Intellectual Journal of Energy Harvesting and Storage
Vol. 4, No. 2, December 2026, pp. 109~116
ISSN: 2963-6272, DOI: 10.11591/ehs.v4i2.pp109-116

Development of solar-assisted drone for disaster management

Mani Sai Aashrith Atkuri, Himabindu Eluri, Naveen Kumar Amasola, Vaila Bhanu
Department of Electrical and Electronics Engineering, Geethanjali College of Engineering and Technology, Hyderabad, India

Article Info

Article history:

Received Mar 31, 2026
Revised Apr 17, 2026
Accepted Nov 1, 2026

Keywords:

Disaster management
Emergency communication
Energy optimization
ESP32
Flight time enhancement
Long-range communication
Solar-assisted unmanned aerial vehicle

ABSTRACT

The growing demand for long-endurance and reliable unmanned aerial systems has led to increased interest in energy-efficient and communication-enabled unmanned aerial vehicle (UAV) platforms. This paper presents the development of a solar-assisted UAV integrated with long-range (LoRa)-based communication for disaster management applications. The system incorporates lightweight photovoltaic panels to support the onboard lithium polymer (LiPo) battery, helping to reduce rapid energy depletion and improve overall flight efficiency. To enable communication in areas where conventional infrastructure is unavailable, ESP32-based LoRa modules are used to establish LoRa low-power wireless links. Experimental observations indicate that the inclusion of solar assistance reduces effective power consumption by approximately 3–5%, resulting in a measurable increase in flight time from around 10–11 minutes to 11–12 minutes. The communication system demonstrated reliable performance over distances of up to 2–5 km under line-of-sight conditions. Overall, the proposed system shows that combining solar energy with LoRa communication can enhance both endurance and connectivity, making it a practical solution for disaster response and emergency communication scenarios.

This is an open access article under the CC BY-SA license.

Corresponding Author:

Mani Sai Aashrith Atkuri
Department of Electrical and Electronics Engineering, Geethanjali College of Engineering and Technology
Hyderabad, Telangana, India
Email: 22r11a0203@gcet.edu.in

1. INTRODUCTION

One of the biggest challenges that unmanned aerial vehicles (UAVs) face in real-world deployments is their limited flight time, which typically hovers around just 20 minutes due to battery constraints. Researchers have explored various approaches to tackle this-from battery swapping and wireless charging to energy harvesting through solar panels. Lee *et al.* [1] took a different route by developing a buoyancy-aided autonomous aerial vehicle (AAV) that uses helium-filled balloons to reduce the drone's effective weight, allowing a higher—capacity battery to be installed without the usual weight penalty. However, the added balloons introduced a new problem, an "inverted pendulum effect" that made the drone unstable under windy conditions. To counter this, the authors applied deep reinforcement learning (DRL) to adaptively control rotor speeds in real time, ultimately achieving a flight time extension of over 112% compared to a standard drone under gusty wind conditions.

The weight of a drone is one of the most critical factors influencing its power consumption, battery life, and overall flight performance. Shafiq *et al.* [2] highlighted that conventional multirotor drones typically achieve only 5 to 30 minutes of flight time due to the heavy energy demands of counteracting gravity, and that reducing structural weight is one of the most effective ways to extend endurance. Their work proposed an innovative penta-copter design built from a soft silicon material infused with helium gas, which significantly cut down the drone's overall weight and extended flight time to over 45 minutes in simulation. The study also

explored solar cells as a complementary energy solution, noting that integrating photovoltaic panels with a maximum power point tracker (MPPT) controller allows harvested solar energy to be directed to the motors or used to charge the battery, effectively increasing airborne time without a significant weight penalty. This directly motivates the solar-assisted approach adopted in the present work, where solar panels are integrated onto the F450 quadcopter frame to supplement the onboard lithium polymer (LiPo) battery and extend operational endurance during disaster relief missions. While extending flight time is a critical design challenge, ensuring reliable wireless communication onboard a UAV is equally important, particularly when the drone is intended to serve as a communication relay in disaster scenarios. Watanabe *et al.* [3] investigated a largely overlooked but serious problem—electromagnetic interference (EMI) caused by the UAV's own internal electronic components, which they termed "self-jamming." Their study found that EM noise generated by internal modules such as the power supply, microcontroller, and camera circuitry degraded the mobile communication receiver sensitivity by as much as 29 dB in the 800 MHz band, effectively reducing the usable communication range to roughly 1/13th of its normal coverage. This finding is directly relevant to UAV-based communication relay systems, where maintaining a stable wireless link is mission-critical, especially in disaster response environments where infrastructure may already be compromised. The study also demonstrated that targeted countermeasures at the printed circuit board (PCB), cable, and chassis level can suppress this self-jamming noise by up to 26 dB, restoring communication performance—a key design consideration for the ESP32-based long-range (LoRa) communication module integrated into the present work.

Beyond the hardware challenges of flight endurance and onboard interference, deploying a UAV as a communication relay during a disaster introduces another layer of complexity-the unpredictable outdoor environment itself. Fujisawa *et al.* [4] examined how wind direction and speed directly affect the performance of drone-based wireless relay networks built on a delay-tolerant network (DTN) framework, which is designed to maintain communication even when direct end-to-end connectivity is unavailable. Their simulations revealed that headwinds are particularly damaging, causing transmission delay times to spike from around 253 seconds under calm conditions to over 648 seconds at just 5 m/s wind speed, as drones collectively drift downwind and lose their spatial coverage. To counteract this, the authors proposed adaptive flight models—including destination extension and flight area bisection—which together reduced transmission delays by over 100 seconds compared to conventional approaches. This research underscores the importance of accounting for real-world environmental factors when designing UAV-based emergency communication systems, a consideration that directly influences the hovering stability and relay positioning strategy of the solar-assisted drone platform presented in this work.

As UAVs increasingly take on the role of aerial communication relays, their integration into mobile network infrastructures introduces a set of unique challenges that go beyond hardware design. Angjo *et al.* [5] provided a comprehensive survey on handover management for connected drones in future heterogeneous networks, highlighting that unlike ground-based users, drones operate in a full three-dimensional environment where high mobility speeds, dominant line-of-sight interference, and antenna side-lobe effects result in significantly more frequent and failure-prone handover events. The study emphasized that conventional handover protocols designed for terrestrial networks are fundamentally inadequate for airborne platforms, and that drones acting as aerial base stations or relays must maintain seamless connectivity even while in motion across multiple cell boundaries. Critically, the survey noted that during disaster scenarios where ground infrastructure is disrupted, drones represent one of the most viable options for rapidly restoring network coverage, provided their communication links remain stable and reliable. This broader context of UAV-based network integration reinforces the relevance of the present work, where a stationary hovering drone is used as a fixed communication relay point-sidestepping the handover complexity while still delivering emergency connectivity to affected individuals on the ground. Underpinning all the technical challenges discussed above is the broader humanitarian imperative that motivates UAV-based communication research in the first place. Tanzi *et al.* [6] outlined the critical role that communication infrastructure plays across all phases of disaster management—from early warning and damage assessment to coordinating relief operations-emphasizing that the disruption of ground-based networks.

During large-scale events such as earthquakes, floods, and cyclones creates an information vacuum that directly costs human lives. The article highlighted how radio science and emerging autonomous aerial systems, including drone fleets, represent some of the most promising tools for rapidly restoring situational awareness in disaster-stricken areas, particularly when conventional infrastructure is rendered non-functional. The paper also drew attention to the growing convergence of personal connected devices—smartphones and tablets—with autonomous drone platforms, noting that drones capable of detecting and communicating with such devices could serve as critical bridges between isolated survivors and rescue teams. This vision directly aligns with the communication relay architecture proposed in the present work, where an ESP32-based LoRa module on a hovering UAV enables affected individuals to connect via their smartphones and establish contact with disaster response teams without any ground infrastructure.

Building on the importance of UAV-based communication systems, recent advancements have focused on improving the reliability and modeling of drone communication networks. Shan *et al.* [7] emphasized that UAVs play a crucial role in emergency communications, device-to-device (D2D) systems, and internet of things (IoTs) applications due to their ability to rapidly establish communication links independent of terrain constraints. The study highlights that drones can dynamically form communication networks, making them highly suitable for disaster scenarios where quick deployment is essential. However, the research also points out that maintaining reliable communication, especially beyond line-of-sight (BLOS), remains a significant challenge due to factors such as signal attenuation, environmental interference, and dynamic flight conditions. To address these issues, the authors proposed a machine learning-based approach for analyzing communication data and improving model accuracy, demonstrating that intelligent data-driven methods can significantly enhance the performance and reliability of UAV communication systems. This reinforces the need for robust communication frameworks in UAV applications, as adopted in the proposed system, where LoRa-based communication ensures LoRa, low-power connectivity suitable for disaster management scenarios.

Extending the discussion on emergency communication systems, Esubonteng and Rojas-Cessa [8] highlighted the critical requirements of public safety communication (PSC) networks, emphasizing the need for high reliability, low latency, and rapid deployment in disaster scenarios. The study points out that during emergencies, conventional communication infrastructure often becomes unreliable or completely unavailable, making it necessary to adopt flexible and adaptive communication systems such as UAV-assisted networks. The authors also discuss the potential of advanced wireless technologies, including ad hoc and mesh-based architectures, which enable dynamic connectivity between multiple nodes such as drones, ground stations, and rescue teams. However, the research identifies key challenges such as signal blockage, high mobility, and dynamic channel conditions, especially in complex environments. These insights reinforce the importance of developing lightweight, LoRa, and infrastructure-independent communication systems, as implemented in the proposed work using LoRa-based communication, which offers reliable connectivity with low power consumption in disaster-affected regions.

In addition to external communication challenges, internal EMI within drones significantly affects communication reliability. Raja *et al.* [9] investigated the impact of onboard electronic noise on mobile communication systems used in industrial drones, highlighting that electromagnetic noise generated by power modules and control circuits can degrade receiver sensitivity, particularly in compact and lightweight drone architectures. The study identifies two major types of interference-random noise and harmonic noise-both of which influence communication performance depending on their spectral characteristics. It was observed that harmonic noise can have a more severe impact on signal quality compared to random noise under similar conditions, leading to reduced communication efficiency. These findings underline the importance of addressing EMI-related challenges through careful system design and noise mitigation techniques to ensure reliable and stable communication in UAV-based applications.

Further expanding on energy and communication challenges in UAV systems, Watanabe *et al.* [10] explored the limitations associated with drone flight time, power consumption, and communication range, particularly in applications involving large-area monitoring. The study highlights that conventional drones typically operate for only 20–40 minutes due to battery constraints, which significantly restricts their operational efficiency. Various solutions, such as increasing battery capacity, battery swapping, and recharging mechanisms were discussed, each presenting trade-offs in terms of weight, cost, and system complexity. The research also emphasizes the role of renewable energy sources such as solar power and advanced techniques like wireless power transfer (WPT) in addressing these limitations. However, practical challenges such as payload constraints and dependency on environmental conditions remain critical factors. These insights directly support the motivation behind the proposed system, where solar-assisted energy supplementation is implemented to enhance flight endurance while maintaining system efficiency. Although several studies have explored UAV-based communication and energy optimization techniques, most existing approaches tend to address these challenges separately. Systems that focus on improving flight endurance often overlook communication reliability, while communication-focused designs do not adequately consider power limitations. As a result, UAVs used in disaster scenarios still face issues such as limited operating time and unstable connectivity. The proposed work addresses this gap by combining solar-assisted energy support with LoRa-based communication, offering a balanced solution that improves both endurance and communication reliability.

Recent advancements in UAV technology have also explored the integration of renewable energy sources and efficient communication systems to enhance operational performance. Studies such as El-Atab *et al.* [11] and Wei [12] highlight the potential of solar and hybrid energy harvesting techniques in improving UAV endurance, particularly for long-duration missions. Similarly, El-Atab *et al.* [13] demonstrated that the use of lightweight flexible solar panels can significantly improve energy efficiency without adding excessive payload. On the communication side, Manuel *et al.* [14] and Sciullo *et al.* [15] emphasized the

effectiveness of LoRa technology in enabling LoRa, low-power communication for remote and disaster-prone environments. Furthermore, Jin *et al.* [16] and López-Villegas *et al.* [17] discussed the importance of energy-efficient UAV communication networks and their role in emergency response systems. Girma *et al.* [18] also explored IoT-enabled UAV frameworks for disaster management, highlighting their ability to provide rapid and reliable connectivity. These studies collectively reinforce the relevance of integrating renewable energy and LoRa communication technologies, which forms the foundation of the proposed solar-assisted UAV communication system.

2. PROPOSED SYSTEM ARCHITECTURE

2.1. Power system and energy management

Uses solar panels (4×70×70 mm) to generate electrical energy, which is processed through an MPPT and supplied to a 3S 2200 mAh LiPo battery. The battery distributes power to all subsystems including motors, flight controller, and communication units. The solar system supports the battery by reducing its discharge rate, improving overall energy efficiency and flight duration [19].

The MPPT improves solar energy harvesting efficiency by operating the panels at optimal voltage and current conditions. Under varying irradiance levels, the MPPT ensures maximum possible power extraction, with an estimated efficiency of 85–95% depending on environmental conditions.

2.2. Flight control and navigation system

Uses a Pixhawk 2.4.8 flight controller connected to the NEO-M8N global positioning system (GPS), FS-i6 remote controller, electronic speed controllers (ESCs), and brushless direct current (BLDC) motors. The controller processes input signals and GPS data to control motor speed and ensure stable flight, navigation, and hovering. The telemetry module transmits real-time flight data to the ground station for monitoring.

2.3. Communication relay system

Uses ESP32 microcontrollers with LoRa modules for LoRa communication. One module is placed on the UAV and another at the ground station. The UAV acts as a relay node, receiving and transmitting data through LoRa, enabling communication in areas without network infrastructure [20].

2.4. Data transmission and user interaction

A wireless fidelity (Wi-Fi) hotspot is created using ESP32, allowing victims to connect via smartphones and send emergency messages. These messages are transmitted through LoRa to the ground station and received by rescue teams. Simultaneously, telemetry data is sent for real-time monitoring, ensuring effective coordination during disaster operations.

3. WORKING PRINCIPLE

The proposed system operates by integrating power management, flight control, and communication modules to enable efficient UAV operation for disaster scenarios. The solar panels continuously generate electrical energy and support the LiPo battery by reducing its discharge rate, ensuring improved flight endurance. The Pixhawk flight controller receives input from the GPS module and remote controller, processes the data, and controls the motors through ESCs to maintain stable flight. At the same time, the ESP32 microcontroller transmits and receives data through the LoRa communication module, enabling LoRa wireless communication between the UAV and the ground station. This allows real-time data exchange and reliable communication relay, ensuring effective monitoring and connectivity during disaster management operations.

Figure 1 discusses the initialization process of the proposed solar-assisted UAV system, where the Pixhawk 2.4.8 flight controller acts as the main control unit. The system is powered by a 2200 mAh LiPo battery supplying energy to all onboard components, while four photovoltaic panels (70×70 mm) generate supplementary power during operation. The solar output is passed through a blocking diode to prevent reverse current flow and support the battery by reducing its discharge rate, improving overall energy efficiency and flight duration. The flight controller initializes and calibrates modules such as the NEO-M8N GPS and telemetry system, ensuring proper system functionality before take-off. Simultaneously, the ESP32 with LoRa module establishes a LoRa communication link with the ground station, making the UAV fully operational, energy-efficient, and ready for disaster communication missions. This hybrid power approach enhances system reliability by optimizing energy usage without adding significant complexity. The integration of communication and power systems ensures uninterrupted operation during mission-critical scenarios. Overall, the initialization stage prepares the UAV for stable flight, efficient energy utilization, and reliable LoRa communication.

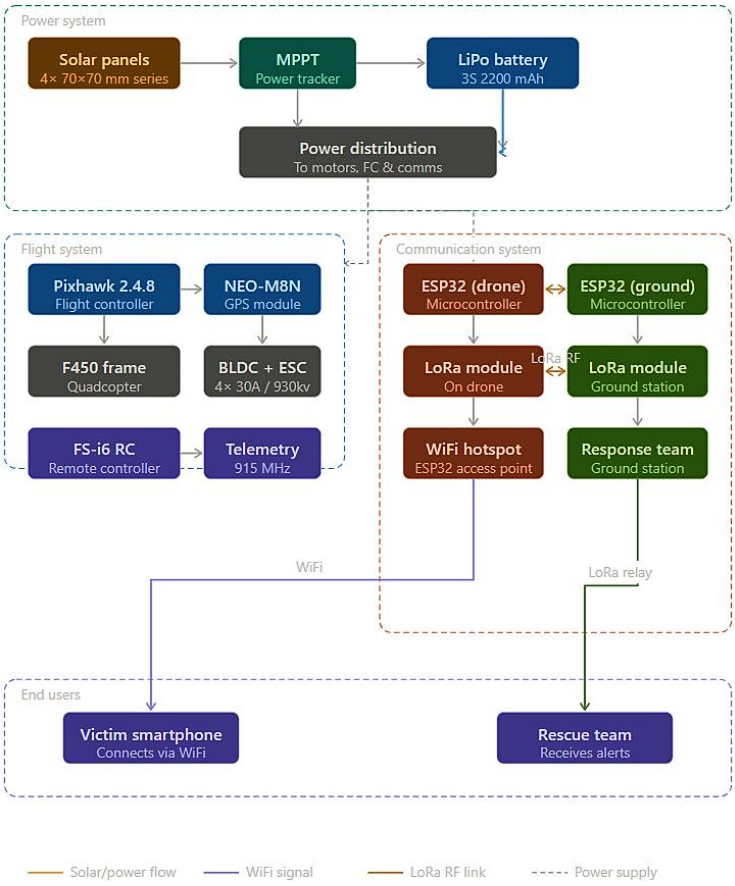


Figure 1. Process flow of the solar assisted UAV

Figure 2 shows the flight control and navigation system of the proposed UAV, where the Pixhawk 2.4.8 flight controller acts as the main controller of the drone. It is connected to the NEO-M8N GPS module, FS-i6 remote controller, ESCs, and BLDC motors. The GPS module continuously provides real-time location data, while the remote controller sends control inputs. The flight controller processes these inputs and generates signals to the ESCs, which regulate the speed of the motors to control movement and stability. The system continuously monitors flight parameters and makes real-time adjustments to maintain balance and stable flight under varying conditions. At the same time, the telemetry module transmits important flight data to the ground station for monitoring. This ensures precise navigation, controlled movement, and reliable performance of the UAV during operation.

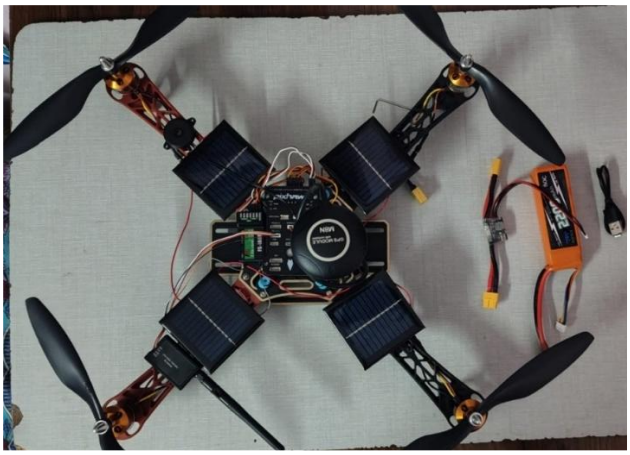


Figure 2. F450 quadcopter UAV Installed with Pixhawk 2.4.8 FC connect with GPS and telemetry

Figure 3 shows the communication relay and monitoring system of the proposed UAV, which uses ESP32 microcontrollers and LoRa modules to enable LoRa wireless communication during disaster situations. The ESP32 acts as the main processing unit for communication, connected to the LoRa module with an antenna, telemetry module, and flight controller. When a user attempts to send a message, the signal is received by the ground node and transmitted through the LoRa module to the UAV. The onboard ESP32 processes this data and relays it to the ground station, enabling communication between affected individuals and rescue teams even in the absence of conventional network infrastructure. At the same time, the telemetry module continuously sends real-time flight data such as location, altitude, and system status to the ground station. This allows operators to monitor the UAV's performance and communication status effectively. The system ensures reliable data transmission, LoRa connectivity, and real-time monitoring, improving the efficiency and response time in disaster management operations. Figure 4 illustrates the LoRa-enabled communication system implemented using the ESP32 module. The main specifications of the proposed solar-assisted UAV, including its platform, battery, flight time, solar panels, and communication system, are summarized in Table 1.



Figure 3. 6-channel (FS-i6) UAV controller with transceiver

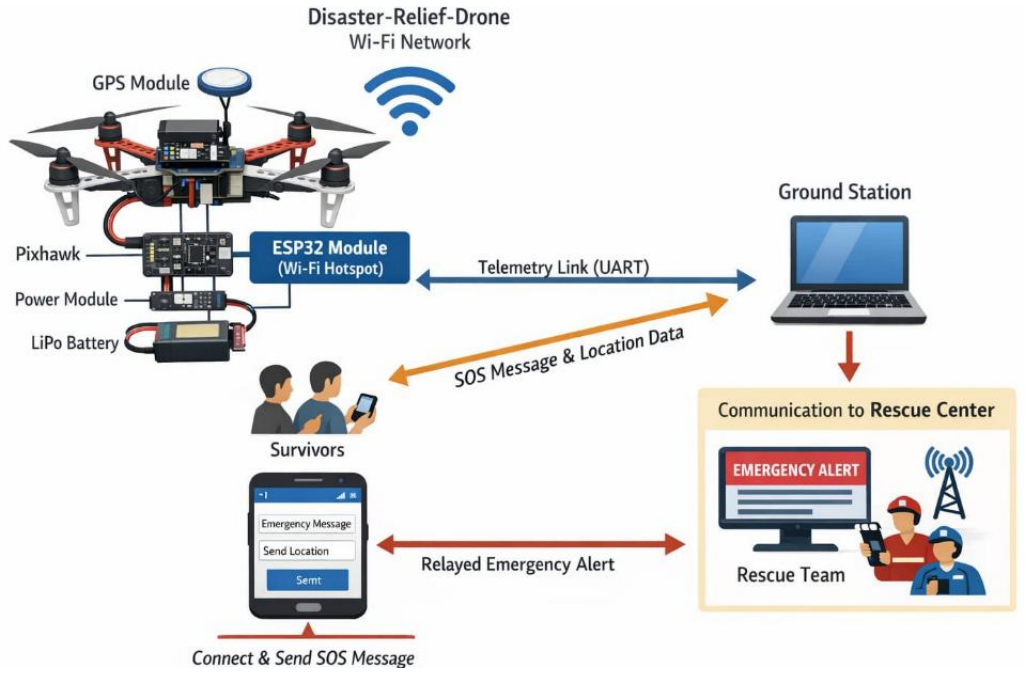


Figure 4. LoRa enabled communication through ESP32 module

Table 1. Parameters of the solar-assisted UAV

Parameter	Specification
UAV platform	Quadcopter (F450)
Flight controller	Pixhawk 2.4.8
Motors and ESC	A2212 BLDC+30A ESC
Battery	2200 mAh, 11.1 V LiPo
Avg. power consumption	~135 W
Flight time	~10–12 min
Solar panels	4×70×70 mm, ~4 W
Improved flight time	~11–12 min
Communication	ESP32+LoRa (SX1278)
Communication range	2–5 km (LoS)
GPS module	NEO-M8N
Operating altitude	50–100 m
Parameter	Specification

4. RESULTS AND DISCUSSION

In this section, it is explained the results of research and at the same time is given the performance of the proposed solar-assisted UAV system was evaluated under practical operating conditions to analyze its effectiveness in terms of flight endurance, power utilization, and communication capability. The system was tested in both baseline (without solar assistance) and solar-assisted modes to observe the impact of photovoltaic integration on battery performance. Key parameters such as flight time, power consumption, and communication range were recorded and analyzed. The LoRa-based communication system was also evaluated for its ability to provide reliable LoRa connectivity in simulated disaster scenarios. The obtained results demonstrate the feasibility of integrating renewable energy and low-power communication systems into UAV platforms for enhanced operational efficiency. The performance differences between the UAV operating with and without solar assistance are summarized in Table 2.

Table 2. Comparison parameters with and without solar

Parameter	Without solar	With solar
Flight time	10–11 minutes	11–12 minutes
Power consumption	~135 W	~131 W
Energy source	Battery only	Battery+solar assist
Efficiency	Standard	Improved (~3–5%)
System performance	Normal operation	Extended endurance

Figure 5 shows the comparison of battery discharge over time for the UAV with and without solar assistance. It can be observed that the battery drains faster in the absence of solar support, whereas the inclusion of solar panels slightly reduces the rate of discharge. Although the improvement is gradual, it results in an extended operational duration. This demonstrates that solar integration contributes to enhanced energy efficiency by reducing the load on the battery during flight.

Although the observed improvement in flight endurance is modest (~3–5%), the results indicate strong potential for scalability. The use of larger surface-area solar panels or high-efficiency lightweight flexible panels could significantly increase energy contribution, potentially achieving endurance improvements of up to 10–15% in optimized designs. This demonstrates that the proposed system can be further enhanced for long-duration missions.

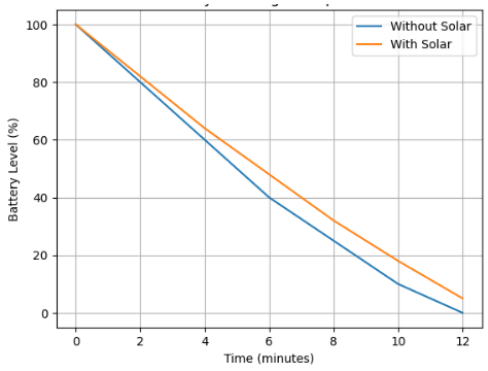


Figure 5. Battery discharge comparison with and without solar

5. CONCLUSION

This paper presented the design and implementation of a solar-assisted UAV system capable of functioning as a communication relay in disaster situations. By combining LoRa-based communication with ESP32 modules, the system enables LoRa, low-power data transmission even in areas where traditional communication networks are unavailable.

The addition of solar panels provides supplementary energy support, helping to reduce battery discharge and slightly extend flight duration. Although the improvement in endurance is modest, it confirms the feasibility of integrating renewable energy into small UAV platforms. The system is lightweight, cost-effective, and can be deployed quickly, making it suitable for real-world disaster response applications. Future work will focus on improving energy efficiency through advanced solar technologies, exploring hybrid energy harvesting methods, and implementing multi-UAV systems to enhance coverage and communication reliability in large-scale disaster environments.

REFERENCES

[1] C.-Y. Lee, A.-H. Tsai, and L.-C. Wang, "Adaptive stabilization control by deep reinforcement learning for hovering drone surveillance," *IEEE Transactions on Mobile Computing*, vol. 24, no. 8, pp. 6720–6733, Aug. 2025, doi: 10.1109/TMC.2025.3548421.

[2] M. Shafiq, M. Awadallah, K. Saleem, and A. E. Youssef, "An energy-efficient and safe landing multirotor design for drones," *IEEE Access*, vol. 12, pp. 110610–110625, 2024, doi: 10.1109/ACCESS.2024.3439400.

[3] K. Watanabe *et al.*, "Electromagnetic interference with the mobile communication devices in unmanned aerial vehicles and its countermeasures," *IEEE Access*, vol. 12, pp. 11642–11652, 2024, doi: 10.1109/ACCESS.2024.3351216.

[4] M. Fujisawa, T. Kamikawa, and A. A. A. M. Kamal, "Flight models considering wind effects on drone-based networks during large-scale disasters," *IEICE Communications Express*, vol. 14, no. 8, pp. 326–329, Aug. 2025, doi: 10.23919/comex.2025XBL0073.

[5] J. Angjo, I. Shayea, M. Ergen, H. Mohamad, A. Alhammadi, and Y. I. Daradkeh, "Handover management of drones in future mobile networks: 6G technologies," *IEEE Access*, vol. 9, pp. 12803–12823, 2021, doi: 10.1109/ACCESS.2021.3051097.

[6] T. J. Tanzi, M. Chandra, J. Isnard, D. Camara, O. Sebastien, and F. Harivelo, "Towards" drone-borne" disaster management: future application scenarios," *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. III–8, pp. 181–189, Jun. 2016, doi: 10.5194/isprs-annals-III-8-181-2016.

[7] L. Shan, R. Miura, T. Kagawa, F. Ono, H.-B. Li, and F. Kojima, "Machine learning-based field data analysis and modelling for drone communications," *IEEE Access*, vol. 7, pp. 79127–79135, 2019, doi: 10.1109/ACCESS.2019.2922544.

[8] P. K. Esubonteng and R. Rojas-Cessa, "RESTORE: Low-energy drone-assisted NLoS-FSO emergency communications," *IEEE Access*, vol. 10, pp. 115282–115294, 2022, doi: 10.1109/ACCESS.2022.3218014.

[9] N. K. Raja, E. L. Lydia, T. A. Acharya, K. Radhika, E. Yang, and O. Yi, "Rider optimization with deep learning-based image encryption for secure drone communication," *IEEE Access*, vol. 11, pp. 121646–121655, 2023, doi: 10.1109/ACCESS.2023.3324068.

[10] K. Watanabe *et al.*, "Simulation-based analysis of noise spectral components affecting mobile communication in industrial drones," *IEEE Letters on Electromagnetic Compatibility Practice and Applications*, vol. 7, no. 4, pp. 129–134, Dec. 2025, doi: 10.1109/LEMCPA.2025.3618568.

[11] N. El-Atab, R. B. Mishra, R. Alshanbari, and M. M. Hussain, "Solar Powered Small Unmanned Aerial Vehicles: A Review," *Energy Technology*, vol. 9, no. 12, 2021, doi: 10.1002/ente.202100587.

[12] X. Wei, Z. Yi, W. Li, L. Zhao, and W. Zhang, "Energy harvesting fueling the revival of self-powered unmanned aerial vehicles," *Energy Conversion and Management*, vol. 283, 2023, doi: 10.1016/j.enconman.2023.116863.

[13] N. El-Atab, S. M. Khan, and M. M. Hussain, "Flexible High-Efficiency Corrugated Monocrystalline Silicon Solar Cells for Application in Small Unmanned Aerial Vehicles for Payload Transportation," *Energy Technology*, vol. 8, no. 11, 2020, doi: 10.1002/ente.202000670

[14] M. P. Manuel, M. Faied, and M. Krishnan, "A LoRa-Based Disaster Management System for Search and Rescue Mission," *IEEE Internet of Things Journal*, vol. 11, no. 20, pp. 34024–34034, 2024, doi: 10.1109/JIOT.2024.3435734.

[15] L. Sciullo, F. Fossemò, A. Trotta, and M. Di Felice, "LOCATE: A LoRa-based mObile emergenCy mAnagement sysTEm," in *2018 IEEE Global Communications Conference (GLOBECOM), Abu Dhabi, United Arab Emirates*, 2018, pp. 1-7, doi: 10.1109/GLOCOM.2018.8647177.

[16] H. Jin *et al.*, "A survey of energy efficient methods for UAV communication," *Vehicular Communications*, vol. 41, Art. no. 100594, 2023, doi: 10.1016/j.vehcom.2023.100594.

[17] I. López-Villegas, E. A. Martínez-Rios, J. Izquierdo-Reyes, R. Bustamante-Bello, and F. Falcone, "A systematic literature review of emergency communications assisted by unmanned aerial vehicles," *Ad Hoc Networks*, vol. 182, 2026, doi: 10.1016/j.adhoc.2025.104063.

[18] A. Girma *et al.*, "IoT-enabled autonomous system collaboration for disaster-area management," in *IEEE/CAA Journal of Automatica Sinica*, vol. 7, no. 5, pp. 1249-1262, September 2020, doi: 10.1109/JAS.2020.1003291.

[19] G. E. M. Abro, A. Ali, S. A. Memon, T. D. Memon, and F. Khan, "Strategies and challenges for unmanned aerial vehicle-based continuous inspection and predictive maintenance of solar modules," *IEEE Access*, vol. 12, pp. 176615–176629, 2024, doi: 10.1109/ACCESS.2024.3505754.

[20] S. H. Alsamhi, O. Ma, M. S. Ansari, and F. A. Almalki, "Survey on collaborative smart drones and internet of things for improving smartness of smart cities," *IEEE Access,* vol. 7, pp. 128125–128152, 2019, doi: 10.1109/ACCESS.2019.2934998.