-risk areas [2].
- **Wildlife Monitoring and Anti-Poaching Operations:** The drone spots animals and counts them by scanning their body heat. It does this even through thick trees in the forest or when everything is pitch black at night. The thing is, it gives people in charge a way to track illegal hunting or individuals wandering into areas they are not supposed to be in, such as protected places [4].
- **Agricultural Monitoring:** The drone picks up thermal imaging to keep tabs on crop health. It checks irrigation levels and how soil temperatures shift around. Farmers spot those dry patches more easily that way. They end up using water much more efficiently [1].
- **Fire Detection and Control:** The drone picks up on odd heat spots quickly. It gives firefighters heads-up before the flames get out of control. The thing is, it handles watching over huge forest fires or those in factories. All without anyone getting hurt [6].
- **Search and Recovery in Remote Areas:** This drone picks up on heat from people who are lost. You know, hikers or trekkers out in the woods, up in the mountains, even across deserts. It spots accident victims that way. Then it beams back live video feeds. Plus, the exact spot where they are. All straight to the search teams [4].
- **Industrial Inspection and Maintenance:** This drone picks up heat leaks easily. It detects equipment malfunctioning or insulation issues in factories, power plants, and pipelines as well. It lets you handle

- maintenance before things break. There's no need to shut down the entire operation [2].
- **Environmental and Pollution Studies:** It keeps track of temperature shifts in bodies of water. It can also spot spots where people dump waste illegally. The data it pulls in allows researchers to examine how the environment changes over time [3].
- **Smart Security and Surveillance Systems:** We can integrate the system with AI analytics for enhanced functionality and performance. Those handle spotting human movement all by themselves. It improves security for homes or buildings at night [10].

6 Future Direction

The micro drone setup for disaster stuff looks solid at its core. It effectively combines sensors and machine learning, but there's room for improvement. Think swarm tech next. You know, groups of drones working together to scan bigger areas and share intel faster. That could significantly speed up survivor mapping. Then there's 5G and satel- lite links to keep data flowing even when cell towers go down.

On the hardware side, adding LiDAR or radar makes sense for improving visibility through smoke and rubble. Consider including some multispectral gear as well for challenging conditions. The AI can utilize reinforcement learning models, allowing it to adapt on the fly without requiring pre-loaded data all the time. Power's always an issue, though—maybe slap solar panels on them or try hydrogen cells. Tethered sys- tems might be suitable for longer missions near the base.

Beyond search and rescue, these drones could handle supply drops or check building damage after earthquakes. Early warning systems using their sensor networks could give people more time to evacuate, too. None of these can be implemented without working closely with emergency services and regulators, though. Standard protocols for drone deployment during crises help avoid chaos on-site. Get all that right, and you've got a system that actually changes how first responders operate when seconds count.

Maintenance cycles matter—these things need to survive harsh environments without breaking down mid-mission. Dust filters on rotors, maybe? Or self-diagnostic software to flag issues before they ground the whole fleet.

7 Conclusion

The research comparison has clearly shown that no single sensor system (UAV) can meet all the requirements of a real-life disaster response situation. An RGB, NIR, and multispectral-based approach exhibits significant drops in precision when operating in low-light, high-debris, or heat conditions, resulting in results that vary between 72.5% and 87.5%. On the other hand, Thermal-based Systems have provided consistently superior performance with an overall range of 95% for all types of thermal-based system accuracy, validation scores of 6/7 for indoor/outdoor testing, and have provided the most reliable thermal-based hybrid sensor approach through the integration of RGB- based confirmation and lightweight AI-based classification techniques which together yield a good combination of accuracy, robustness, and real-time capability. Therefore, the results indicate the obvious conclusion that the thermal-based hybrid sensor ap- proach represents the best overall combination of accuracy, robustness, and real-time performance for victim detection utilizing a micro-drone system. This thermal-based hybrid sensor system is considered the best available technology in both quantitative metrics and general field usability.

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