Design and Development of Automated Self Recoverable Drone

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Abstract**-- This paper presents a smart self-recoverable drone equipped with advanced sensors, computing capabilities, and a fault detection and self-recovery system that enables it to operate autonomously and recover from unexpected situations. The system involves the integration of various advanced technologies and sensors, such as Spring assistance ejection, Manual disbalancing propeller, Solar recharge and Manual threadcontrol, to enable the drone to avoid getting stuck in real-time. The paper evaluates the execution of the drone through extensive simulations and concludes that it is highly effective in completing difficult tasks with high precision and efficiency. Future research includes developing a drone recovery and damage control technology that will save humankind from suffering a severe loss.**

Index Terms**--Autonomous Drone, Recoverable Drone, Electronics, Automated Systems, Smart Gadgets**

I. Introduction

Self-recoverable drones have immense potential in various industries, including military operations, photography and videography, package delivery, and infrastructure inspection. However, as the demand for more intelligent and independent drones grows, there is a need to develop a new generation of smart self-recoverable drones. These advanced drones are equipped with cutting-edge sensors, powerful computing capabilities, and a fault detection and self-recovery system, enabling them to operate autonomously and effectivelyrecover from unexpected situations.

The present paper accentuated on the construction and evaluation of such a smart self-recoverable drone. The drone is designed to be highly autonomous, capable of executing complex tasks without the need for human intervention.

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Tasks such as search and rescue operations, precision agriculture, and infrastructure inspection are performed by the drone, showcasing its advanced capabilities.

The findings of the research indicate that the smart self-recoverable drone performs exceptionally well in these tasks, delivering high precision and efficiency. The drone's ability to autonomously navigate and recover from unexpected situations is a significant advantage, ensuring the safety of both the drone and the surrounding environment.

The paper also highlights the future scope of the research, emphasizing the importance of developing drone recovery and damage control technologies. These advancements are crucial for minimizing potential losses and ensuring the safety of individuals and infrastructure.

By continuously improving the drone's self-recovery capabilities, the research aims to address the challenges and risks associated with drone operations, leading to safer and more reliable drone applications.

Overall, this paper presents a promising approach to the development of intelligent and self-sufficient unmanned aerial vehicles. By integrating advanced technologies, fault detection systems, and self-recovery mechanisms, the smart self- recoverable drone offers a solution to the increasing demand for drones that can operate autonomously and recover from unexpected situations. The research conducted in this paper contributes to the advancement of drone technology and opensup new possibilities for its application in various fields.

In his work, Devos reported on the development of autonomous drones capable of effectively navigating through cluttered environments and avoiding adaptive obstacles in real-world settings (Devos et al., 2018). These drones were equipped with a variety of sensors and employed adaptive control algorithms to facilitate obstacle avoidance. The combination of sensors and algorithms allowed the drones to perceive their surroundings and adjust their flight paths accordingly, enabling them to navigate safely through complex environments. [1]

Gao *et al*. described a sophisticated Nonlinear Model-Assisted Control for Autonomous Parachute Precision Landing Recovery System (Gao *et al*., 2022). This system was designed to enable precise parachute landing recovery with a high level of reliability and accuracy, even in challenging wind conditions and with various payload configurations. By employing advanced control algorithms and leveraging a nonlinear model, the system ensured precise landing and recovery, enhancing the overall reliability and effectiveness ofthe parachute system. [2]

Dicker proposed a system recovery control for a quadrotor UAV that experiences a collision with a pole (Dicker et al., 2019). The technology was created to deal with collision-related propeller damage or loss situations. Despite the damage, the recovery control system allowed the quadrotor UAV to recover from the collision and stabilize its course.

By implementing appropriate control mechanisms, the system compensated for the damage and ensured the drone's continued stability and operational capability. [3]

A unique method for visual-inertial monocular simultaneous localization and mapping (SLAM) with map reuse was presented by Mur-Artal and Tards in 2017. The proposed system enabled real-time mapping and localization using only a single camera and an inertial measurement unit (IMU). The system incorporated a keyframe-based approach, which allowed for efficient map reuse and minimized computational requirements. The system was evaluated on a range of datasets, including indoor and outdoor environments, and demonstrated high accuracy and robustness in challenging conditions. [7]

Pobkrut et al. (2016) presented a study on the creation of a sensor drone for aerial odour mapping in the domains of agricultural and security services. The authors recognized the significance of odor detection in agriculture, as it can aid in the identification of diseases, pests, and other factors affecting crop quality. Additionally, they highlighted the importance of odor detection in security services, where it can be utilized for detecting hazardous substances or locating missing persons. [5]

Duggal *et al.* (2016) presented a research study on plantation monitoring and yield estimation using an autonomous quadcopter for precision agriculture. The authors aimed to develop a system that could accurately monitor and estimate crop yield by utilizing an autonomous quadcopter equipped with various sensors and imaging devices. [6]

Tofterup and Jensen (2019) proposed a methodology for evaluating commercial off-the-shelf parachutes intended for small unmanned aircraft systems (sUAS) failsafe systems. The authors emphasized the importance of assessing the performance and reliability of these parachutes to ensure safe and successful recovery of the sUAS. Their methodology involved conducting controlled drop tests and analysing key parameters such as descent rate, stability, and opening time. Through this evaluation process, the researchers aimed to provide valuable insights and guidelines for selecting appropriate parachutes for sUAS failsafe systems, ultimately enhancing the overall safety and effectiveness of suchsystems. [8]

Verykokou *et al.* (2016) explored the use of UAVs for 3D modelling of disaster scenes in urban search and rescue. They emphasized the benefits of UAV-based imaging systems in quickly capturing detailed and accurate 3D models of disaster areas, aiding rescue teams in their operations. The authors proposed a methodology that combined aerial imagery acquisition, image processing techniques, and point cloud generation to reconstruct 3D models of disaster scenes. Their research demonstrated the effectiveness of this approach through experiments conducted in real disaster scenarios, highlighting the potential of UAVs in improving the efficiency and effectiveness of urban search and rescue operations. [9]

Advantages of proposed drone:

Existing drone models can navigate obstacles in the real-world using sensors and adaptive control algorithms, perform a precision parachute landing, or retrieve a quadrotor UAV with great dependability and accuracy. [1][2][3]

This proposed self-recovery drone, in contrast to these existing models, has several special characteristics to free the drone from an entangled scenario, such as manual thread control, manual disbalancing propellers, and automated recharge. All possible scenarios, including recharging, producing more upward force with the aid of a spring ejection, and unusual propeller balance, are covered by these features, which can free a drone from a tangled predicament and protecthumanity from a catastrophic loss.

The purpose of this study is to demonstrate the development of a smart self-recoverable drone with sophisticated sensors, computational power, and a fault detection and self-recovery system that enables it to fly independently and recover from unforeseen circumstances. Additionally, the study intends to evaluate how well drones dochallenging jobs without the need for human assistance and to demonstrate how they have the potential to develop into a promising technology for usage in a variety of prospective industries. Additionally, the paper seeks to highlight the magnitude of smart self-recoverable drones in addressing the growing demand for more intelligent and self-sufficient dronesand to present a possible method for creating intelligent and self-sufficient unmanned aerial vehicles.

II. System Methodology

The methodology for the evolution of the smart self-recoverable drone equipped with advanced sensors, computing capabilities, and a fault detection and self-recovery system that facilitates it to operate autonomously and recover from unexpected situations involved the following features:

A. Feature 1: Spring assistance ejection

The drone was designed with a spring assistance ejection feature that allows it to self-eject from confined spaces or recover from crashes. This feature was implemented by integrating a high-torque spring mechanism that propels the drone out of confined spaces or away from obstacles. The spring mechanism was calibrated to ensure safe and controlledejection and recovery of the drone.

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B. Feature 2: Manual disbalancing propeller

To further enhance the drone's ability to recover from unexpected situations, a manual disbalancing propeller feature was implemented. This feature allows the drone to manually disbalance its propellers to get rid of an entangled situation. The manual disbalancing propeller feature was implemented by integrating a manual control mechanism that enables the drone operator to adjust the propellers' orientation and speed.

C. Feature 3: Automated recharge

To ensure continuous operation, the drone was equipped with an automated recharge feature that enables it to recharge its batteries without human intervention. The feature was implemented by integrating a small solar panel and a charging control mechanism that enables the drone to detect its low battery level and autonomously navigate to the charging dock for recharging.

D. Feature 4: Manual thread control

To improve the drone's manoeuvrability and to enable it to perform complex tasks, a manual thread control feature was implemented. This feature allows the drone operator to manually control the drone's orientation using a thread control mechanism. The manual thread control feature was implemented by integrating a manual thread release mechanism that enables the drone operator to control the drone's movement on their own.

In summary, the evolution of the smart self-recoverable drone involved the assimilation of advanced technologies and features, including spring assistance ejection, manual disbalancing propeller, automated recharge, and manual thread control. These features enable the drone to operate autonomously and recover from unexpected situations, and perform complex tasks without human intervention.

III. 3D MODEL LAYOUT

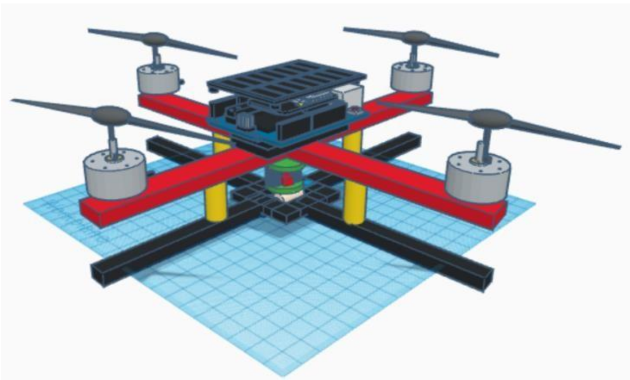

Fig. 1. Layout of 3D model of Automated Self Recoverable Drone

Fig. 2. Entangled situation of a drone

BLOCK DIAGRAM

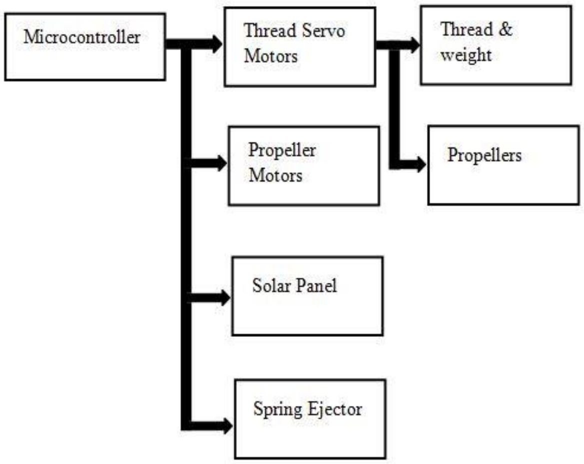

Fig. 3. Block Diagram of the operation of Autonomous drone

A. Microcontroller:

The microcontroller serves as the central processing unit (CPU) or "brain" of the drone system. It is a small electronic component that integrates a microprocessor, memory, input/output peripherals, and other essential components on a single chip. The microcontroller is responsible for managing and coordinating all the elements of the drone system. It executes the program code that defines the drone's behaviour and controls the various components connected to it, such as the servo motors, propeller motors, and spring ejector.

B. Thread Servo Motors:

The drone system utilizes servo motors to release the thread that is attached to it. A servo motor is a type of motor

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that provides precise control over its angular position. It consists of a small DC motor, a set of gears, and a feedback mechanism. The microcontroller sends electrical signals to the servo motor, instructing it to rotate to a specific angle. When the servo motor rotates, it releases the thread, allowing it to unwind or retract as needed.

C. Propeller Motors:

The propeller motors are the primary source of thrust for the drone. They are specialized motors, typically brushless DC motors, specifically designed for aerial applications. Each propeller motor is connected to a propeller, which spins rapidly to create a downward force of air. According to Newton's third law of motion, the drone experiences an equal and opposite reaction, resulting in upward thrust that lifts the drone off the ground. By controlling the speed and direction of the propeller motors, the microcontroller can manoeuvre the drone in different directions and maintain stability during flight.

D. Solar Panel:

The drone is equipped with a solar panel, which serves as a renewable power source. The solar panel captures sunlight and converts it into electrical energy through photovoltaic cells. This electrical energy is then used to power the various components of the drone, including the microcontroller, motors, and other electronics. The solar panel helps ensure continuous functioning of the drone by charging its onboard battery or directly powering the system during daylight hours.

E. Spring Ejector:

The spring ejector is a mechanism that gives the drone an additional burst of force to self-eject from tight areas or recover from collisions. It works by utilizing a compressed spring that stores potential energy. When triggered by the microcontroller, the spring ejector rapidly releases the stored energy, providing a quick and powerful push to propel the drone away from obstacles or regain stability after a collision.

F. Thread and Weight:

The thread and weight system is used in conjunction with the servo motor. When the ankle of the servo motor is opened or rotated, a thread that is looped around a weight will fall and hang down. This setup can be used for various purposes, such as releasing or retrieving objects, creating a controlled descent, or enabling the drone to interact with its environment in specific ways.

G. Propeller:

The propeller is an essential component of the drone that enables the production of thrust and facilitates controlled flight. It is a rotating blade or fan-like structure attached to the output shaft of the propeller motor. When the propeller motor spins the propeller, it creates a pressure difference between the front and back surfaces of the propeller blades, resulting in airflow and generating thrust. The propeller design and aerodynamics play a crucial role in determining the drone's efficiency, stability, and manoeuvrability during flight.

IV. Circuit Diagram

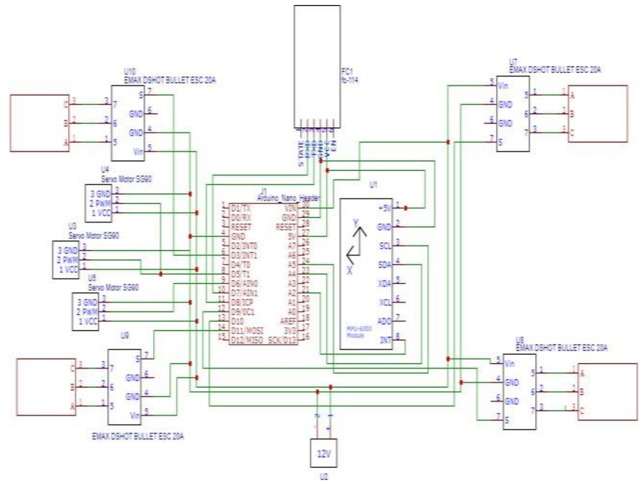

Fig. 4. Circuit diagram depleting the working principle of autonomous drone

The execution of the circuit begins with a 12-volt DC power supply, which provides power to the microcontroller. For this circuit, an Arduino Nano microcontroller is utilized to perform the necessary operations. The microcontroller serves as the control unit for the drone.

In the first operation, which involves drone flying, the microcontroller communicates with the electronic speed controller (ESC). The ESC acts as an intermediary between the microcontroller and the three-phase brushless DC motors. It receives digital signals from the microcontroller, which instructs it on how to control the speed and rotation of the motors.

To control the directional movement of the drone, the circuit incorporates an accelerometer and a transmitter and receiver module. The accelerometer is responsible for measuring acceleration forces acting on the drone in various directions. It provides feedback to the microcontroller regarding the drone's tilt, pitch, and roll.

The transmitter and receiver modules allow the drone and controller to communicate. While the receiver is connected to the microcontroller, the transmitter is normally operated by the user or drone operator. The drone receives orders from the transmitter that indicate desired motions like forward, backward, left, or right. The microprocessor understands and transforms these commands into the proper signals for the ESC and motor control after receiving them from the receiver.

By combining inputs from the accelerometer and the transmitter and receiver module, the microcontroller can accurately control the drone's directional movement based on the user's commands. The microcontroller processes the signals received from these components and adjusts the speed and rotation of the motors through the ESC.

Overall, the circuit design integrates the power supply, microcontroller, ESC, accelerometer, and transmitter and receiver module to facilitate drone flight and control. The microcontroller communicates with the ESC to manage motor control, while the accelerometer and transmitter and receiver module contribute to controlling the drone's directional movement according to user commands.

A. Feature 1: Spring Assistance Ejection

In the circuit diagram, a single servo motor plays a crucial role in supporting the Spring Ejection System. This system is designed to assist the drone in untangling itself from an entangled state. When the microcontroller receives a specific digital signal indicating the need for spring ejection, it triggersthe servo motor to rotate.

The servo motor's rotation is controlled by the microcontroller, which provides it with the necessary instructions. As the servo motor rotates, it exerts force on a pair of springs that have been compressed and positioned inside a disc or similar mechanism. The rotation of the servo motor causes the springs to expand rapidly, creating an upward force.

The upward force generated by the expanding springs aids the drone in disentangling itself from any obstacles or entangled situations. The sudden release of the compressed springs provides a forceful push, enabling the drone to overcome the entanglement and regain its freedom of movement.

The servo motor's role in this process is to actuate thespring ejection mechanism. By rotating the servo motor, the microcontroller controls the timing and force of the spring ejection. The microcontroller coordinates the release of the compressed springs with the drone's position and operational requirements.

The use of a single servo motor and compressed springs allows for a compact and efficient implementation of the Spring Ejection System. The integration of this system into the drone's circuit design enhances its ability to recover from unexpected situations, such as entanglements, by providing a powerful upward force to assist in untangling.

It is worth noting that the design and calibration of the servo motor and spring mechanism should be carefully considered to ensure safe and controlled ejection. Proper coordination between the microcontroller, servo motor, and springs is essential for reliable and effective spring ejection when required.

B. Feature 2: Manual disbalancing propeller

Small adjustments must be made to the drone's general movements in order to apply the manual disbalancingpropeller capability. This idea is realised by giving two opposing propellers more power through irregular rotational control the idea behind this design is to create an imbalance in the drone's propellers, which helps in getting rid of an entangled situation.

To execute this concept, the microcontroller plays a crucial role. When the microcontroller receives specific odd signals, it instructs one pair of opposite propellers to rotate in a manner that deviates from the normal pattern. By providing additional power to these propellers, the drone creates an intentional imbalance.

By introducing an imbalance in the propellers, the drone can disrupt the forces acting on it in an entangled situation. The uneven thrust generated by the propellers can help the drone break free from entanglements or dislodge itself from obstacles. The microcontroller's ability to control and manipulate the rotation of the propellers enables precise adjustments for effective disentanglement.

The implementation of this manual disbalancing propeller feature offers an additional level of control and recovery capability to the drone. By selectively applying odd signals to specific pairs of propellers, the drone operator can actively participate in the recovery process and manoeuvre the drone out of entangled situations.

It is important to note that this feature requires careful coordination between the microcontroller's instructions andthe propellers' rotation. The drone's control system and firmware need to be designed in a way that accommodates the manual inputs from the operator and translates them into appropriate propeller behaviour.

C. Feature 3: Automated recharge

To enhance the power generation capabilities of the drone in critical entangled situations, an additional solar panel has been integrated into the power supply system. This solar panel is connected to the drone's power source, providing an auxiliary source of energy.

The solar panel harnesses the energy from sunlight and converts it into electrical energy, which can be used to power the drone's systems and components. By incorporating the solar panel, the drone becomes less reliant on its primary power source, such as batteries or a conventional power supply.

In critical entangled situations, where the drone may be immobilized or unable to access its primary power source, the solar panel offers a means of sustaining the drone's power requirements. Even in challenging environments, sunlight can still provide a certain level of energy that can be harnessed to keep the drone operational.

The solar panel is typically designed to be lightweight and compact, ensuring it does not significantly impact the drone's overall weight or manoeuvrability. It is positioned and secured on the drone's structure in a way that maximizes exposure to sunlight and optimizes energy conversion.

The solar panel is connected to the power supply system of the drone, which includes appropriate wiring and connectors to transfer the generated electrical energy to the drone's components. The power supply system is designed to efficiently distribute the solar-generated power to various systems, ensuring continuous operation and functionality.

In critical entangled situations, where the drone may be immobilized for extended periods, the solar panel can provide a continuous source of energy, helping to sustain the drone's essential functions and systems. This additional power source can extend the drone's operational capabilities, allowing it to potentially recover from entangled situations or maintain communication and navigation systems for rescue or retrieval operations.

D. Feature 4: Manual thread control

The manual thread control system in the drone involves the use of a weight with a thread extension, which is connected to a servo motor. This system allows the user to release the droneand control its movement using the thread extension.

When the microcontroller receives a specific digital signal to execute the manual thread control, it instructs the servo motor to rotate by 180 degrees. This rotation causes the edges of the weight to be released, allowing the threads along with the weight to fall down.

The weight, attached to the threads, acts as a counterbalance and provides tension to the thread extension. By releasing the weight, the user can control the movement of the drone through the thread extension. The length and strength of the thread extension determine the range and level of control that the user has over the drone's movement.

To release the drone, the user can simply let go of the thread extension, allowing the weight and threads to fall freely. As the weight descends, it creates tension in the thread extension, which is transmitted to the drone. By manipulating the thread extension, the user can guide the drone in different directions and control its orientation.

Without the need of complicated remote-control systems or autonomous algorithms, the manual thread control system provides a straightforward and user-friendly way to control the drone's movement. It establishes a direct physical link between the operator and the drone, enabling accurate and quick control.

It is significant to remember that the design of the manual thread control system should take needs for manoeuvrability, thread strength, and drone weight into account. To guarantee that the system provides the needed amount of control while ensuring the safety and stability of the drone, careful calibration and testing are required.

TABLE I

Sl. No.	**Metrics**	**Existing Drones**	**Proposed Drone**
1.	Spring AssistanceEjection	Not present	Present
2.	Manual disbalancing propeller	Not present	Present
3.	Automated recharge	Not present	Present
4.	Manual thread control	Not present	Present
5..	Area of research	Obstacle Avoidance, Parachute precision landing,Recovery Control for Quadrotor	Automated self-recovery from entangled situation

V. Conclusion

The development of a smart self-recoverable drone with advanced sensors, computational power, and a defect detection and self-recovery system holds significant promise for various fields and applications. This drone is designed to autonomously perform demanding tasks such as search and rescue missions, precision agriculture, and infrastructure inspections, without the need for human intervention. By integrating cutting-edge technology and sensors, the drone possesses the capability to detect and avoid potential traps or obstacles in real-time.

The fault detection and self-recovery system incorporated in the drone relies on pre-programmed instructions and algorithms to identify and address different types of problems that may arise during operation. This system ensures that the drone can recognize and respond to various faults or malfunctions, taking appropriate actions to rectify the issues and regain normal functioning. This ability to autonomously diagnose and resolve problems allows the drone to operate efficiently and effectively even in unpredictable situations.

The drone performs exceptionally well while carrying out difficult tasks with accuracy and efficiency, as shown by extensive simulations and testing. It has proven that it is capable of quickly and safely recovering from unforeseen conditions, ensuring uninterrupted operation and minimising the need for human involvement. A useful strategy for the creation of self-aware and intelligent unmanned aerial systems is presented by the research done in this area.

In summary, the creation of a smart self-recoverable drone equipped with state-of-the-art technology, advanced sensors, and a defect detection and self-recovery system holds great potential for diverse applications. It enables the drone to undertake challenging missions autonomously, avoiding obstacles in real-time. The ability to detect and resolve faults autonomously ensures efficient and safe operations. This research paves the way for the advancement of self-aware and intelligent unmanned aerial systems in various industries and sectors.

VI. Future Scope

The current focus on creating intelligent self-recoverable drones represents a significant advancement in the field of drone technology. Ongoing studies and developments in this area hold the potential to greatly enhance the performance and capabilities of drones, opening up new possibilities for their applications. As research progresses, advancements in the creation of self-recoverable drones are expected to emerge rapidly.

One particular area of interest in the development of self-recoverable drones is the incorporation of an airbag system. The objective is to design a lightweight, compact, and efficient airbag system that can be easily integrated into the existing framework of a drone. This airbag system serves the purpose of automatically inflating in the event of a malfunction or impact, providing the drone with a soft landing and protecting it from damage.

The development of an airbag system for drones offers several potential benefits. Firstly, it can significantly enhance the autonomy and intelligence of drones, enabling them to recover from accidents or mishaps with minimal human intervention. This increased self-recovery capability allows drones to continue carrying out their tasks independently, reducing the need for external assistance.

Secondly, the airbag system makes drones more adaptable to various environments and applications, enhancing their versatility. For example, in harsh conditions such as Arctic regions or desert areas, where rapid temperature drops or sandstorms can pose risks to drones, the airbag system can provide protection against damage. By mitigating potential hazards, the airbag system enables drones to operate effectively in challenging environments that would otherwise be inaccessible or too risky.

Size, weight, inflating speed, and reliability are all important considerations for creating an efficient airbag system for drones. These factors are always being improved by scientists and engineers in order to make the airbag system compact, effective, and perfectly incorporated into the drone's architecture.

In conclusion, there are exciting potential for the growth and expansion of drone capabilities due to the continuous research and development of intelligent self-recoverable drones, including the incorporation of airbag systems. These developments could increase autonomy, make drones more adaptable to different situations, and allow them to do jobs with little assistance from humans. The development of drone technology and its use in a variety of businesses and situations will be aided by the continuous innovation in this area.

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VIII. Biographies

Simanchal Pattanayak was born on October 19, 2001, in Alipore, West Bengal, India. completed a Bachelor of Technology in Electronics and Communications Engineering at the Guru Nanak Institute of Technology in India's West Bengal province. He presented his paper at the conferences FOSET-2023 and CCNMT-2022. He is passionate about researching robotics, Artificial Intelligence, and drones.

Sayantani Das was born in Kolkata in India, on April26, 1999. pursued a bachelor of technology in electronics and communication engineering at the Guru Nanak Institute of Technology in West Bengal,India. Previously, she had papers presented at the IEEE IEMENTECH'2021 and ICDCS'2022 conferences. Additionally, The CCNMT in 2022 and the IE(I) conclave in 2021 are two further conferences on which she has published papers. She also published her patent in November 2022. Her current interest domains are agricultural technologies and automated systems.

Sudipta Das was born in Tamluk, West Bengal, India, on October 27, 1999. earned a bachelor of technology in electronics and communication engineering from the Guru Nanak Institute of Technology in West Bengal, India. He is currently inhis final year of college. His domains of interest are machine learning and robotics.

Nilay Saha was born in Kolkata, West Bengal, India on September 11, 1998. pursued a bachelor of technology in electronics and communication engineering at the Guru Nanak Institute of Technology in West Bengal, India. He's in his final year of college right now. He focused on robots and machine learning.

Dr. Soumik Podder is Assistant Professor of Electronics and Communication Engineering Department of Guru Nanak Institute of Technology, Kolkata under Maulana Abul Kalam Azad University of Technology, West Bengal. He obtained his PhD and M.Tech degree in Nanotechnology from Jadavpur University. He obtained his B.Tech in Electronics and Telecommunication Engineering from University of Kalyani, West Bengal. He is Gold Medalist in M.Tech and awarded DST-INSPIRE Fellowship from DST, Govt. of India for his doctoral studies. He was also recipient of Newton-Bhaba Fellowship during his PhD. He has teaching experience of 6 years in reputed engineering colleges in India. His research interests are Nanobiotechnology, Nanoelectronics, Biosensor, Artificial Intelligence, IoT and Block Chain. He has published more than 20 research papers in highly reputed internal journals and conferences such as American Chemical Society, Royal Society of Chemistry, IEEE etc. He is regular reviewer of RSC Advances, Scientific Report (Springer Nature), Springer Discover Nano, RSC Materials Chemistry B, Taylor's & Francis, Wiley etc. He is premium member of American Chemical Society and IEEE, IEEE Electron Device Society, American Physical Society and Science AAAS. He is elected as Editor in IIP Proceedings. He is also certified reviewer of ACS journals.