International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 10 – Issue 02 || February 2025 || PP. 39-46

Utilization of Intelligent Systems for Error Prevention during Takeoff and Landing

Oleg Barchugov
Airbus A320 Captain, Technical pilot, Air Astana, Almaty, Kazakhstan

Abstract: The article examines the potential of intelligent systems in reducing errors during critical phases of flight, such as takeoff and landing. The objective of this study is to analyze methods that enhance aviation safety and identify technologies that improve reliability. The study considers key system design elements, including sensor-analytical modules, predictive analytics, and decision-support mechanisms.

Scientific research indicates that the implementation of intelligent technologies, including convolutional neural networks, adaptive models, and machine learning algorithms, reduces the likelihood of crew errors. A notable example is runway condition monitoring systems capable of detecting contaminants and foreign objects in real time. Additionally, algorithms for preventing aircraft runway excursions are analyzed, predicting aircraft behavior during the final stages of landing.

The study results demonstrate that intelligent systems improve crew situational awareness, thereby mitigating the impact of human factors and ensuring the precise execution of critical maneuvers during takeoff and landing. The findings presented in this study will be valuable for aviation technology developers, engineers, pilots, and researchers specializing in automation and aviation safety.

Keywords: intelligent systems, takeoff and landing, aviation safety, artificial intelligence, machine learning, error prevention, automation.

Introduction

The takeoff and landing phases are critical, as they account for a significant number of aviation incidents. These operations take place under high dynamic conditions, changing external environments, and limited timeframes for decision-making. Consequently, the implementation of technologies that can assist pilots and prevent errors has become a crucial area of research.

The increasing volume of air traffic, the growing complexity of aircraft movement management, and the rising demands for flight safety necessitate the introduction of new solutions. Intelligent technologies, such as predictive algorithms and automated decision-support systems, have the potential to minimize human error and enhance operational reliability. However, challenges remain regarding the integration of various technologies into a unified system, ensuring fault tolerance, and adapting to non-standard conditions.

Research in this area focuses on analyzing the potential of intelligent technologies to prevent errors during takeoff and landing. Both existing solutions and emerging developments are examined, including autonomous control systems, predictive algorithms, and real-time data utilization.

The use of smart glasses, as proposed by Li D. et al. [1], provides crews with real-time access to digital instructions and checklists, reducing the likelihood of errors during pre-flight inspections. This approach enables the prompt identification of oversights, ensuring precise execution of all necessary preparation stages. Yongsheng F. [10] highlights errors in landing gear operation and suggests improvements to interfaces that interact with visual and auditory signals, enhancing the crew's accuracy in complex conditions.

The study by Ismayilov I. and Orujov I. [2] focuses on principles that allow systems to not only process current data but also adapt to new scenarios. Puviyarasi B. et al. [6] further develop this concept by designing predictive algorithms to prevent emergency situations. These methods utilize sensor data to assess the probability of threats and enable proactive measures.

Baomar H. and Bentley P. J. [3] introduced an autopilot system based on neural networks, enabling adaptation to conditions such as strong winds or limited visibility, thereby expanding the capabilities of traditional systems. Gil D. et al. [4] developed the E-Pilots system, which analyzes weather data, aircraft position, and dynamics to predict the likelihood of a hard landing. If necessary, this system recommends a go-around, reducing the crew's workload and enhancing safety.

The integration of artificial intelligence into air traffic management enhances the accuracy of takeoff and landing operation planning while reducing the risk of runway incidents. Kumar P., Hussain M., Reddy K., and Deep S. [5] focused on using AI to analyze multiple factors, such as traffic, weather conditions, and runway status, facilitating more precise operational planning. Zhang T. and Wang X. [8] proposed a method for preventing runway overruns through dynamic modeling, reducing the likelihood of incidents at the final landing stage.

To improve safety in ground operations, Amit R. A. and Mohan C. K. [9] introduced a system utilizing R-CNN technology for analyzing images obtained through remote sensing. This technology accurately detects runway locations in low visibility conditions, which is crucial for ensuring operational reliability during adverse weather.

Ilyas M. et al. [7] explored the development of resilient vertical takeoff and landing systems, particularly for new types of aircraft such as unmanned air taxis and short takeoff aircraft. Robust control strategies are employed to minimize oscillations and ensure stability during vertical maneuvers, contributing to the safe operation of such vehicles in urban environments.

Source [11] was used for the practical demonstration of intelligent systems in takeoff and landing operations. The data from this source is published on the Labellerr website.

Despite the diversity of proposed solutions, several critical challenges remain unresolved. Some studies emphasize improving pilot-system interaction by introducing new intelligent devices and interfaces, while others focus on fully autonomous systems. This approach raises concerns regarding trust in such technologies, certification processes, and their integration with existing aviation standards. Additionally, the economic aspects of implementing intelligent systems, including development and operational costs, require further investigation to address practical application challenges.

The objective of this study is to analyze methods that enhance aviation safety and identify technologies that improve reliability.

The scientific novelty lies in applying an interdisciplinary approach to the analysis of intelligent technologies in critical aviation operations, specifically during takeoff and landing.

Additionally, the author has developed a mobile application called "Pilot's Corner" or "Wind Check" depending on localization, which assists pilots in utilizing alternative options to avoid recalculations when receiving updated — potentially significantly different — runway condition and wind data just before takeoff or landing clearance, particularly under severe time constraints.

The author's hypothesis is based on the premise that the use of intelligent systems incorporating machine learning algorithms and sensor data integration will not only reduce errors during takeoff and landing but also create conditions for the partial or complete automation of these operations.

The study methodology involves an analysis of relevant scientific publications by other researchers on this topic.

Research Results

Modern intelligent systems integrate multiple technologies aimed at ensuring flight accuracy and threat prevention. Among these systems is the autopilot, which performs numerous tasks, including maintaining course, altitude, speed, and executing maneuvers during takeoff and landing. The latest autopilot models utilize precise sensors and advanced algorithms, enabling stable flight performance and enhanced accuracy during alignment and approach.

To ensure landing safety, ground collision warning systems such as GPWS (Ground Proximity Warning System) and TAWS (Terrain Awareness and Warning System) play a crucial role. These systems continuously monitor the distance to the ground and objects along the flight path, helping to prevent collisions under limited visibility and adverse weather conditions. By utilizing radar sensors and altitude data, these systems can predict rapid ground proximity or trajectory deviations, issuing timely warnings that allow pilots to adjust their course accordingly.

Instrument Landing Systems (ILS) provide critical information about an aircraft’s position relative to the runway and approach trajectory. ILS helps maintain alignment with the runway centerline and stabilizes the vertical descent, which is essential under low-visibility conditions. In some cases, marker beacons or high-intensity runway lights may assist with landing. However, in many airports, these have been replaced by Distance Measuring Equipment (DME) systems. Below, Figure 1 illustrates the components of ILS.

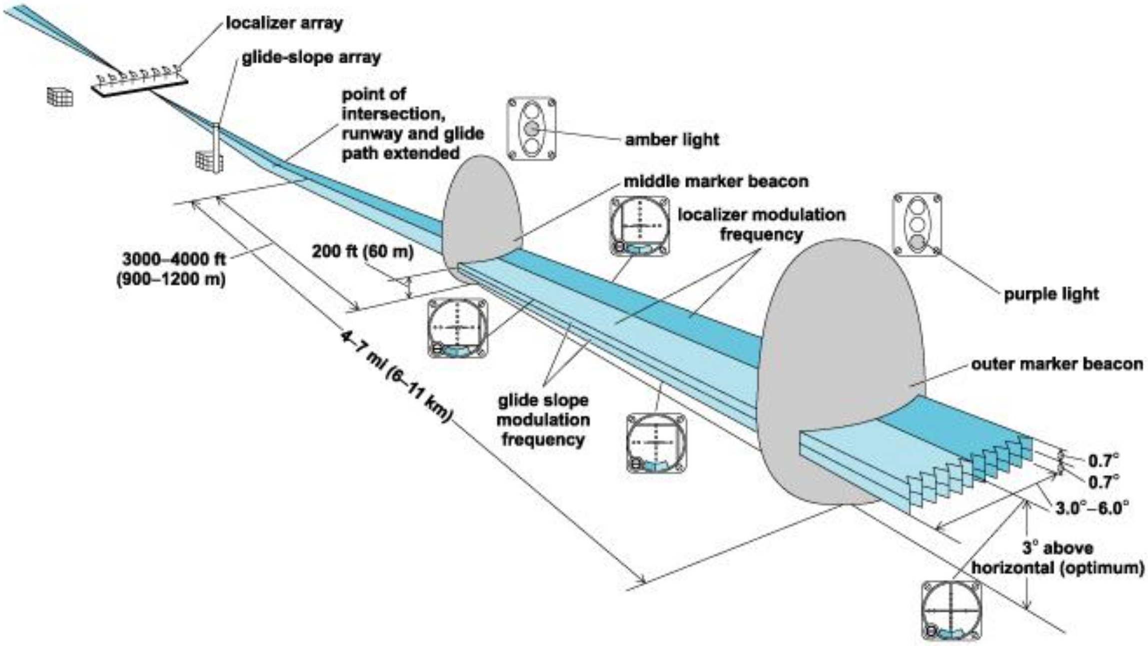

Fig.1. ILS and its various components [11].

However, this method is costly and less practical, which limits its implementation to only a few airfields. An alternative is ATTOL. The aircraft is equipped with a set of sensors, actuators, and computers that enable the use of computer vision and machine learning to achieve autonomy. ATTOL allows the aircraft to "learn" to recognize and navigate the runway similarly to a pilot. Neural network methods facilitate the simultaneous processing of temporal information from multiple sequences, such as time series, textual data, audio signals, or video frames, where the order of elements is crucial for analysis and prediction.

This system can detect a runway from several miles away and calculate the distance to it. However, assessing deviations from the localizer and glide path is more complex. Even an error of 0.1 degrees can be critical. For example, during approach, such a deviation may result in the aircraft being displaced by dozens of meters from the center of the runway, increasing the risk of an emergency, particularly under poor visibility conditions or on narrow runways. Below is an example of computer vision being used for runway detection.

Fig.2. The Wayfinder computer vision software detects the runway [11].

Even after training on synthetic images, the network demonstrated strong performance on real-world images. Collecting a larger dataset could further enhance the network's accuracy and reduce the gap between synthetic and real data.

Additionally, incorporating auxiliary information, such as airport layouts, runway dimensions, or non-standard glide paths, could improve network performance [11].

Situational awareness systems also play a crucial role in ensuring flight safety by providing pilots with real-time data on aircraft position, speed, and altitude. These systems process sensor information to deliver a comprehensive situational overview. Moreover, they display external weather conditions, aircraft system statuses, and engine performance data. By offering immediate access to critical information, these systems help minimize decision-making errors and enhance overall flight safety (Fig. 3).

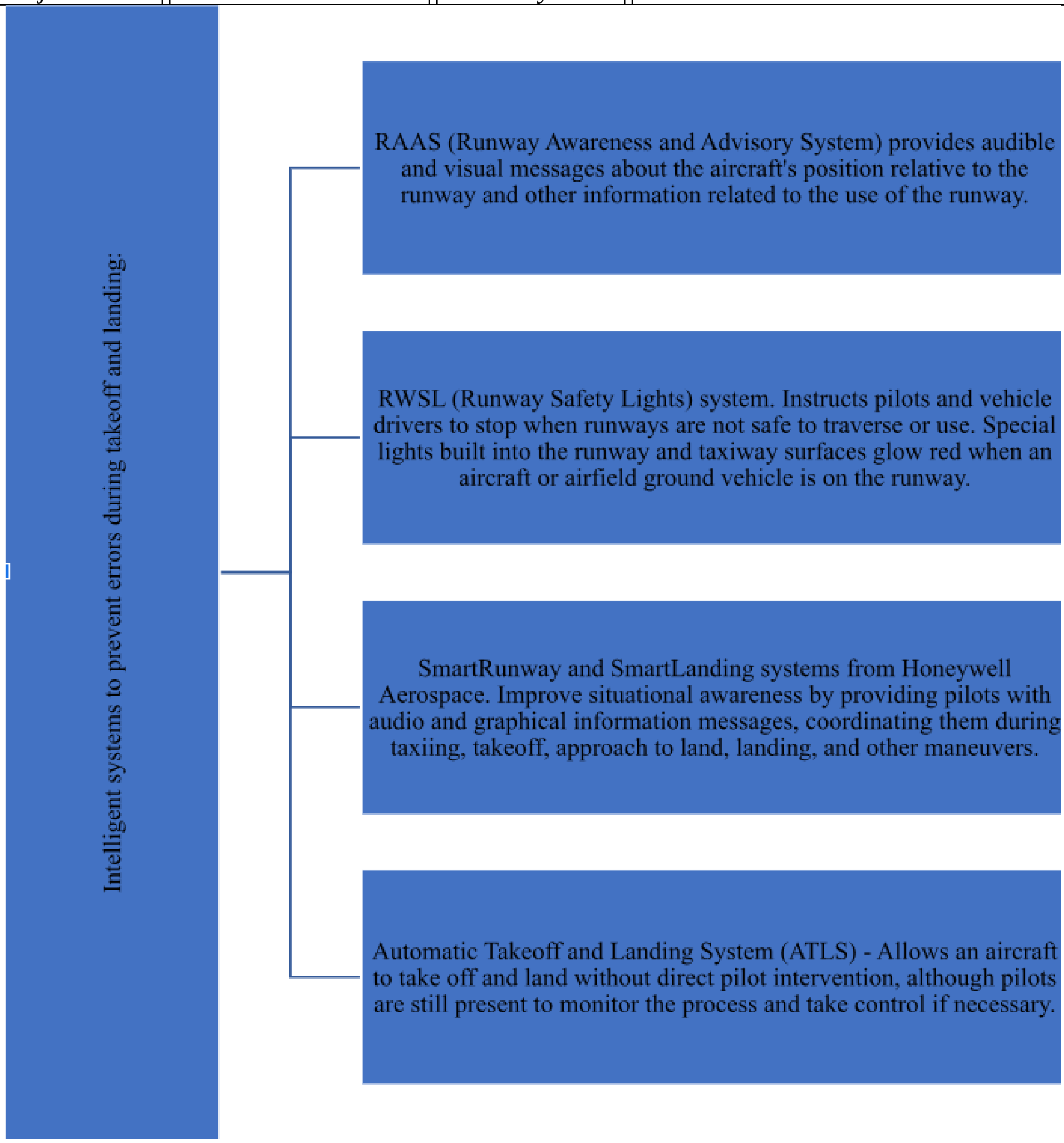

Fig.3. Error prevention systems [2,3,4,6]

The systems for error prevention presented in Figure 3 will be examined in detail below:

The sensor-analytical module processes data from various sensors, including inertial measurement units, meteorological sensors, radar systems, and cameras. To ensure data accuracy, noise filtering and interpretation of multidimensional signals are required. This process utilizes methods for analyzing temporal and spatial characteristics, such as wavelet transformations and singular value decomposition.

Models based on aggregated data detect deviations in aircraft behavior, predicting potential risks. These models assess the likelihood of exceeding acceptable limits and suggest ways to prevent such situations. Adaptive algorithms, which learn with each operational cycle, enhance the accuracy of predictions.

The autonomous control module processes incoming information to generate decisions for flight optimization. For instance, in the presence of crosswinds, the system adjusts the trajectory, reducing the likelihood of excessive bank angles or overloads.

Another critical component involves weather forecasting tools and environmental analysis. These technologies provide real-time data on current weather conditions, such as turbulence, thunderstorms, and strong winds, aiding the crew in adjusting flight paths. Storm prediction and radar monitoring help avoid hazardous zones [5, 8].

Automatic flight control systems support route planning and adjustments, automating operations related to takeoff and landing. These systems analyze parameters such as speed, pitch angle, and airfield conditions while providing recommendations to pilots, enabling optimal decision-making. In the event of an engine failure or other system malfunctions, these technologies automatically propose adjustments to the route or landing trajectory.

Modern pilot training simulators utilizing virtual reality (VR) and augmented reality (AR) also play a crucial role in preparing for emergency situations. These simulators replicate emergency scenarios, including takeoff and landing errors, allowing pilots to train in conditions as close to real-life as possible. This approach helps develop experience and confidence in handling non-standard situations, enhancing crew professionalism.

Intelligent systems designed to prevent takeoff and landing errors form a multi-layered structure that integrates advanced technologies to enhance safety. These systems minimize human error, adjust flight trajectories, and provide support during critical flight phases where every action is crucial. Modern control and monitoring systems significantly reduce risks, ensuring safety during the most critical flight stages—takeoff and landing [1, 10].

The future of intelligent systems is tied to their integration with other high-tech fields. The development of machine-to-machine communications will improve synchronization between aircraft and ground services. One of the promising directions is the implementation of generative models, which allow for testing rare-event scenarios in simulation mode [7, 9].

Below, Table 1 presents future trends in the development of systems for error prevention during takeoffs and landings.

Table 1. Future trends in the development of systems for error prevention during takeoffs and landings (compiled by the author, based on [3-6]).

Type of Intelligent System	Function	Example of Use	Advantages	Risks/Limitations	Technologies/ Methods
Lane Departure Warning Systems (LDWS)	Alerts the pilot when deviating from the designated trajectory during takeoff or landing	Runway excursion warning system	Enhances maneuver precision, timely intervention	Potential false alarms in low visibility conditions	Laser sensors, GPS, inertial systems
Automatic Altitude Control Systems (RA/TA)	Warns of potential collisions with other aircraft	Use of TCAS to prevent vertical collisions	Reduces collision risk, improves safety	Data interpretation errors, dependence on other systems	Radar, infrared sensors, altitude analysis algorithms
Automatic Throttle Control Systems (Autothrottle)	Regulates engine power for optimal maneuver execution	Automatic thrust control during landing to maintain stable speed	Reduces pilot workload, improves landing precision	Limitations in adapting to changing weather conditions	Controllers, optimization algorithms
Stall Warning Systems	Alerts the pilot of potential aerodynamic stall in critical flight conditions	System signaling approach to critical angle of attack	Early warnings prevent loss of control	Potential false activations in severe turbulence	Angle of attack sensors, computational models

Intelligent Flight Path Optimization Systems (Flight Management System, FMS)	Calculates the optimal flight path and landing approach	Use of FMS for trajectory planning considering wind and weather conditions	Reduces human error, improves flight planning	Dependent on the accuracy of input data and mapping information	Navigation systems, weather modeling
Runway Excursion Warning Systems	Alerts the pilot of potential runway overrun	System warning based on runway movement analysis and braking characteristics	Reduces risk of runway overrun during landing	Reduced effectiveness in severe weather conditions	Motion sensors, braking systems, GPS
Autoland Systems	Fully automates takeoff and landing in complex conditions	Use of autopilot for landing in low visibility	Enhances landing accuracy, minimizes human error	Limitations in non-standard situations or system failures	Sensors, GPS, laser-based precision positioning systems

Intelligent systems contribute to the improvement of takeoff and landing procedures by reducing risks associated with human error and enhancing operational precision. Ongoing advancements in computational technologies, sensors, and data processing methods continue to open new opportunities for aviation, increasing safety, reliability, and efficiency.

Conclusion

The study established that the implementation of intelligent systems during takeoff and landing significantly enhances air traffic safety by mitigating the impact of human error. The application of adaptive machine learning algorithms, predictive analytics, and sensor technologies enables the rapid detection of threats and the elimination of risks. These technologies ensure precise flight trajectory modeling, real-time monitoring of runway conditions, and management of flight scenarios, including adverse weather conditions and crew workload optimization.

The advantages of such systems include their ability to self-learn, process large volumes of data in real time, and provide recommendations to the crew in uncertain conditions. However, challenges remain in the standardization of these technologies, improving fault tolerance, and adapting them to various types of aircraft.

The findings confirm that the research objectives have been achieved. An analysis of existing intelligent technologies has been conducted, identifying their capabilities and limitations, as well as proposing directions for further research. The results obtained may serve as a foundation for developing new methods for designing and integrating intelligent systems into aviation operations, contributing to increased reliability and efficiency in response to the growing complexity of air traffic.

References

[1]. Li D. et al. Research on Aviation Maintenance Quality Control Technology Based on Intelligent Glasses //2023 2nd International Conference on Robotics, Artificial Intelligence and Intelligent Control (RAIIC). – IEEE, 2023. – pp. 241-245.

[2]. Ismayilov I., Orujov I. Basic principles of building intelligent systems flight control // ETM - Equipment, Technologies, Materials. - 2023. - pp.1-10.

[3]. Baomar H., Bentley P. J. Autonomous flight cycles and extreme landings of airliners beyond the current limits and capabilities using artificial neural networks //Applied Intelligence. – 2021. – Vol. 51(9). – pp. 6349-6375.

[4]. Gil D. et al. E-pilots: A system to predict hard landing during the approach phase of commercial flights //IEEE Access. – 2021. – Vol.10. – pp. 7489-7503.

[5]. Kumar P., Hussain M., Reddy K., Deep S. Methods of Air Traffic Management Using Artificial Intelligence in India // International Journal of Scientific Research in Science and Technology. - 2022. - Vol.9 (4) - pp.560-568.

[6]. Puviyarasi B. et al. Design of Aircraft Control System for Accident Prevention //2023 Intelligent Computing and Control for Engineering and Business Systems (ICCEBS). – IEEE, 2023. – pp. 1-4.

[7]. Ilyas M. et al. Experimental Stability Analysis of Vertical Takeoff and Landing System Based on Robust Control Strategy //Applied Sciences. – 2023. – Vol. 13 (20). – pp. 11209.

[8]. Zhang T., Wang X. Design and simulation of system to prevent runway overrun during landing of civil aircraft //Journal of Physics: Conference Series. – IOP Publishing, 2024. – Vol. 2791(1). – pp.1-11.

[9]. Amit R. A., Mohan C. K. A robust airport runway detection network based on R-CNN using remote sensing images //IEEE Aerospace and Electronic Systems Magazine. – 2021. – Vol. 36 (11). – pp. 4-20.

[10]. Yongsheng F. Study of Design Means to Prevent Errors Resulting from Flight Crew Operating Landing Gear System Controls //2021 4th International Conference on Advanced Electronic Materials, Computers and Software Engineering (AEMCSE). – IEEE, 2021. – pp. 946-949.

[11]. How Computer Vision Based ATTOL System Helps Air Crafts in Landing & Takeoff . [Electronic resource] Access mode: https://www.labellerr.com/blog/how-computer-vision-based-attol-system-helps-air-crafts-in-landing-takeoff/ (date of access: 25.01.2025).