International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 07 , July - 2026

Design And Development of Ai Driven Glide Path System Smart Terrain Adaptive Landing System (Stals)

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Abstract - Landing a helicopter is one of the most difficult parts of a flight, especially in bad weather, low visibility, and over difficult terrain. Conventional landing guidance systems are often inadequate for dealing with the fast changing of different environmental conditions and the recognition of new threats.

In this regard, an AI-based Precision Glide Guidance and Smart Terrain Adaptive Landing System has been developed. The purpose of this system is to increase the safety, precision, and reliability of landing a helicopter. The system described in this paper combines data from both onboard and ground-based sensors and focuses on the following: weather sensors, terrain and obstacle sensing and mapping, and flight parameter integration. AI and the science of integrated sensing provide the continuous monitoring of the environment with the ability to offer real time support for decisions during landing.

To substantiate the proposed approach, a prototype built on a Smart Helipad System has been developed. The system is intended to improve a pilot's awareness of a situation, control the risks of the landing, and increase the effectiveness of the landing for both normal and emergency flight missions.

Keywords - Artificial Intelligence, Helicopter Landing, Precision Glide Guidance, Terrain-Adaptive Landing, Smart Helipad, Sensor Fusion, Obstacle Detection, Flight Path Optimization, Aviation Safety, Decision Support System

INTRODUCTION

Helicopters are fast and versatile, which is why many industries, including private and public sectors, use them for a broad range of activities, including, but not limited to, transportation of personel, soldiers, and resources, emergency medical services, and disaster response and recovery activities. They are equipped, unlike their fixed-wing counterparts, to serve in areas with limited and/or restricted access. However, the process of landing a helicopter is difficult, especially when classified as a high-risk landing, due to the presence of an unfamiliar landing zone and/or adverse weather conditions. Landing a helicopter is easier said than done due to the presence of external factors such as strong winds, adverse weather, and poor visibility.

Most landing systems that assist a pilot during a landing rely on conventional means of navigation and landing aids, and the skill and/or experience of the pilot, to complete a safe landing when the time of landing the natural conditions

changes that leads to accidents especially in mountain regions. While these systems of landing aids are typically insufficient to provide the required assistance when the landing conditions are unstable, they are insufficient to provide necessary assistance when the conditions are rapidly changing natural conditions like fog, mist, rainy etc. Because of the increased operational range and decreased pilot skill, the demand for systems that aid landing and can provide enough assistance to a pilot during landing is increased.

With the recent advancements in technology, especially in the fields of Artificial Intelligence [12], [13] (AI), embedded systems, and sensors, landing helicopter safety can be improved. There are systems and sensors such as support and surveillance (i.e., tracking) systems, and weather monitoring sensors that collect information of the helicopter and the surrounding environment. These systems, when consolidated through a process called sensor fusion [6], [7], allow the aid of landing through the use of AI, which may assist in evaluating the safety and feasibility of a chosen landing zone in the presence of potential landing obstacles.

EXISTING SOLUTION

The conventional landing systems still integrate the use of navigation systems coupled with the pilot's decisions when

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 07 , July - 2026

landing the helicopter. Most of the systems relied upon are the Instrument Landing System (ILS) [15], Global Navigation Satellite System [5] , radar altimeters, TAWS, and the onboard weather radar. All these systems give information on the aircraft's position, the aircraft's altitude, the terrain, and the weather, hence assisting the pilot with informed decisions on a landing.

Recently, more systems have been developed to assist visibility to the pilot in landing in challenging weather or low light situations. These systems incorporate the use of infrared cameras, terrain information series, and other onboard systems to generate a virtual representation of the environment. These systems, notwithstanding the additional features, are less reliant on the pilot to make the landing decisions and hence enhance the systems as they are fundamentally systems in support of a decision.

Landing systems have a lot of challenges even with the recent improvements. Most of the assistance systems do not work in a cohesive manner to integrate several sensors to create a single intelligent system. Most of the systems do not have the capabilities to analyze and adjust the glide path in correlation with the weather challenges, terrain changes, or environmental variations. Due to these challenges, systems place a burden on the pilots as they have to integrate information from several systems.

Normally, support systems and infrastructure are limited, and therefore landing systems are constrained in remote, offshore, disaster relief landing zones. As highlighted in the challenges, there is a need for an intelligent landing support system based on Artificial Intelligence [12], [13] and real-time sensor fusion [6], [7] to provide intelligent seamless support on demand.

PROPOSED SOLUTION

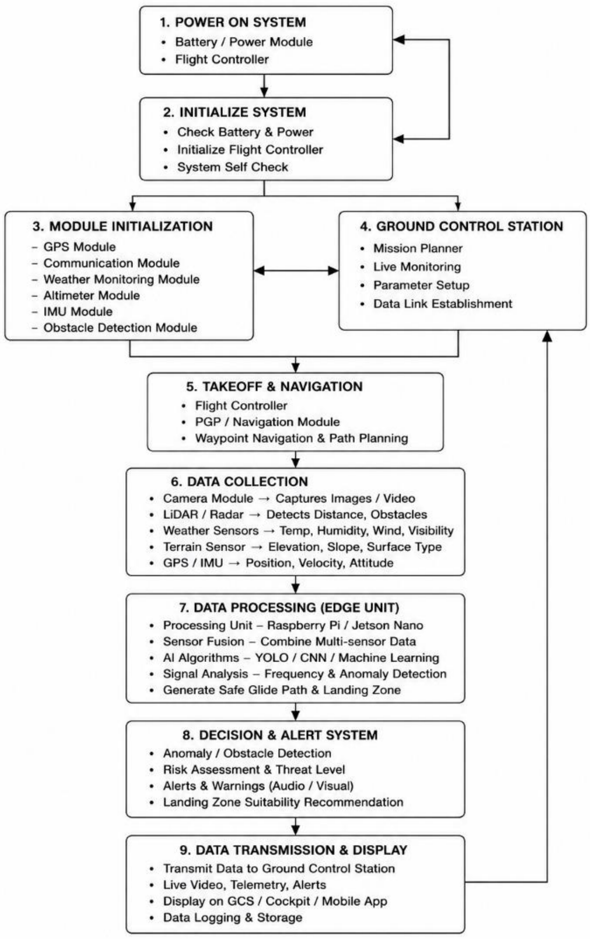
This system proposes an AI-Driven Precision Glide Guidance and Smart Terrain-Adaptive Landing System, offering features that increase safety, precision, and reliability during helicopter landings. Traditional systems assist pilots based on experience, and the direct use of certain navigation aids. The proposed system utilizes AI and sensor fusion [6], [7] to offer real-time landing assistance and smart support decision.

Multiple sensors located on the helicopter and at the landing site, including but not limited to, Global Navigation Satellite System [5]s (GNSS [5]), LiDAR [20], radar, Inertial Measurement Units, weather sensors and vision-based cameras, are integrated into this system. These sensors gather data pertaining the helicopter's location, velocity and the height relative to the surrounding weather, and the obstacles on and in the vicinity of the proposed landing site. The data are analyzed by a sensor fusion [6], [7] unit to create a comprehensive picture of the landing scenario.

AI algorithms are employed to analyze the fully fused sensor data to determine the most optimal Glide Path, the most safe landing zone, and the threats that may be posed by the surrounding landing environment, including, but not limited to, the variability of the landing zone, the obstruction of a landing zone, and the changing weather. The system alters the landing assistance on the approach, and, during landing, provides numerous aids to the pilot.

This system is designed to be used in difficult operating environments, including but not limited to, offshore platforms, helicopter landings in remote and mountainous areas, and disaster zones.

The proposed framework is designed to operate effectively in challenging environments, including disaster zones, offshore platforms, mountainous regions, and remote helipads where conventional navigation support may be limited. By combining AI, advanced sensing technologies, and intelligent decision-making, the proposed system enhances situational awareness, reduces pilot workload, improves landing precision, and minimizes operational risks, contributing to safer and more efficient helicopter operations.



Flow diagram

Start(helicopter comes to a range)
|
▼
Power ON System
|
▼
Initialize Controller and Sensors

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|
▼
Establish Radio Communication
|
▼
Acquire Environmental and Distance Data
|
▼
Process Sensor Data
|
▼
Predict Glide Path
|
▼
Evaluate Landing Safety
|
▼

├──── Safe → Continue Landing
└──── Unsafe → Generate Alert
|
▼
Transmit Data to Ground Station
|
▼
Display Live Monitoring
|
▼
Repeat Until Landing Completed

|
▼
Landed

- System Power-Up(power ON/OFF)

(Aircraft Electrical Power System (28 VDC/115 VAC), Flight Control Computer (FCC), Power Distribution Unit (PDU))

- System Initialization

(Industrial Edge Computer, ADS-B [17] Transceiver, Aviation VHF/UHF Radio)

- Sensor Initialization

(Multi-Constellation GNSS [5] Receiver (GPS/Galileo/GLONASS), IMU (Inertial Measurement Unit), LiDAR [20] Altimeter, HD PTZ Camera, Millimeter-Wave Radar)

- Ground Control Station (GCS) [16] Communication

(ADS-B [17] Ground Receiver, Ground Control Station (GCS) [16] (GCS), Aviation Communication Radio)

- Glide Path Prediction

(Flight Management Computer (FMC), Flight Control Computer (FCC), GNSS [5] Receiver, LiDAR [20] Altimeter)

- Data Collection

(LiDAR [20] Scanner. PTZ Camera, Thermal Camera, Radar Altimeter [4])

- Data Processing

(NVIDIA Jetson AGX Orin / Industrial AI Computer, GPU-Based AI Processor, ROS 2 Middleware)

- Decision and Alert Generation

(AI Decision Engine, Cockpit Multi-Function Display (MFD), Audio Warning System)

- Data Transmission

(ADS-B [17], Aviation VHF/UHF Radio)

- Ground Station Monitoring

(Industrial Monitoring Server, Multi-Monitor Operator Console, AI Monitoring Dashboard, Database Server)

The proposed (STALS): AI-Driven Glide Path Prediction and Smart Landing Assistance System is designed to enhance helicopter landing safety by integrating intelligent sensing technologies, onboard avionics, environmental monitoring, artificial intelligence, and real-time communication. Helicopter landing is one of the most demanding phases of flight because pilots must continuously evaluate aircraft position, altitude, weather conditions, terrain, and surrounding obstacles before touchdown. In adverse weather conditions such as fog, heavy rain, strong crosswinds, or low visibility, conventional landing procedures become increasingly difficult as they rely mainly on pilot experience, visual observation, and communication with ground personnel. To overcome these limitations, the proposed Astr system continuously acquires navigation and environmental information, predicts an optimal glide path, detects potential hazards, and provides real-time landing guidance to improve operational safety and reduce pilot workload.

The proposed system consists of three major subsystems: the Onboard Helicopter Unit, the Smart Helipad Unit, and the Ground Control Station (GCS) [16] (GCS**)**. These subsystems operate together through continuous communication and intelligent data processing. The onboard helicopter unit acquires aircraft navigation information, the smart helipad monitors environmental conditions and landing zone safety, while the Ground Control Station (GCS) [16] supervises the complete landing operation and displays real-time information for operators. The integration of these subsystems establishes an intelligent decision-support framework capable of assisting helicopter pilots during approach and landing.

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Initially, electrical power is supplied to the helicopter avionics and the smart helipad infrastructure. The onboard electrical system activates the Flight Management Computer (FMC), Flight Control Computer (FCC), Mission Computer, communication modules, and navigation sensors. During startup, the Built-In Test Equipment (BITE) performs automatic diagnostic procedures to verify the operational status of all critical hardware components. These diagnostics ensure that navigation sensors, communication interfaces, and processing units are functioning correctly before landing operations begin. At the same time, the smart helipad activates its environmental monitoring system, obstacle detection sensors, communication devices, and edge computing platform, thereby preparing the entire system for real-time operation.

After successful initialization, the helicopter continuously determines its flight parameters using multiple navigation sensors. A Global Navigation Satellite System [5] (GNSS [5]) receiver provides accurate aircraft position, geographical coordinates, ground speed, and navigation information. The Inertial Measurement Unit (IMU) continuously measures aircraft attitude by estimating roll, pitch, and yaw angles. The Radar Altimeter [4] measures the helicopter's height above the ground with high precision during low-altitude flight, while the Air Data Computer (ADC) calculates airspeed, atmospheric pressure, and altitude. These navigation parameters provide an accurate representation of the helicopter's flight condition and serve as the primary inputs for glide path prediction.

Simultaneously, the smart helipad continuously observes environmental conditions that directly influence helicopter landing safety. The environmental sensing subsystem consists of an Industrial Weather Station, Ultrasonic Anemometer, Visibility Sensor, and Laser Ceilometer. The weather station continuously measures ambient temperature, humidity, and atmospheric pressure. Wind speed and wind direction are measured using the ultrasonic anemometer, while the visibility sensor estimates atmospheric visibility under fog, smoke, rain, or dust conditions. The laser ceilometer measures cloud base height and provides additional weather information required during low-visibility operations. These environmental parameters are continuously updated and transmitted to the helicopter and Ground Control Station (GCS) [16], enabling the system to respond to changing weather conditions in real time.

To improve landing safety, the smart helipad incorporates multiple sensing technologies for obstacle detection and surveillance. A LiDAR [20] Scanner performs three-dimensional scanning of the landing area by generating high-resolution distance measurements of surrounding objects. Since LiDAR [20] performance may be affected by severe weather conditions, the system also incorporates a Millimeter-Wave Radar, which can detect obstacles under fog, rain, and dust by utilizing electromagnetic waves. In addition, High-Definition PTZ Cameras provide continuous visual monitoring during daytime operations, while Thermal Cameras support obstacle detection during nighttime and low-light conditions. These sensing devices identify both static and dynamic obstacles such as vehicles, maintenance equipment, personnel, wildlife, and foreign objects that could interfere with safe helicopter landing. The obstacle information is continuously updated and integrated with environmental and navigation data to generate a comprehensive model of the landing environment.

Reliable communication between the helicopter, smart helipad, and Ground Control Station (GCS) [16] is established using aviation-grade communication technologies. The proposed framework supports Automatic Dependent Surveillance–Broadcast (ADS-B [17]), Aviation VHF/UHF Radio, Private LTE/5G Networks, and Satellite Communication (SATCOM) depending on operational requirements. These communication systems enable continuous transmission of aircraft position, altitude, weather information, obstacle data, and landing guidance. The Ground Control Station (GCS) [16] receives and displays this information through an interactive monitoring interface, allowing operators to observe helicopter movement and environmental conditions in real time. Continuous communication ensures synchronization between airborne and ground-based systems throughout the landing operation.

The collected navigation, environmental, and obstacle information is processed using an onboard Artificial Intelligence [12], [13] Computing Platform, such as the NVIDIA Jetson AGX Orin or another industrial edge computer. The AI platform performs sensor fusion [6], [7], combining information from GNSS [5], IMU, LiDAR [20], radar, weather sensors, cameras, and radar altimeters into a unified environmental model. Sensor fusion minimizes individual sensor errors, eliminates redundant measurements, and improves overall system reliability. The integrated dataset provides comprehensive situational awareness, enabling the system to accurately estimate the surrounding landing environment.

Based on the processed sensor information, the Flight Management Computer continuously predicts the optimal glide path by considering aircraft position, altitude, vertical descent rate, wind speed, visibility, terrain characteristics, and detected obstacles. Unlike conventional landing systems that rely mainly on pilot judgment, the proposed AI-based framework dynamically updates the predicted landing trajectory whenever environmental conditions or aircraft motion change. This adaptive prediction capability enables safer landing operations under varying weather conditions and complex operational environments.

The decision-making module continuously evaluates the predicted glide path using predefined aviation safety criteria. The AI algorithm computes a landing confidence score based on aircraft stability, navigation accuracy, weather conditions, communication reliability, and obstacle proximity. When all operational parameters remain within acceptable safety limits, the system recommends continuation of the landing procedure. However, if hazardous conditions such as strong crosswinds, poor visibility, heavy rainfall, communication failure, or obstacle intrusion are detected, immediate warning notifications are generated. Visual alerts are displayed on the cockpit Multi-Function Display (MFD), while audio warning messages notify the pilot regarding potential hazards. Simultaneously, these warning messages are transmitted to the Ground Control Station (GCS) [16], enabling operators to monitor the landing operation and provide additional assistance whenever required.

The Ground Control Station (GCS) [16] serves as the central supervision platform of the proposed (STALS) system.

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It continuously displays aircraft position, altitude, flight trajectory, environmental conditions, obstacle information, landing confidence score, communication status, and system health parameters. The monitoring interface enables operators to observe the complete landing process in real time while maintaining communication with the helicopter. Furthermore, all operational data are securely stored for post-flight analysis, maintenance planning, and future performance evaluation.

The sensing, communication, processing, prediction, and decision-making cycle continues throughout the landing operation until the helicopter safely reaches the helipad. By continuously updating navigation data, weather information, and obstacle positions, the proposed (STALS) system dynamically refines the predicted glide path and provides real-time landing guidance. The modular architecture also supports future integration with autonomous flight control, machine learning models, digital twin technology, and advanced aviation communication systems. Therefore, the proposed framework offers a scalable and intelligent solution capable of improving helicopter landing safety, enhancing pilot situational awareness, reducing operational workload, and supporting the development of next-generation intelligent aviation systems.

RESULTS AND DISCUSSION

The proposed AI-Driven Glide Path Prediction and Smart Landing Assistance System was developed and evaluated to validate the feasibility of integrating environmental sensing, navigation, wireless communication, and artificial intelligence into a unified landing assistance framework for helicopter operations. The architecture consisted of a helicopter module, a smart helipad module, and a Ground Control Station (GCS) [16] (GCS), all working together to exchange operational information in real time. The helicopter module continuously acquired navigation parameters such as position, altitude, and approach distance, while the helipad module monitored environmental conditions including temperature, humidity, atmospheric pressure, visibility, and wind characteristics.

The collected data were transmitted through the communication network to the processing unit, where sensor fusion [6], [7] algorithms integrated information from multiple sensing devices to generate a comprehensive representation of the landing environment. Throughout the experimental evaluation, the communication link remained stable, enabling uninterrupted transmission of environmental and navigation data between the helicopter and the helipad.

The proposed system demonstrated the capability to monitor changing environmental conditions continuously and update landing guidance accordingly, thereby improving situational awareness during the landing phase. The integration of weather monitoring with navigation information provided more comprehensive landing support than conventional visual landing procedures, allowing the system to identify environmental changes before they became critical to flight safety.

The obstacle detection subsystem successfully identified objects located within the landing zone using LiDAR [20], radar, and vision sensors. The detected obstacle information was incorporated into the glide path prediction algorithm, enabling the system to recommend alternative landing approaches whenever an obstruction was identified within the predefined safety region.

This capability reduced the possibility of unsafe landing attempts and improved the reliability of the decision-making process. The AI-based sensor fusion [6], [7] algorithm effectively combined navigation data, environmental measurements, and obstacle information to estimate the safest landing trajectory under varying operating conditions. Unlike conventional systems that rely primarily on pilot judgment and individual sensor readings, the proposed framework continuously evaluated multiple operational parameters simultaneously, thereby providing a more reliable estimate of landing safety. The predicted glide path was dynamically updated as new sensor information became available, allowing the system to adapt to variations in aircraft position, wind speed, visibility, and obstacle location throughout the landing approach.

Experimental observations indicated that continuous environmental monitoring improved the consistency of landing recommendations by reducing uncertainty associated with rapidly changing weather conditions. This centralized monitoring capability enhanced coordination between the helicopter and ground personnel while improving operational awareness during critical landing operations.

Although the present work was implemented as a prototype, the experimental results demonstrate that the proposed architecture is capable of supporting intelligent helicopter landing assistance under a wide range of operational conditions. The incorporation of artificial intelligence into the decision-making process reduced dependence on manual interpretation of environmental information and enabled automatic assessment of landing safety.

The continuous feedback provided by the system can assist pilots in maintaining an optimal approach trajectory while simultaneously reducing workload during with rapidly changing weather conditions with rapidly changing weather conditions when landing. Compared with conventional helicopter landing procedures, which largely depend on pilot experience and visual observation, the proposed (STALS) framework provides continuous environmental awareness, intelligent obstacle detection, adaptive glide path prediction, and automated warning generation. These capabilities contribute to improved landing reliability, enhanced situational awareness, and increased operational safety. The proposed methodology also demonstrates the feasibility of integrating modern sensing technologies, edge computing, and intelligent communication systems into future helicopter landing assistance platforms.

Overall, the project validation confirms that the proposed (STALS) system successfully achieves its primary objective of providing real-time environmental monitoring, intelligent glide path prediction, obstacle awareness, and continuous landing guidance through an integrated AI-based framework. The obtained results demonstrate the potential of the proposed approach to improve helicopter landing safety while providing a scalable foundation for future research involving autonomous landing assistance, advanced machine learning algorithms, digital twin technology, and next-generation aviation communication systems.

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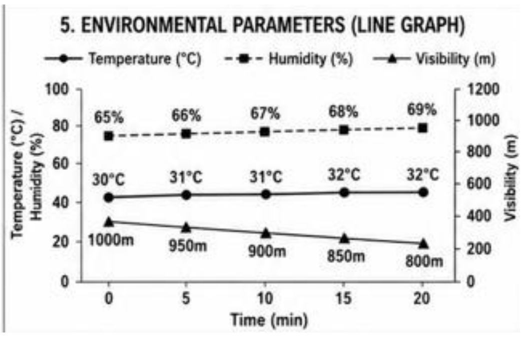
CONCLUSION

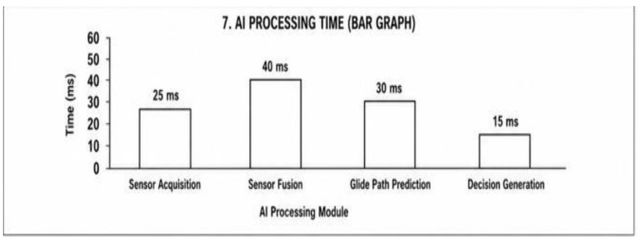
This paper presented (STALS), an AI-driven glide path prediction and smart landing assistance system designed to enhance helicopter landing safety through the integration of navigation sensors, environmental monitoring, obstacle detection, artificial intelligence, and aviation communication technologies. The proposed framework continuously acquires flight and weather information, performs sensor fusion [6], [7], predicts an optimal glide path, and provides real-time guidance and warning alerts to both the pilot and the Ground Control Station (GCS) [16].

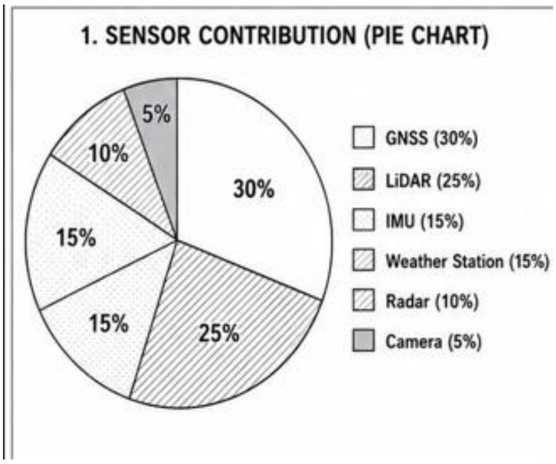
The prototype evaluation demonstrates the feasibility of the proposed architecture in improving situational awareness, supporting landing decision-making, and reducing operational risks during helicopter landing. The modular design of the system enables easy integration with existing avionics and future intelligent aviation platforms. Although the current implementation is limited to a prototype-level validation, the results indicate that the proposed methodology provides a promising foundation for intelligent helicopter landing assistance.

Future work will focus on implementing deep learning-based prediction models, integrating certified aviation sensors, enhancing long-range communication using satellite networks, and validating the system through hardware-in-the-loop simulations and real-world flight testing. These advancements are expected to further improve landing accuracy, operational reliability, and aviation safety under diverse environmental conditions.

FIGURES AND GRAPHS







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