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Contents

14-24
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INNOVATIVE APPROACHES TO THE APPLICATION OF ROBOTICS IN ENSURING SUSTAINABLE AIRPORT DEVELOPMENT

Anton Borysiuk, Dmytro Bugayko. «Innovative Approaches to the Application of Robotics in Ensuring Sustainable Airport Development». *Airports around the world are increasingly using the integration of artificial intelligence (AI) and robotics to streamline processes, enhance security, and improve customer service. The demand for automation, increased by the COVID-19 pandemic, has given rise to innovative solutions, from automated baggage handling to customer service robots that assist travelers in real time. Nearly half of the world's airlines and 32% of airports have announced plans to increase the deployment of robotic systems, highlighting the growing momentum of modernization in the industry. The purpose of this article is to identify the main promising areas of robotics in the process of sustainable development of airports, to study the history and determine the near-term prospects for the use of robots at airports, and to identify the advantages, disadvantages, and risks of such use.*

Keywords: robotics, artificial intelligence, robots, airport, sustainable development

Антон Борисюк, Дмитро Бугайко. «Інноваційні підходи до застосування робототехніки в забезпеченні сталого розвитку аеропорту». *Аеропорти по всьому світу все частіше використовують інтеграцію штучного інтелекту (ШІ) та робототехніки для оптимізації процесів, підвищення безпеки та покращення обслуговування клієнтів. Попит на автоматизацію, що збільшився у зв'язку з пандемією COVID-19, призвело до появи інноваційних рішень — від автоматизованої обробки багажу до роботів для обслуговування клієнтів, які допомагають мандрівникам у реальному часі. Майже половина авіакомпаній світу та 32% аеропортів оголосили про плани щодо більш інтенсивного впровадження роботизованих систем, що підкреслює динаміку модернізації в галузі, що зростає. Мета цієї статті – виявити основні перспективні напрямки*

роботизації у процесі сталого розвитку аеропортів, вивчити історію та визначити найближчі перспективи використання роботів в аеропортах, а також виявити переваги, недоліки та ризики такого застосування.

Ключові слова: робототехніка, штучний інтелект, роботи, аеропорт, сталий розвиток

Introduction. Airports around the world are increasingly using the integration of artificial intelligence (AI) and robotics to streamline processes, improve security, and enhance customer service. The demand for automation, increased by the COVID-19 pandemic, has resulted in innovative solutions, from automated baggage handling to customer service robots that assist travelers in real time. Nearly half of the world's airlines and 32% of airports have announced plans to deploy robotic systems more intensively, highlighting the growing momentum of modernization in the industry [1], [2]. The rapid adoption of drone robotics in aviation has sparked debate about the safety and effectiveness of their use at airports. While some proponents argue that robotics improves operational efficiency and eliminates labor shortages and reduces the impact of "human error," there are concerns about various implications, particularly in areas such as data privacy and the balance between human and robotic interactions. Controversy has arisen over the use of facial recognition technology in airport security operations, as well as the potential job losses of airport personnel due to increasing automation. Stakeholders are trying to address these concerns, promising that technological advances will benefit both the industry and passengers [3], [4], [5].

The purpose of this paper is to identify the main innovative areas of robotics in the process of sustainable development of airports, to examine the history, current and future prospects of airport robots, and to identify the advantages, disadvantages and risks of such solutions.

Presentation of the main results. The main types of robots currently used at airports include:

- security robots,
- baggage handling robots,
- cleaning robots, and
- customer service robots, each designed to fulfil specific operational needs [6], [7], [8].

Innovations such as CoBRo for baggage handling and various autonomous vehicles for car parking illustrate the diverse capabilities of airport robotics. Experts predict that by 2030, robots will play a central role in processes such as check-in and security, revolutionizing airport technology by helping to improve the efficiency of flight, passenger, and cargo handling [9], [10]. As airports continue to adopt robotic technologies, the industry is poised for significant transformation driven by the dual goals of streamlining operations and improving the passenger experience. New advances and promising research in robotics not only address pressing issues such as increasing passenger volumes and labour shortages, but also put airports at the forefront of using technological advances in the transportation sector [11], [12].

History of Robotics in Airports. The integration of robotics into the operations of large and medium-sized airports is a modern trend that has gained momentum in the last few years as advances in robotics and artificial intelligence (AI) technologies allow them to be used in a variety of operations. Early implementations focused on improving the efficiency of traditional airport functions such as cleaning, security, and baggage handling, and were mostly limited to larger airports.

A survey conducted by Air Transport IT Insights found that by 2023, nearly half of the world's airlines and 32% of airports were actively seeking partnerships to expand their capabilities over the next three years [1]. These initial steps included deploying robots to perform tasks such as cleaning and providing information to passengers, thereby relieving some of the burden on human staff [13], [2].

The Covid-19 pandemic has accelerated this trend, resulting in increased demand for solutions to maintain hygiene standards through various protocols or other automated services [1], [2]. Airports have started to implement a wide range of different robotic solutions, including automated baggage handling, check-in and boarding pass scanning, and even valet parking services [2]. The range of airport robotics has changed significantly, especially with the development of AI technologies. SITA reports show a direct correlation between the development of generative AI and its growing adoption among airlines and airports [3], [4]. By 2023, the trend towards integrating AI-based solutions into airport operations has become evident, with over 90% of airlines and airports already planning to develop long-term programs that include this technology [4]. This demonstrates a dramatic shift towards using robotics not only to improve operational efficiency and reduce the impact of "human error", but also as advanced AI assistants for passengers.

Current trends and future prospects. The trend of implementing AI and robotics at airports is rapidly accelerating. Innovative solutions such as AI-powered chatbots to assist passengers and other robots to interact with travelers at various customer touchpoints have become more common [14]. In addition, the growing interest in robotics, illustrated by the rise in Wikipedia editing activity related to this topic, indicates greater public participation and interest in the application of these technologies [15]. This trend suggests that robotics will continue to play a key role in the transformation of airport passenger and cargo handling operations, promising entirely new passenger experiences and a new level of optimization and automation of airport operations in the coming years [16], [3].

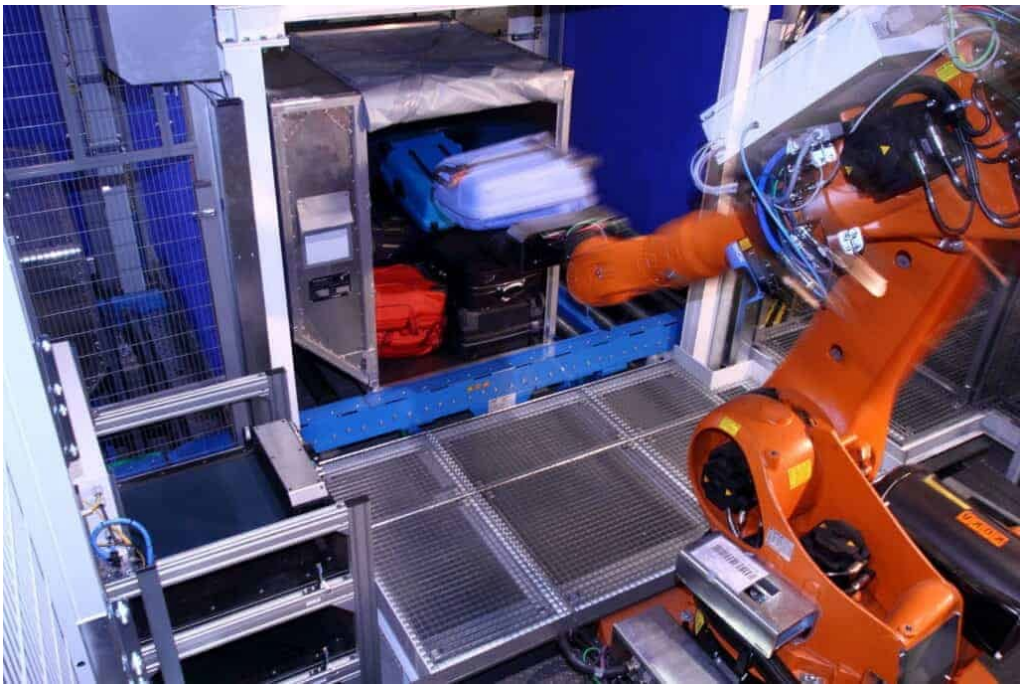
Types of robots used in airports. Types of Robots Used at Airports. Airport robots are autonomous machines designed to perform a variety of tasks to improve efficiency, accuracy, and passenger service. These robots use technologies such as artificial intelligence (AI), machine learning, and sensor suites to operate autonomously, performing a variety of functions ranging from baggage handling to customer service and security screening [6], [7].

There are several main categories of robots used at airports, each designed for a specific function:

• *Security robots*. Security robots are used to patrol airport premises and perimeters, identify potential threats, and ensure safety. They are equipped with advanced sensors and AI technology that allow them to detect suspicious behaviour, monitor unattended baggage or suspicious items, detect violations, and scan boarding passes. These robots provide real-time alerts to security personnel, thereby enhancing the overall security of the airport [6], [13].

Pic.1. Texas airport to get a 420-pound security robot
Source: https://www.digitaltrends.com/news/texas-airport-to-get-420-pound-security-robot/

• *Baggage handling robots.* Baggage handling robots provide baggage check-in, handling, transportation from check-in counters to the aircraft and its loading/unloading. Using GPS and various sensors for navigation, these robots facilitate baggage check-in and check-in without additional waiting, optimize and speed up the baggage handling process, significantly reducing the risk of improper handling and increasing the efficiency of the entire system [6], [7]. The use of robots in cargo handling is even more justified.



Pic.2. Robot loading luggage into a container.
Source: Vanderlande Industries.https://innovationorigins.com/en/laio/airport-baggage-handling-automation-to-the-rescue/

• *Cleaning robots*. Cleaning robots are designed to maintain hygiene in various areas of the airport. These autonomous machines can clean floors, carpets, and other surfaces, working on a schedule to minimize disruptions. Equipped with sensors, cameras, and navigation technologies such as LiDAR, these robots can navigate crowded areas and avoid obstacles while performing their tasks, reducing the use of unskilled labour and the burden on staff [13], [8].

Pic.2. Birmingham Airport has installed cleaning collaborative robots (cobots)
Source: https://www.roboticsandautomationmagazine.co.uk/news/cleaning-sanitation/birmingham-airport-introduces-ice-cleaning-cobots.html

• *Customer service robots*. Customer service robots can act as information assistants for passengers, assisting with inquiries, navigation, and real-time flight information. They can communicate in multiple languages, adapting to the passenger's needs, assisting with information, check-in operations, and navigating travellers at airports, directing them to boarding gates, duty-free shops, or restaurants [6], [7], [8].

Pic.3. AIRSTAR robot at Seoul Incheon International Airport.
Source: https://jordanfraser.medium.com/the-robot-airport-workers-of-seoul-a08349f4f44e

• *Specialized robots*. Beyond the core categories, airports have begun experimenting with specialized robots for unique applications. For example, parking robots, such as the droid Stan at Gatwick Airport, can autonomously park passenger vehicles using advanced GPS systems. In addition, robots, such as Anbot at Shenzhen Airport, are equipped for security screening, with facial recognition technology and the ability to notify aviation security teams [13], [8].

Pic.4. London's Gatwick Airport parking robot Stan.
Source: https://edition.cnn.com/videos/business/2019/01/28/stan-valet-parking-robot-orig.cnn-business

As airports ramp up their adoption of robots and automation in an effort to provide high levels of safety and passenger experience while reducing operating costs, we can expect to see the development of more sophisticated robotic systems and highly specialized AI models in the near future. Predictions suggest that by 2030, robots will play a central role in processes such as check-in, boarding, and passenger assistance, thereby significantly transforming existing airport technology for both passengers and staff [9]. The integration of robotic technologies promises to improve productivity, service efficiency, and the passenger experience while enhancing safety.

Benefits of using robots in airports. The integration of robots into airport operations offers many benefits such as improved operational efficiency, passenger service levels, and safety. As airport volumes continue to grow, innovation and robotics play an increasingly important role in transforming aviation services.

Improving of passenger experience. Robots further contribute to the overall improvement of the passenger experience. They assist in check-in processes, accompany passengers at the airport, participate in passenger service in restaurants and shops, and provide other services to passengers [1], [17]. The use of robots can reduce waiting times, speed up service, and improve passenger comfort. Surveys show that a significant proportion of airlines and airports are actively seeking to expand their robotic services to further improve passenger interactions and streamline operations [1].

Improving of operational efficiency. One of the main benefits of using robots at airports is a significant increase in operational efficiency. Robots are capable of performing various tasks such as cleaning, baggage handling, and security screening with high accuracy and minimal errors [18], [19]. Automating these processes will allow airports to reduce personnel costs and optimize resource allocation, which leads to significant cost savings in the long run [20]. For example,

robots at airports can operate continuously with minimal errors and downtime, increasing productivity compared to human workers who need breaks [21]. In addition, the use of advanced AI technologies allows robots to interact in real time, which greatly expands their application range and accuracy [18].

Improving of safety. Although the use of robots raises some concerns regarding human-robot interaction, they can improve safety at airports. Robots are designed to operate autonomously, are not susceptible to fatigue and emotions - which minimizes the risk of human error that can lead to accidents or injuries [6]. For example, baggage handling robots can reduce the likelihood of collisions with passengers, thereby improving safety in high-traffic areas [6]. With proper supervision and balanced integration - the use of robots can create a good environment for both passengers and airport staff [17].

Scalability and flexibility. The introduction of robots makes it easier for airports to adapt to daily or seasonal fluctuations in traffic. As global air traffic resumes following the pandemic, robotic operations are critical to handling the growing number of passengers without the additional costs of lengthy staff training [18]. Robots can be used to efficiently meet increasing demand while maintaining high service standards [20].

Cost savings. The integration of robots into airport operations results in long-term cost savings. Automated systems can operate with fewer operational constraints during peak periods, which is especially beneficial during periods of high demand [22], [20]. In addition, the precision and stability of robots results in reduced costs and minimized unit costs, and as a result, increases the financial efficiency of airport operations [19]. The savings can be reinvested in further ensuring its sustainable development.

Challenges and limitations. The integration of robotics and AI-based solutions at airports may have challenges and limitations. These barriers include financial, technical, regulatory and ethical aspects that stakeholders must consider in order to realize the existing potential of these technologies.

Technical challenges. Technical barriers play a significant role in the implementation of robotics. For example, the complexity of existing airport operations often requires various stakeholders to effectively communicate to share data and coordinate processes. As experts highlight, achieving this level of integration can be challenging due to fragmentation of systems and the lack of common databases [23]. In addition, although some robotic solutions, such as CoBRo for baggage handling, have demonstrated successful implementation, these technologies remain rare in the industry due to the limited size of the Ukrainian market and regulatory restrictions that make innovation risky [24].

Financial considerations. One of the main challenges faced by airports is the financial investment required to implement robotics technologies. Initial costs can be significant, including the cost of acquiring and implementing robots, necessary accessories, software licenses. In addition, implementation costs must also be taken into account, including installation, setup, provision of infrastructure, staff training and compliance with regulatory standards [25]. Therefore, conducting a detailed cost-benefit analysis is essential to ensure that the long-term benefits outweigh the initial financial outlay, which may deter some airports from implementing such innovations [25].

Regulatory and compliance issues. Defining regulatory requirements is another important issue. Airports must ensure that any robotics and AI solutions comply with a multitude of regulations related to security, data privacy, legal regulations and ethical standards. Ensuring compliance often requires extensive cooperation with government agencies and adherence to strict data handling and privacy policies [26].

Ethical issues. The ethical implications of the implementation of AI technologies, especially those related to facial recognition, have always been highly sensitive and have

generated considerable public debate. Concerns about data retention, its inappropriate use and the overall impact on passenger privacy are paramount. Vendors involved in these implementations are generally prohibited from storing or selling data; however, public trust remains an ongoing issue, complicating the implementation of AI at airports [5]. Additionally, while AI has shown promise in improving operational efficiency, there are cases where its limitations have led to unsatisfactory results, particularly in scenarios where human empathy is critical, such as request handling where a human would need to be sympathetic [27].

Balance between automation and human factors. Ultimately, while automation offers numerous benefits in terms of efficiency and cost savings, achieving a balance between the implementation of new technologies and the human factor is paramount. The nuances of passenger interactions often require human involvement that AI cannot replicate, highlighting the need for continuous improvement of AI systems to complement, rather than replace, humans in customer service and other sensitive areas of airport operations [27]. As stakeholders address these challenges, successful integration of robotics and AI into airport systems will depend on thoughtful implementation, continuous improvement of technologies, and maintaining a healthy balance in the interactions between humans and robotic systems and AI.

World Airport Robotics. Amsterdam Airport Schiphol: Fraim Initiative. Amsterdam Airport Schiphol has embraced innovation through the Fraim Initiative, a joint project with Delft University of Technology and KLM on baggage handling services. This five-year research effort aims to explore the future roles of humans and robots in baggage handling systems. By collecting information directly from employees about their challenges and experiences, the initiative aims to develop comprehensive projects that address pain points while building trust in robotic systems. The project takes a multidisciplinary approach, combining perspectives from design, psychology, organizational change and robotics to ensure that projects are efficient, enjoyable and meaningful for all stakeholders [24].

San Sebastian Airport: Integrating Drones and AI. San Sebastian Airport has successfully demonstrated the use of drones and AI to improve operational efficiency. The project highlights the importance of collaboration between technology providers and airports in applying innovative solutions to specific operational needs. Integrating drones into airport operations not only streamlines processes but also improves overall productivity, demonstrating the potential benefits of such technology in real-world scenarios [28].

Gatwick Airport: AI-powered smart check-in kiosks. Gatwick Airport has pioneered the adoption of AI-powered smart check-in kiosks, which have shown significant promise for improving airport operations. These innovations are part of a wider trend towards automation, increasing passenger throughput and reducing wait times through self-service check-in kiosks and automated screening. Gatwick Airport aims to streamline processes, improving the overall passenger experience and making the most efficient use of staff and resources [29].

Toronto Pearson International Airport: Total Optimizer management tool. Total Optimizer, an airport management tool developed by SITA and unveiled at Passenger Terminal Expo 2024, has been implemented at Toronto Pearson International Airport. The tool uses AI to holistically optimize various airport functions, demonstrating how advanced technology can centralize data from multiple sources and integrate previously disparate workflows. This initiative is a step forward in airport management, enabling more effective strategic and operational decisions [28], [30].

Baggage Counting Solution: Japan Airlines. Japan Airlines tested an AI-based baggage counting solution to improve its

baggage accounting system. This innovative approach enables more systematic baggage monitoring, which in turn facilitates the application of excess baggage fees. By using AI to accurately assess and report baggage, Japan Airlines can not only improve operational efficiency but also create a transparent revenue stream for the airline, improving the customer experience during air travel [29].

The article is a logical continuation of the authors' research in the field of sustainable air transport [34 - 40].

Conclusions. The future of airports lies in the transformation through the integration of robotics and artificial intelligence (AI) into existing technologies, which aims to improve operational efficiency and enhance the passenger experience. Innovation in this field is driven by the need to address significant challenges such as labour shortages and the growing demand for air travel. The focus on integrating robots into operations highlights the desire to create a collaborative environment where humans and machines work seamlessly together to improve the efficiency, safety and sustainability of civil aviation.

According to reports, by 2026, a significant percentage of airlines are expected to implement biometric digital identification technologies, which will ensure a seamless and contactless boarding of passengers. Similarly, AI technologies are expected to fundamentally transform the industry landscape, requiring airports to implement fully scalable solutions that legacy systems can no longer support. Focusing on innovation, including the implementation of robots and AI, is seen as a vital strategy for the sustainable development of global and regional civil aviation. Robotics and the introduction of artificial intelligence will also be important in the post-war development of Ukrainian civil aviation in the post-war period.

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