Technologia i Automatyzacja Montażu

Volume 124, Issue 2/2024, Pages 47-53
https://doi.org/10.7862/tiam.2024.2.6

Original Research/Review

USING DRONES AND ARTIFICIAL INTELLIGENCE TO ASSESS DAMAGE IN AIRCRAFT ASSEMBLY JOINTS

UŻYCIE DRONÓW ORAZ SZTUCZNEJ INTELIGENCJI W PROCESIE OCENY USZKODZEŃ POŁĄCZEŃ MONTAŻOWYCH SAMOLOTU

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Abstract

Rapid development of Artificial Intelligence (AI) technologies in recent years has created new opportunities to address the growing challenges in the aviation industry. Machine learning and Deep Learning, particularly through Convolutional Neural Networks (CNNs), have advanced image recognition capabilities, enhancing inspection processes possibilities. This paper explores the integration of AI with drones to improve the precision, efficiency, and speed of inspections of airframe emphasizing the necessity of accurate equipment preparation and precise operational planning. The study demonstrates how AI algorithms can process high-resolution images and sensor data to identify and classify defects. The motivation for this paper is to address the critical need for more efficient inspection methods in aviation, driven by the industry's increasing demand for higher repair process throughput and stringent safety standards.

Keywords: artificial intelligence, image recognition, drones, defects detection

Streszczenie

Szybki rozwój technologii sztucznej inteligencji (SI) w ostatnich latach stworzył nowe możliwości radzenia sobie z rosnącymi wyzwaniami w przemyśle lotniczym. Metody uczenia maszynowego i głębokiego uczenia, szczególnie za pomocą konwolucyjnych sieci neuronowych (CNN), poprawiły zdolności rozpoznawania obrazów, usprawniając możliwości procesów inspekcji. Niniejszy artykuł opisuje propozycję integracji SI z dronami i w celu poprawy precyzji, efektywności i szybkości inspekcji płatowców podkreślając konieczność dokładnego przygotowania sprzętu i precyzyjnego planowania operacji. Tekst omawia przetwarzanie obrazów wysokiej rozdzielczości i danych z czujników, identyfikując i klasyfikując uszkodzenia. Motywacją do omówienia danego tematu jest konieczność opracowania bardziej efektywnych metod inspekcji w lotnictwie, co wynika z rosnącego zapotrzebowania na większą przepustowość procesów napraw i rygorystyczne standardy bezpieczeństwa w branży.

Słowa kluczowe: sztuczna inteligencja, rozpoznawanie obrazów, drony, wykrywanie uszkodzeń

1. Introduction

In recent years, there has been observed a tremendous development in technologies related to Artificial Intelligence. This revolution has not bypassed aviation sector, which has been facing numerous industry challenges, such as decreasing availability of raw materials and tightening legal requirements. The aircraft manufacturing, assembly and inspection industry is extremely complex within the meaning of its smooth and accuracy operation level requirements. Therefore, there is the demand for significant involvement of modern solutions that facilitate and speed up the work.

The need to accelerate and improve maintenance processes in aviation can be observed by looking at current forecasts related to aircrafts production volume, which clearly indicate the necessity to increase the capacity of service units (Zachariah, Sharma, Kumar, 2023). Currently, problems arising in aviation companies also require quick and reliable solutions. Recent issues with geared turbofan (GTF) engines produced by Pratt & Whitney have significantly impacted the operations of many airlines. As a result, European carrier WizzAir had to ground over 40 aircraft (Garbuno, 2024). Following a shocking incident during a Boeing 737 Max 9 flight, where evacuation doors were torn off shortly after take-off, investigation discovered anomalies in how they were attached to the fuselage (National Transport Safety Board, 2024).

Artificial Intelligence has an untapped potential to execute and speed up maintenance processes by using algorithms and machine learning techniques enabling workers to complement traditional quality control methods and increase the precision and efficiency of supervision operations. AI-based systems can analyse vast amounts of data in real-time, enabling proactive identification of potential defects and anomalies during the process. This approach not only reduces the risk of errors, but also ensures that aircraft meet rigorous safety standards.

Moreover, combining data analysis with algorithms and delivering images from cameras mounted on drones or virtual reality (VR) goggles could result in significantly facilitating maintenance processes in service organisations, thereby leading to increase of the industry's development pace.

The next part of the paper presents the goal of the work and the applied methodology. The third section describes the capabilities and limitations of AI systems focusing on data processing. The following chapter covers image recognition technologies development considering latest technological advancements. Subsequently, the paper discusses types of data collected and industry sectors actively utilising drones while the sixth section of the work shows current solutions based on image recognition algorithms in aviation manufacturing. The final chapters describe the proposed concept of a System Assessing Damage in Aircraft Assembly Joints and provide the summary of AI usage in process of assessing structural damages.

Based on current literature, the proposed system allows for combining capabilities of these technologies in the aviation industry, leading to further enhancement of the efficiency and accuracy of processes in the aircraft production and inspection. The work focuses on applications in detecting cracks in the airframe structure as well as damaged rivets.

2. Goal and work methodology

Rapidly advancing technology significantly facilitates the accomplishment of complex AI systems into existing solutions. Market needs and trends in aviation clearly indicate the necessity of a new solution development that support maintenance processes.

The aim of this work is to propose the integrated system that could meet those needs. To achieve this goal, literature review is conducted regarding Artificial Intelligence, its construction and abilities in data processing (Step 1). Then the focus changes to Image Recognition where possibilities regarding current technologies and AI implementation in this field are discussed (Step 2). Additionally, drones' employment for the real time image collection is analysed (Step 3), as well as current AI technologies used in aviation are reviewed (Step 4). This is to expand and combine existing solutions into a system with new capabilities (Step 5).

The work methodology is summarized in the Table 1 containing each step, method conducted, and output received.

Table 1. Methodology and received output

	Step	Method	Output
1	Exploration of AI capabilities	Literature Review	Data processing capabilities
2	Research of Image Recognition technologies	Literature Review	Deep learning models
3	Analysis of drones' deployment	Review of current applications	Technological possibilities
4	Review of AI technologies in aviation	Research of existing solutions	Current AI implementations
5	Development of a new concept	Analyzing needs and capabilities	A new concept of a System Assessing Damage in Aircraft Assembly Joints

After examining the limitations and possibilities of existing solutions, an integrated multifunctional system is proposed, combining various technologies to facilitate daily work in construction inspection. The work includes a conceptual description of how such system operates, highlighting the use of existing systems and the associated limitations.

3. Artificial Intelligence – Capabilities and limitations

Artificial Intelligence (AI) offers a wide range of possibilities that significantly impact society, economy and transformation of many fields. One of the most promising aspects of AI is its ability to automate routine tasks by machine learning techniques utilisation and automatization. AI may take over many repetitive jobs, such as quality control in manufacturing, data management or customer service (Kuittinen, 2024). This results in increased efficiency, cost reduction and may free employees' time up for more creative and strategic work.

Artificial Intelligence enables quick and effective analysis of vast amounts of data, which can be used in the identification of significant patterns, trends and relationships (Milson, Bruce, 2024). One significant limitation is its dependence on the quality and quantity of presented data. Poor data quality or insufficient data can lead to inaccurate and biased outcomes. Additionally, AI systems often require substantial computational power and resources, which can be costly. Another limitation is the lack of contextual understanding, which means processing information and making predictions based only on known patterns without any of the nuanced perception humans have. Furthermore, ethical concerns arise among the society (e.g. data privacy), security and the potential perpetuation or even exacerbation existing biases. Therefore, cautious approach, ensuring reliable ethical standards and addressing limitations, is necessary in the development and implementation processes, despite comprehensive potential of Artificial Intelligence (Kaushikkumar, 2024).

4. Image recognition

Image recognition is one of the oldest areas of Artificial Intelligence development, which beginning is dated back to the 1950s and has grown to today's advanced technologies. In 1950, British computer scientist Alan Turing proposed the concept of a "learning machine", which initiated research into Artificial Intelligence (Copeland, Proudfoot, 2007). The first attempts at image recognition were made in the 1960s, focusing on simple tasks such as identifying handwritten characters using rule-based methods and simple shape analysis (Andreopoulos, Tsotsos, 2013). At the end of the 20th century, Yann LeCun and his team introduced Convolutional Neural Networks (CNN) through the LeNet model, which succeeded in recognizing handwritten digits (LeCun et al., 1998). The increase in computing power and the availability of larger datasets enabled the development of more advanced algorithms. A breakthrough appeared in 2006 when Geoffrey Hinton and his team introduced Deep Neural Networks, making deep learning possible to be achieved (Hinton, Osindero and Teh, 2006). This resulted in revolutionary achievements in competitions like ImageNet, where Neural Networks began to show the potential of deep learning in image recognition tasks (Deng et al., 2009).

Image recognition is an intelligent technique for identifying and detecting objects or features in a digital image. The process assigns labels to objects extracted from a scene, which means that image recognition assumes that objects in the scene have been extracted as individual elements. Extraction of characteristic features is possible for Artificial Intelligence by using various visual techniques such as edge detection, image segmentation and feature extraction (Javidi, 2002). Edge detection allows algorithms to identify the boundaries of object, while image segmentation divides it into more understandable parts. Feature extraction involves identifying significant characteristics of objects which help in their identification process. Typical image recognition algorithms are used in operations such as optical character recognition, pattern matching, face recognition, license plate matching, scene identification, and detecting changes in scenes (Javidi, 2002).

Machine Learning and Deep Learning methods are useful approaches to image recognition (Bagheri, Akbari and Mirbagheri, 2019). In the Machine Learning approach, key features of the image, which are identified and extracted, are used as inputs to the model. On the other hand, Deep Learning focuses on models based on the structure and function of the brain, known as Neural Networks. The most commonly used models are Convolutional Neural Networks (Long, Shelhamer and Darrell, 2015). These are used to learn significant patterns from image samples and identify those features in newly processed images.

Despite significant progress in the field of image recognition, there are certain challenges that limit and complicate the operation of such models. Image recognition often requires taking context into account and dealing with dynamically changing conditions, for example distinguishing between a cat sitting on a table and a cat sitting on the floor can be difficult for such systems. Artificial Intelligence may struggle to recognize images under variable conditions, such as changing lighting, perspective or weather. This phenomenon can occur particularly in video surveillance structure or autonomous systems, where conditions are unpredictable (Javidi, 2002). Furthermore, the effectiveness of Machine Learning algorithms mostly depends on the quality and diversity of the training data set. An absence of data variety can lead to overfitting or underfitting of models, which affects ability to properly recognize images (Javidi, 2002). However, continuous development and advances in sensory technologies (high-resolution cameras, 3D scanners) are facilitating collecting increasingly detailed image data.

5. Employing drones for data acquisition

Drones are capable of gathering a variety of data types such as aerial imagery, videography, thermal imaging, multispectral and hyperspectral imaging, photogrammetry, environmental sensor data and geophysical sensor data. Aerial imagery and videography are based on capturing high-resolution photos and videos, which are used in mapping, surveying, and monitoring processes (Pargieła, 2023). Moreover, images can be captured by using thermal imaging which detects heat differences. This solution is making invaluable support for applications like search and rescue operations or inspecting infrastructure looking for heat loss or other issues. Multispectral and hyperspectral imaging capture data across various wavelengths, which is particularly useful for agricultural analysis, environmental monitoring, and detecting specific material properties (Yao, Qin and Chen, 2019).

Furthermore, drones play a significant role in agriculture supporting controlling process. Unmanned Aerial Vehicle (UAV) can enhance effectiveness of crop monitoring, identifying pest infestations and managing irrigation. Drones are used in the construction and infrastructure sectors for site surveying, conducting topographic maps and monitoring construction work progress (Nex, Remondino, 2014). They are also crucial for inspecting infrastructure such as bridges, buildings, power lines, which enhance maintenance and safety by providing detailed and current information (Yao, Qin and Chen, 2019).

Another field where drones have made a remarkable impact is environmental monitoring. They are used in wildlife conservation to track animal movements, monitor habitats and assess biodiversity. In forestry, drones support management of forest health, monitoring illegal logging activities and conducting fire appraisal (Sun et al., 2023). Disaster management efforts also benefit from UAV technology by involving drones in search and rescue missions to locate missing people and assess deterioration in disaster-stricken areas (Zwęgliński, 2020).

The advantages of using drones for data acquisition are considered because UAV missions are cost-effective, reducing the need for expensive manned aircraft or extensive ground surveys. They enhance safety by allowing data collection in hazardous or inaccessible areas without risking human beings. Providing high-end sensors can result in precision, delivering superior images and accurate measurements. Furthermore, various sensors can be carried to collect different types of data depending on the specific needs of a project.

6. The utilization of image recognition technologies and Artificial Intelligence in aviation

Current literature positions indicate the usage of image recognition in the process of identifying aircraft airframe damage, including various types of structural element joints. The work (Brandoli et al., 2021) discusses the application of Artificial Intelligence to detect corrosion on aircraft fuselages. The authors present a methodology for utilizing Machine Learning algorithms to analyse image and sensor data, providing the automatic identification of corroded areas. Portable Data Acquisition and Integration System (DAIS) for non-destructive testing is used to capture images of the airframe. Solution contains charge-coupled device (CCD) camera and a double pass retroreflection projected onto the screen. The study employs advanced image processing techniques, Neural Networks, and classification models, which have been tested on real data collected during aircraft inspections. The results show that the application of AI significantly improves the accuracy and efficiency of corrosion detection compared to traditional inspection methods.

Another notable paper (Amosov, Amosova and Iochkov, 2022) explores usage of Deep Neural Networks for recognizing defects in rivet joints during the manufacturing processes of aircraft parts. The authors describe a methodology for employing advanced Artificial Intelligence algorithms to analyse and recognize images of rivet joints, enabling the automatic and accurate detection of defects. The image is captured by a manipulator arm moving along a preplanned path according to the design documentation. The manipulator arm is equipped with video cameras positioned at various angles, laser rangefinders, and Light Emitting Diode (LED) lights. The accuracy of defect detection is influenced by several external factors: lighting direction, flickering, reflections, shadows, and image angle. The LEDs create directional lighting to mitigate external influences on the examined surface. The obtained data undergoes preliminary information processing and a detection and classification system, after which the final information is transmitted to the operator's monitor with recommendations for defect removal. The study includes training Neural Network models on image data sets and testing them on real-world examples, demonstrating high effectiveness in defect identification.

7. Concept of a System Assessing Damage in Aircraft Assembly Joints

Combining the capabilities of systems listed above with the practicality of drones and VR can significantly improve precision, efficiency and speed of inspections. The authors of this work propose a concept of a System Assessing Damage in Aircraft Assembly Joints. Schematic principle of operation of the system is presented in Fig. 1.

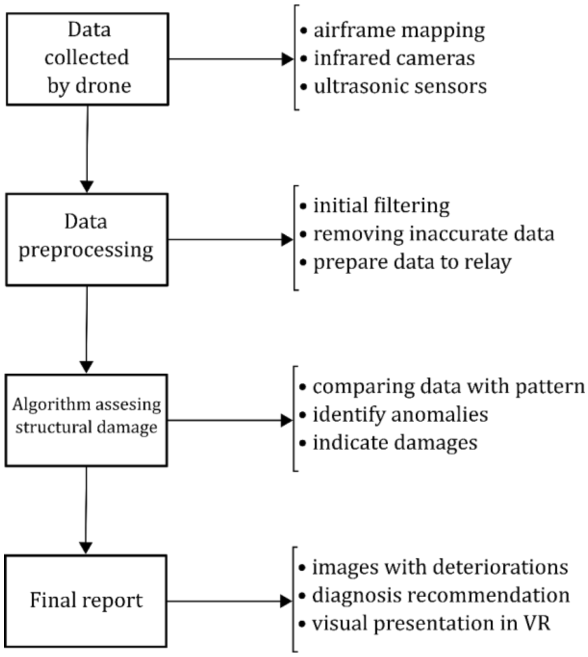

Fig. 1. Schematic principle of operation of the proposed System for Assessing Damage in Aircraft Assembly Joints

To proceed appropriately for this process, it is essential to accurately prepare the equipment before use by completing given checklist, e.g. checking the functionality of sensors, cameras and the drone's control surfaces. The operation should be thoroughly planned and defined in advance, establishing exact flight path covering all inspection-required areas. The paths could be predefined which may advantage in allowing the usage of multiple drones simultaneously while avoiding potential collisions.

During inspection, the drone follows the established path using sensors designed for this purpose, which ensure safe movement around the aircraft structure.

Furthermore, a certain safety margin would be set so that the appropriate distance would be maintained even in the event of measurement inaccuracies or sensor failure. The drone should collect high-resolution images and data from other sensors analysing the structure's condition, such as infrared cameras or ultrasonic sensors. Moreover, it is crucial to ensure proper lighting of the inspected object due to the potential inaccuracies in poorly illuminated parts of the aircraft. Adequate directional lighting (e.g. LED diode) and advanced imaging technologies are essential to achieve precise and reliable detection results, minimizing the risk of overlooking critical defects. Additionally, infrared cameras and ultrasonic sensors might help eliminate some imprecise measurements caused by possible shadows. The inspection process can be significantly enhanced by employing a combination of directional lighting, infrared imaging, and ultrasonic sensing, which leads to more accurate assessments and improved time need in this process. Special attention should be given to the Light Detection and Ranging (LiDAR) system, which could be used in this case for precise mapping of the airframe (Kaartinen, Dunphy and Sadhu, 2022). LiDAR is a remote sensing technology that uses distance measurements to a target. It operates on the principle of sending out laser beams and measuring the time it takes for the light to bounce back, thus determining the distance to objects in its path. In the context of aircraft inspection and maintenance, LiDAR systems offer a non-contact method for assessing the structural integrity of aircraft components.

The data collected during the inspection undergoes preliminary analysis and filtration to remove low-quality images. The remaining data is transmitted to central data analysis systems using appropriate servers.

An example of aircraft fuselage inspection performed by drone is presented in Fig. 2.

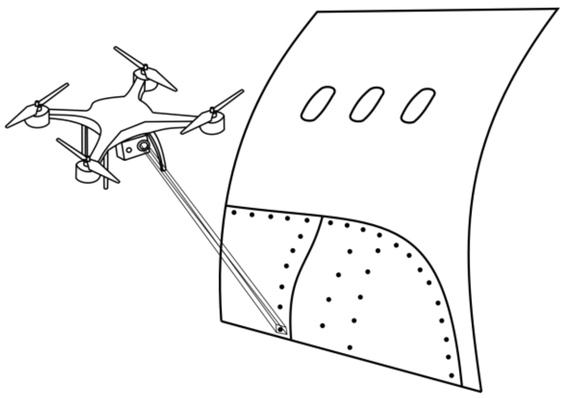

Fig. 2. Example of aircraft fuselage inspection performed by drone

Once the data passes the preliminary filtration, it is fed into Artificial Intelligence algorithms trained to analyse this type of information. This process begins with cleaning and preparing the data, reducing image noise and enhancing the quality of data set. After initial analysis and sorting, CNN detect cracks, corrosion and other anomalies previously defined in the network's database. Deep Learning models classify the types of damage and assess their severity along with significance determining the potential threat to the durability of the structure.

A detailed inspection report containing images with marked damage locations, sensor data summaries, and diagnostic conclusions, is generated after the analysis. Additionally, by integrating LiDAR into aircraft inspection processes, maintenance teams can streamline their workflows, reduce inspection times and improve overall safety by identifying potential issues. Such a report can create an image of the aircraft with highlighted sensitive areas, which allows for early detection of failures or structural problems. In addition, such information may initiate optimalization process of the structure in case of regularly occurring defects. It also provides a visual representation of damage locations using Augmented Reality technologies for real-time visualization of structural damage areas.

AI systems send automatic alerts to maintenance teams when critical issues are detected, allowing for the planning of maintenance tasks based on previously generated priority lists. Comparative analysis of historical data with current inspections enables the identification of trends and recurring problems.

8. Summary

Usage of drones and Artificial Intelligence to assess damage in aircraft assembly joints offers benefits such as increased precision, efficiency and inspection speed, which impacts on improvement of reliability and safety of aircraft. As the analysed literature shows, the proposed technologies yield satisfactory results with an adequate number of training examples. The Neural Network is capable of detecting all defects on the airframe with high probability. Additionally, continuous advancements in Machine Learning algorithms further enhance the accuracy and trustworthiness of these systems. By integrating the advanced algorithms with real-time data processing capabilities, the inspection process becomes more efficient and cost-effective, ultimately leading to increase in productivity protocols in the aviation industry.

This project involves technical challenges, such as ensuring high-quality data despite environmental conditions, continuously training and validating AI models to maintain sufficient accuracy level. The highest level of technological expertise is required to ensure adequate data. It is also crucial to comply with aviation authority regulations and guidelines concerning drone operations. By extension, implementing strict safety protocols for drone operations is needed to prevent accidents. Furthermore, protection of the data and communication channels is required to prevent potential cyber threats.

Future development directions for the project point enhancing AI capabilities, such as developing self-learning systems which could continually learn from new data and improve their performance, and implementing AI systems that collaborate with inspectors in decision-making process.

Moreover, integrating advanced data analytics and machine learning techniques could further optimize inspection processes and predictive maintenance strategies, leading to greater efficiency in aircraft maintenance operations.

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