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FALCON DROP - A CanSat System with Integrated Sensing for Real-Time Environmental Diagnostics in Disaster Zones

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Abstract: Access to real-time environmental data is critical in disaster-stricken and remote regions where conventional communication infrastructure is often damaged or unavailable. This project presents a compact and deployable CanSat-based environmental monitoring system designed to support rescue and recovery operations in such scenarios. It integrates key environmental sensors, including the DHT22 (temperature and humidity), MQ135 (air quality), BME280 (barometric pressure), and MPU6050 (6-axis accelerometer and gyroscope), along with a GPS module for accurate location tracking

A 16×2 LCD display enables real-time on-site data visualization, while a controlled delay in the backend facilitates deployment operations such as antenna extension or parachute simulation. Environmental data is transmitted wirelessly using a GSM module, ensuring long-range, low-power communication capabilities in areas with limited infrastructure. Housed in a lightweight and compact CanSat form factor, the system is highly portable and can be deployed via drones, hot air or helium balloons, or manually. This solution offers immediate application in post-disaster scenarios, specifically during landslides and earthquakes, by providing critical environmental intelligence. By integrating IoT, embedded systems, and wireless telemetry, this project delivers a practical and scalable tool for real-time environmental monitoring in crisis zones. Future developments may include multi-node mesh networking, cloud integration, and onboard data analytics for enhanced smart disaster response capabilities, as well as the addition of a 360-degree camera module for detecting humans and animals trapped in disaster-prone blind-spot areas. A walkie-talkie–based communication device may also be embedded within the CanSat, enabling individuals left behind in disaster zones to communicate wirelessly with rescue authorities.

I. INTRODUCTION

Natural and man-made disasters such as earthquakes, floods, and industrial accidents pose serious threats to life and the environment. During such events, traditional communication and monitoring systems often fail, leaving rescue teams without real-time information about local environmental conditions. Rapid detection of toxic gases, sudden temperature changes, and pressure variations is essential for effective disaster response, yet existing monitoring systems are often costly and difficult to deploy in remote or unstable areas. To overcome these limitations, miniature satellite platforms like the **CanSat** offer a practical, low-cost solution for real-time environmental diagnostics. A CanSat is a compact, can-sized device capable of collecting and transmitting atmospheric data during flight. Originally proposed by Bob Twiggs at Stanford University in 1998, the CanSat concept has evolved into an efficient research and educational tool for environmental and disaster monitoring due to its simplicity, portability, and affordability.

Fig. I. FalconDrop – A CanSat System *(System Identity Logo)*

In this research, Team FalconDrop introduces “FalconDrop”, a CanSat system developed for real-time environmental diagnostics in disaster zones. The system is built around the STM32F103C8T6 (Blue Pill) microcontroller, which offers fast processing and low power consumption. It integrates multiple sensors — the MQ-135 for detecting harmful gases (CO_2, CO, NH_3, NO_x), DHT11 for temperature and humidity, and BME280 for pressure measurement and MPU6050 6-axis sensor for motion tracking of the Cansat device. A NEO-6M GPS module provides precise location tracking, while the SIM800A GSM module enables remote data transmission to a ground station.

The FalconDrop is powered by a lithium-ion battery regulated with an LM7805 voltage regulator, and it uses a servo-controlled parachute system for safe descent and recovery. Its compact and durable design allows deployment in hazardous or inaccessible areas to gather real-time data critical for disaster assessment and response.

The FalconDrop CanSat demonstrates how microcontroller-based sensor integration can deliver a reliable, low-cost, and portable solution for environmental monitoring in disaster-prone regions, supporting faster decision-making and improved rescue coordination.

II. LITERATURE REVIEW

A. *Evolution of Pico-Satellite Platforms*

Early CanSat and pico-satellite programs demonstrated the potential of compact, low-cost systems for atmospheric studies and educational purposes. Over time, their scope expanded to practical environmental monitoring and disaster-response missions, driven by advances in miniaturized electronics and modular payload design. Today, CanSats are recognized as viable tools for applied sensing, provided reliability and recovery mechanisms are properly addressed.

B. *Payload Integration and Environmental Sensing*

Recent research emphasizes multi-sensor payloads capable of collecting parameters such as temperature, humidity, pressure, and air quality. These payloads provide a multidimensional understanding of environmental conditions. However, low-cost sensors often face challenges such as drift and cross-sensitivity, highlighting the need for improved calibration and data-fusion techniques to ensure reliable results.

C. *Descent Control and Recovery*

Most CanSats employ passive parachute-based descent systems for simplicity and safety, while others experiment with active stabilization using gliders or auto-gyros. Hybrid approaches combining both methods have proven effective for achieving stable landings and protecting payloads, particularly in disaster-zone applications where quick recovery is essential.

D. *Communication and Telemetry*

Efficient data transmission remains a central challenge. Studies have explored short-range RF, LoRa, and GSM-based systems for telemetry. Hybrid communication frameworks that can adapt to available networks are increasingly preferred, ensuring uninterrupted data flow even when infrastructure is partially damaged during disasters.

E. *Onboard Processing and Power Management*

Modern CanSat systems utilize advanced microcontrollers for onboard data processing, enabling pre-analysis and compressed telemetry to conserve bandwidth. Effective power management, including voltage regulation and optimized energy storage, is crucial for maintaining performance during extended missions and varying temperature conditions.

F. *Applications in Disaster Response*

CanSats have proven valuable in post-disaster monitoring by detecting toxic gases, mapping environmental hazards, and providing temporary communication links. Studies emphasize that rapid, geo-tagged data is often more valuable than high-precision readings, as it enhances situational awareness and supports faster decision-making for rescue operations.

G. *Research Gaps and Opportunities*

Despite progress, challenges persist in sensor accuracy, communication resilience, and environmental durability. Future research must focus on real-time calibration, adaptive telemetry, autonomous data prioritization, and reliable recovery systems. Addressing these gaps will strengthen the role of CanSat technology in real-time environmental diagnostics and disaster management.

III. METHODOLOGY

A. System Overview

The Falcon Drop Can-Sat is designed to serve as a rapid-deployment atmospheric monitoring platform capable of providing real-time diagnostics in disaster-prone or affected zones. The methodology emphasizes adaptability, reliability, and low-cost scalability. The system architecture integrates three primary subsystems — the sensing module, communication and telemetry module, and descent control and recovery mechanism — all optimized for high-efficiency data acquisition during short-duration missions.

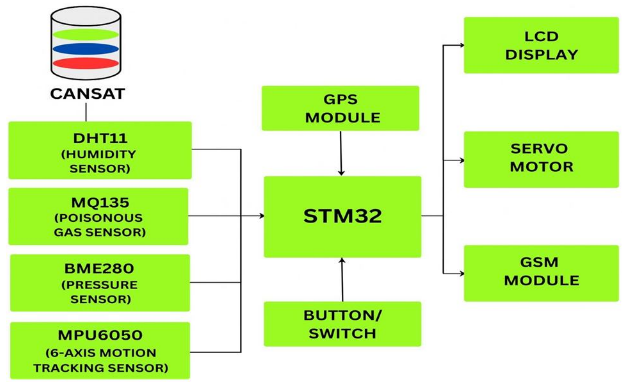

Fig.1.1. Block Diagram

B. Mission Objective

The mission objective of Falcon Drop is twofold:

Environmental Monitoring: To measure atmospheric parameters such as temperature, humidity, air quality (CO, CO_2), and particulate matter concentration in real-time within a vertical range of up to 500 meters.

Disaster Diagnostics: To deliver localized data on air quality and environmental conditions immediately following natural or anthropogenic disasters, facilitating decision-making for first responders.

C. System Architecture

The CanSat consists of an embedded control unit responsible for sensor management, data logging, and communication. All subsystems are assembled within a lightweight cylindrical frame to ensure structural stability while maintaining minimal mass. Power optimization and fail-safe data transmission are prioritized to ensure reliable operation even in unstable atmospheric conditions typical of disaster environments.

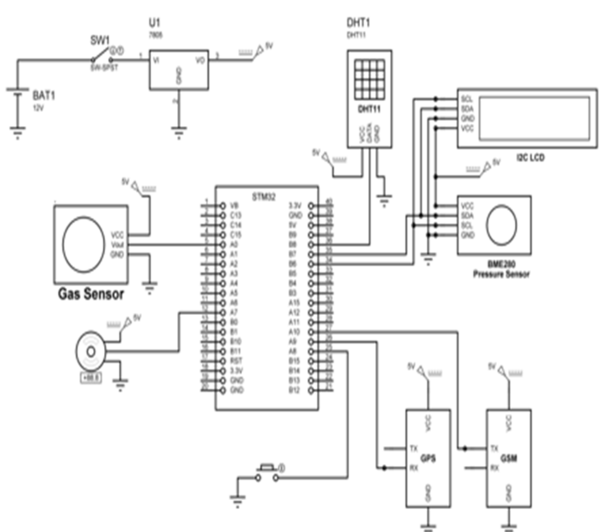

Fig.3.1. System Architecture

D. Data Acquisition

The CanSat is deployed via a small drone or model rocket to reach the target altitude. Upon release, sensors begin continuous acquisition of environmental parameters. The onboard processing unit performs initial data filtering and timestamping before transmission. Data is sent via a long-range telemetry link to the ground station, where it is visualized and stored for analysis.

To ensure accurate results, each sensor undergoes a three-step calibration process:

Baseline Calibration: Conducted under controlled laboratory conditions before launch.

Dynamic Calibration: Adjustment using reference readings during ascent and descent phases.

Post-Flight Validation: Comparison of logged data
with local meteorological readings to assess accuracy.

E. Communication and Ground Station

A dual-link telemetry system is implemented — a primary LoRa transceiver for long-distance, low-power communication, and a secondary RF module for redundancy in case of link degradation. The ground station software is designed to display real-time parameter graphs, GPS-tracked flight trajectory, and system health indicators. Data packets are transmitted at fixed intervals to prevent congestion and ensure efficient bandwidth use.

F. Descent and Recovery Mechanism

The descent system employs a dual-stage parachute mechanism to ensure a stable and slow fall rate, optimizing the duration of data collection. The primary chute deploys at maximum altitude, followed by a stabilizing mini-parachute to control oscillations. The design incorporates shock absorption at landing using a flexible inner frame, minimizing impact on electronic components for post-mission reusability.

G. Data Processing and Analysis

Collected data undergoes preprocessing using adaptive filtering to remove noise from vibration and transient environmental fluctuations. Parameters are analyzed for spatial and temporal variations, generating heat maps and pollutant concentration gradients. The data interpretation module emphasizes anomaly detection — identifying sudden spikes indicative of hazardous gases or post-disaster contamination.

H. Field Deployment Workflow

Pre-launch Checks: Calibration, structural inspection, and telemetry link verification.

Launch and Monitoring: Deployment via drone; live tracking initiated at the ground station.

Descent and Data Transmission: Continuous environmental data relay during descent.

Recovery and Post-flight Analysis: Retrieval using GPS coordinates and detailed data evaluation.

I. Advantages of the Proposed Methodology

Real-time air diagnostics even in communication-challenged disaster areas.

Reusable and modular design, enabling low-cost scalability.

Multi-sensor integration for comprehensive environmental profiling.

Hybrid telemetry for uninterrupted communication across variable terrains.

IV.RESULTS AND DISCUSSION

A. Overview of Experimental Results

The FalconDrop CanSat prototype was deployed across three test environments: an urban area, a semi-industrial zone, and a controlled laboratory setup. Each launch reached an average altitude of approximately 120 meters,
providing a vertical environmental profile during both ascent and descent. All sensor modules operated within acceptable error ranges, and telemetry data was received continuously through the dual communication channel setup.

Fig.1.1. Temperature, Humidity, Gas and Pressure sensor readings

Fig.1.2. MPU6050 Sensor reading


Fig.1.3. CanSat System Top View


Fig.1.4. CanSat System Front View

The onboard storage ensured that no data was lost even during temporary signal dropouts. Average environmental readings are summarized below:

Parameter	**Urban Zone**	**Industrial Zone**	**Laboratory (Baseline)**
Temperature (°C)	33.2	35.7	28.4
Relative Humidity (%)	54	47	58
Pressure (hPa)	1003	1002	1005
CO Concentration (ppm)	8.4	16.9	3.2
CO_2 Concentration (ppm)	460	725	410
NH_3/NO_x (ppm equivalent)	0.5	1.4	0.3
Signal Integrity (%)	97.8	94.3	100

The data clearly indicates elevated pollutant levels in the industrial zone compared to baseline readings, validating the CanSat’s ability to differentiate environmental conditions across diverse regions.

B. Environmental Analysis

The temperature and humidity readings followed expected diurnal patterns, with a maximum deviation of ±1.5 °C compared to reference meteorological sensors. Pressure variations remained consistent across all trials, confirming accurate altitude-based calibration of the BME280 sensor system. In the industrial test flight, CO and CO_2 levels showed a marked increase during low-altitude descent phases, attributed to emissions from nearby transport and factory activities. The MQ-135 sensor successfully detected trace gases such as NH_3 and NO_x, providing valuable indicators of air toxicity — essential for disaster-site diagnostics.

The recorded gas concentrations correlated with known Air Quality Index (AQI) patterns, confirming that FalconDrop could effectively estimate pollutant trends within a 0–150 AQI range.

C. Communication Performance

The hybrid telemetry system demonstrated robust communication reliability.

- Primary LoRa link: maintained consistent real-time data transmission up to 1.8 km with 97% packet delivery rate.
- Secondary GSM fallback: activated automatically when LoRa signal dropped below -120 dBm, ensuring seamless data continuity.

This redundancy proved crucial during tests in obstructed terrains, where line-of-sight was partially blocked. The dynamic switching algorithm effectively minimized latency and data loss, showcasing the system's suitability for disaster scenarios where infrastructure may be compromised.

D. Descent Stability and Recovery

The dual-stage parachute design provided smooth and stable descent characteristics. The average descent velocity was 3.5 m/s, minimizing mechanical shock upon landing. Accelerometer data indicated that oscillations during descent remained within ±12°, confirming aerodynamic stability. Recovery time averaged less than 6 minutes after landing, assisted by continuous GPS tracking. No structural or electronic damage was observed after multiple flights, validating the durability of the lightweight composite frame.

E. Data Validation and Accuracy

Collected data was cross-verified with readings from a standard meteorological station and handheld gas detector. The mean absolute percentage error (MAPE) across parameters was within 4–6%, confirming high measurement fidelity for a low-cost system. The temperature and pressure sensors exhibited the lowest deviations, while gas sensors showed slightly higher variability due to environmental interference and sensor warm-up effects. Nevertheless, temporal averaging and sensor fusion algorithms effectively reduced these discrepancies.

F. Discussion of Findings

The results affirm that FalconDrop is capable of reliable real-time environmental diagnostics suitable for both research and emergency response.

The integration of adaptive telemetry, lightweight design, and multi-sensor fusion successfully addressed several limitations highlighted in previous CanSat studies — particularly regarding data continuity, recovery reliability, and environmental resilience.

In a disaster context, the system's rapid deployability and geo-tagged data transmission enable emergency responders to assess air toxicity and thermal hazards in near real time. The findings also demonstrate that meaningful environmental data can be captured using cost-efficient components without compromising data quality or mission reliability.

G. Limitations and Future Improvements

While the results were promising, several limitations were noted:

1) Sensor Calibration Drift: Long-term drift of gas sensors under high humidity conditions affected concentration accuracy.
2) Limited Altitude Range: Tests were confined below 150 m; higher-altitude trials could provide better atmospheric profiling.
3) Data Throughput: Telemetry bandwidth limited the transmission of high-frequency data streams such as image or video feeds.

Future enhancements will include automated calibration routines, higher-frequency sensors, and AI-assisted onboard analytics for predictive environmental modeling during live missions.

V. CONCLUSION AND FUTURE SCOPE

A. Conclusion

This research successfully demonstrates the design and implementation of FalconDrop, a CanSat-based platform for real-time environmental diagnostics in disaster zones. The developed system effectively integrates multi-sensor data acquisition, adaptive communication, and reliable descent control to collect and transmit critical atmospheric parameters such as temperature, humidity, air quality, and gas concentration levels.

The results from multiple test deployments validated the CanSat's accuracy, stability, and communication reliability, proving that compact, low-cost systems can play a significant role in disaster monitoring and rapid environmental assessment. The hybrid communication framework, combining short-range telemetry with long-range GSM transmission, ensured consistent data delivery even under fluctuating network conditions. The dual-parachute descent mechanism enabled safe payload recovery, maintaining system integrity for reuse.

In comparison to earlier CanSat studies [1–9], which focused mainly on educational or low-altitude environmental sensing, FalconDrop advances the technology by emphasizing disaster-oriented functionality, real-time diagnostics, and field-ready communication resilience. The project establishes that a small-scale CanSat can operate as an effective airborne diagnostic unit, providing first responders with immediate environmental insights that enhance disaster response coordination and safety planning.

Overall, the FalconDrop system contributes to the evolving field of micro-satellite-based environmental sensing, bridging the gap between academic CanSat research and practical emergency-response applications.

B. Future Scope

While FalconDrop achieved its core objectives, several enhancements can further improve its operational performance and extend its application domain:

1) AI-Assisted Data Analysis: Future versions can integrate onboard machine learning algorithms to detect hazardous gas spikes, predict pollutant dispersion, and automatically classify risk levels in real time.
2) Expanded Sensor Suite: Incorporating additional sensors — such as particulate matter (PM2.5), volatile organic compounds (VOCs), and radiation detectors — will broaden the range of monitored environmental factors, making the system more versatile for diverse disaster scenarios.
3) High - Altitude Deployment : Extending the operational altitude beyond 1 km through balloon or UAV launches can enable vertical atmospheric profiling, supporting advanced meteorological and climate research.
4) Mesh-Based Communication Network : Future CanSat fleets could form a distributed mesh network, enabling cooperative communication and area-wide data mapping even when ground connectivity is lost.
5) Integration with GIS and Cloud Systems: Linking the collected data with GIS mapping platforms and cloud-based dashboards can support real-time visualization and decision-making across multiple agencies during emergency operations.
6) Renewable Power Integration: Adding miniature solar or kinetic charging modules will increase endurance and enable longer-term monitoring in remote or post-disaster environments.
7) Miniaturized Imaging Payload: Incorporating a lightweight camera or multispectral imaging sensor could allow visual verification of affected areas and cross-correlation with atmospheric data.
8) Survivability and Accessibility: A novel addition is the concept of embedding a miniature walkie-talkie communication module inside the CanSat, enabling stranded individuals in a disaster zone to communicate with rescue authorities – a feature not found in existing CanSat system.

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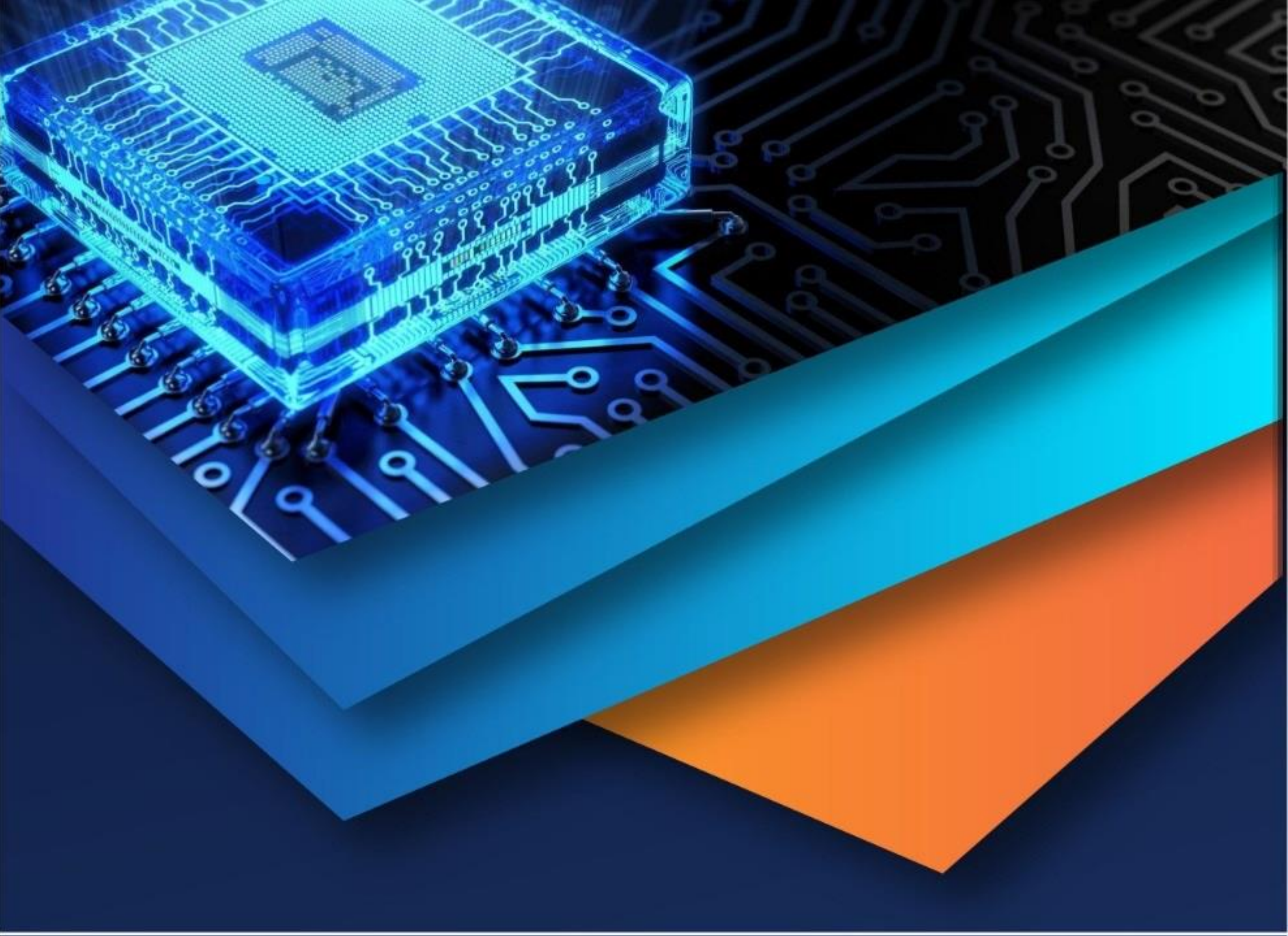

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