



Aerial Robots In Industry 4.0: A Review

¹Anisha Bhattacharya, ²Sree Valli TS, ³Chandra Kumar R

¹Student, ²Student, ³Assistant Professor

¹Department of Aerospace Engineering,

¹RV College of Engineering, Bangalore, India

Abstract: Industry 4.0 focuses on the shift towards digital transformation, integrating advanced technologies such as those of robotics and artificial intelligence to improve manufacturing units. Aerial robots, including ornithopters and drones, are playing a major role in this change. Aerial robots inspired by birds, offer new found agility and efficiency, making them suitable for complicated tasks such as surveillance, delivery, and environmental monitoring. This paper reviews various aerial robots, highlighting their bioinspired designs and capabilities. These robots demonstrate diverse applications in industrial settings, contributing to enhanced operational efficiency, safety, and data collection. Despite challenges such as payload limitations and control complexities, there is ongoing research and development in the advancement in the field of aerial robotics, which aligns with the goals of Industry 4.0 to create smarter, more agile, and efficient industrial systems.

Index Terms - Industry 4.0, Robotics, Automation

I. INTRODUCTION

Industry 4.0, recognizes the need for transformation into the digital realm and making manufacturing smarter with many new technologies including artificial intelligence and robotics. Aerial robots include both ornithopters and drones. Such technologies are increasingly pivotal in advancing Industry 4.0. Ornithopters draw inspiration from designs that emulate bird flight. These innovative machines leverage the agility and efficiency of flapping-wing flight to enhance a wide range of industrial applications. In robotics, ornithopter bots are becoming more sophisticated, offering improved capabilities for tasks such as surveillance, delivery, and environmental monitoring. Their flight dynamics are unique, enabling them to navigate complex environments with greater manoeuvrability and precision.

The principles of bioinspired design have long been revolutionizing robotics and automation. By the same principles, engineers can develop more versatile and efficient robotic systems for manufacturing, logistics, and other sectors, leading to enhanced productivity and operational efficiency. [1]

The study of ornithopter aerodynamics also contributes significantly to refining aircraft design, which impacts the efficiency of transport logistics and reduces energy consumption. This deeper understanding of flight dynamics helps create more efficient transportation solutions, aligning with the goals of Industry 4.0 to optimize resource use and streamline processes. [1][2]

Overall, aerial robots based on ornithopter technology are not just a fascinating example of biomimicry but also a driving force in the evolution of smart industries. Their advanced capabilities are helping to shape the future of automation and technology, playing a crucial role in the development of next-generation industrial systems. finance.

II. REVIEW ON EXISTING AERIAL ROBOTS

Through the following section, we shall take a look at some robots that have been developed or are still in development. These robots include not only drones but also bio-inspired aerial robots that offer much more advanced capabilities in terms of motion. Possible and existing areas of utilization of such robots has also been mentioned.

2.1 BionicSwift

BionicSwift is an advanced ornithopter-inspired aerial robot developed by Festo, a global automation technology company. Weighing only 42 grams, this innovative device mimics the swallow to achieve highly efficient and agile aerial movement. [3]

The bot is designed to replicate the flapping-wing motion of swallows, which allows it to turn and loop with remarkable manoeuvrability and energy efficiency. Its wings are constructed with flexible foam lamellae connected by a carbon quill and equipped with lightweight actuators that mimic the natural flapping motion of bird wings. It is connected through a radio-based indoor GPS system with other bots of the same kind through which path planning is performed. It has a flight time of seven minutes. [4]

BionicSwift's advanced capabilities allows it to perform intricate tasks such as inspecting hard-to-reach areas, conducting aerial surveys, and facilitating inventory management in warehouses. Its ability to navigate confined spaces and perform precise manoeuvres makes it a valuable tool for enhancing automation and operational efficiency in modern industrial settings.

2.2 Flyability Elios

Flyability Elios is a spherical drone spanning 40 centimetres in diameter, designed specifically for indoor and confined space inspections. Its innovative design features a robust, spherical carbon-fibre based cage that surrounds the drone, protecting its rotors and body from collisions. This allows Elios to navigate even narrow passages and interact closely with obstacles without risking damage. The drone's controls are maintained despite its protective frame, enabling it to manoeuvre through complex environments with ease.

Elios is equipped with cameras which capture high-definition and thermal images and videos, providing clear and accurate inspections. Its stability and manoeuvrability make it an excellent tool for inspecting hard-to-reach areas such as tanks, pipelines, and industrial equipment. This capability is crucial for conducting inspections in hazardous or otherwise difficult environments where traditional methods might be risky or impractical. [5]

Flyability Elios plays a vital role in enhancing operational efficiency and safety in sectors such as energy, utilities, and construction, to assess the condition of infrastructure and equipment. By reducing the need for human inspectors to enter dangerous areas, Elios improves safety, facilitates timely maintenance, aids in better data acquisition and operational control. [6]

2.3 RoboBees

Harvard's RoboBees are tiny robotic devices designed to mimic the flight and behaviour of real bees. Developed by the Wyss Institute at Harvard University, these miniature robots feature flapping wings and are constructed to replicate the aerodynamics of bees. The use of Pop-Up microelectromechanical (MEMS) technologies along with lightweight materials such as carbon fibre and plastic enable them to perform intricate manoeuvres and navigate complex environments with high efficiency. [8][9][10]

Weighing 80 milligrams and spanning 3 cm, the wings flap 120 times per second. These tiny robots are capable of vertical take-off and landing, hovering and steering. Piezoelectric actuators that expand and contract upon application of an electric field cause the motion of the wings. [8][9]

RoboBees are equipped with various sensors and cameras that allow them to perform tasks such as environmental monitoring and data collection. Their small size and unique flight capabilities make them particularly suited for applications like crop monitoring, where they can gather valuable data from hard-to-reach areas. [11] This ability to perform detailed and delicate tasks is essential for their potential use in agricultural and ecological research.

RoboBees' bioinspired design represents a leap forward in the development of small-scale robots capable of performing complex tasks in various environments. By improving detailed data collection and monitoring capabilities, RoboBees can contribute to enhanced efficiency and innovation in industries such as agriculture and environmental management.

2.4 DelFly Nimble

DelFly Nimble is a flapping-wing drone developed by Delft University of Technology. The DelFly Nimble is a small, lightweight aerial robot that mimics the flight dynamics of real insects. Its design includes four flexible wings and lightweight materials, allowing it to achieve highly manoeuvrable and stable flight patterns. This capability enables the DelFly Nimble to perform intricate aerial manoeuvres such as hovering on the spot, rapid banked turns inspired by fruit flies and 360-degree flips. [12][13]

Equipped with high-resolution cameras and advanced sensors, the DelFly Nimble is capable of capturing detailed visual data and conducting inspections in hard-to-reach areas. Its agility and manoeuvrability make

it particularly useful for tasks such as indoor surveillance, environmental monitoring, and research into animal flight dynamics. [14]

The DelFly Nimble can contribute to improved inspection and monitoring processes, especially in environments where traditional drones may struggle. By incorporating bioinspired principles, the DelFly Nimble aligns with Industry 4.0's goals of integrating sophisticated, adaptable technologies into practical industrial and research applications

2.5 Loon Copter

Loon Copter is a versatile and innovative drone designed to transition seamlessly between flying in air as well as floating and diving. Developed by researchers at Oakland University, this unique aerial robot combines the capabilities of a conventional drone with the functionality of an aquatic vehicle. Its design features a specialized buoyancy system that allows it to land on water, float, and then take off again. [15]

The Loon Copter is equipped with two high-resolution cameras and sensors, enabling it to conduct detailed aerial surveys, underwater pipeline monitoring, and data collection both in the air and on the water's surface. Its ability to operate in and around water bodies expands its utility, making it particularly valuable for tasks such as monitoring waterways, inspecting floating structures, and conducting search and rescue operations. The design of a buoyancy chamber which can pump water in and out allows it to handle transitions between flying, floating and diving smoothly. [16][17]

Loon Copter's ability to operate in multiple environments contributes to more comprehensive data collection and monitoring capabilities. Its integration of aerial and aquatic functionality supports enhanced efficiency in industries such as environmental management, infrastructure inspection, and emergency response.

2.6 Parrot Anafi

Parrot Anafi is a high-performance drone developed by Parrot SA, renowned for its advanced features and versatility. The lightweight and foldable drone is designed for both professional and recreational use, offering exceptional camera capabilities and flight performance. The Anafi stands out for its 4K HDR camera, which includes a 180-degree tilt gimbal and a 21-megapixel sensor, allowing it to capture high-resolution imagery and video from a wide range of angles. [18]

The Parrot Anafi's design emphasizes portability and ease of use, with a foldable frame that makes it easy to transport and deploy. Its advanced flight features include a robust GPS system, obstacle detection, and automated flight modes, which enhance its stability and manoeuvrability. The drone is equipped with various intelligent flight modes, such as Follow Me, Orbit, and Smart Dronies, which facilitate complex aerial shots and automated filming, making it suitable for both professional photography and personal use. [19]

Parrot Anafi is capable of data collection, monitoring, and inspection tasks. Its high-quality camera and advanced flight capabilities make it a valuable tool for applications in areas such as surveying, real estate, agriculture, and infrastructure inspection. [20]

2.7 SenseFly eBee X

SenseFly eBee X is a fixed-wing drone designed for large-scale mapping, surveying, and inspection tasks. Developed by SenseFly, a Parrot company, the eBee X is renowned for its versatility and high-performance capabilities. This drone features a robust and lightweight design that allows it to cover extensive areas efficiently, making it ideal for applications in agriculture, mining, construction, and environmental monitoring. [21]

The eBee X is equipped with a range of advanced sensors and payload options, including high-resolution cameras, multispectral sensors, and thermal imaging devices. These capabilities enable the drone to capture detailed aerial imagery and data from various perspectives. Its long endurance of 90 minutes and large coverage area, exceeding 100 kilometres per flight, make it suitable for conducting comprehensive surveys and inspections over vast terrains. [22] The drone's fixed-wing design allows for efficient, high-speed flight and stable, accurate data collection.

The SenseFly eBee X enhances operational efficiency and precision in data collection and analysis. Its ability to cover large areas and gather high-resolution data supports industries such as agriculture for crop monitoring, mining for resource management, and construction for site planning and progress tracking. [23]

2.8 DJI Mavic 3

DJI Mavic 3 is a state-of-the-art consumer and professional drone developed by DJI, known for its advanced features, high-quality imaging capabilities, and robust performance. The Mavic 3 is equipped with a dual-camera system, including a 4/3 CMOS Hasselblad camera and a telephoto lens. The Hasselblad camera offers 20-megapixel resolution and 5.1K video recording, providing exceptional image quality and colour accuracy. The telephoto lens allows for zoom capabilities up to 28x, enabling detailed and versatile shooting from various distances. [24] Its advanced obstacle detection system and omnidirectional sensors ensure safe and stable flight, even in complex environments. The drone's folding design enhances portability, making it convenient to transport and deploy.

The DJI Mavic 3 excels in a range of applications, including aerial photography, videography, surveying, and inspection. Its high-resolution cameras and advanced flight features make it suitable for capturing stunning visuals for media and entertainment, conducting detailed surveys for real estate or construction projects, and inspecting infrastructure such as power lines, bridges, and buildings. The drone's extended flight time and improved battery life enhance its capability to cover large areas and perform extended missions. [25]

The DJI Mavic 3 contributes to enhanced data collection, monitoring, and analysis. Its high-quality imaging and advanced flight features support industries in obtaining precise, actionable insights for various applications

2.9 AscTec Firefly UAV

The AscTec Firefly UAV is a general-purpose aerial robot designed for industrial inspection tasks. This is an ultra-compact and very lightweight robot featuring a redundant propulsion system that keeps it in the air in a controlled way even when one rotor fails. The payload is the Skybotix/ASL VI-Sensor, including two Aptina MT9V034 global shutter imagers and an Analog Devices ADIS 16488 inertial measurement unit (IMU). This sensor suite, together with a lightweight Intel Core 2 Duo computer running the Robotic Operating System on Ubuntu 13.04, enables robust GPS-denied vision-inertial navigation. Due to the tightly coupled visual-inertial state estimation framework and stereo-based depth estimation scheme, this UAV is capable of accurate localization and mapping. [26]

There are several important advantages of the AscTec Firefly UAV. It can be operated efficiently by non-expert pilots in order to provide real-time, dense 3D maps of environments, ensuring collision-free flights with obstacle avoidance capabilities. The system is robust to remain in rough industrial conditions and does not rely on GPS, thus being suitable for GPS-denied environments. The high-level operator interface enables easy control via waypoints or velocity commands, while redundancy in the UAV improves safety due to the fact that it is able to continue flying with a rotor failure.

It is only able to estimate depth images upon generation of new keyframes, and this might lead to trajectory drift. While real-time mapping is very well done with the UAV, there is a need for post-processing to finally generate consistent and accurate final maps. The AscTec Firefly UAV generally stands out in its robust navigation, real-time mapping, and the ability to adapt to industrial conditions—making it an important tool in conducting visual inspections in confined and challenging environments. [26]

III. AERIAL ROBOT TESTED IN AIRBUS D&S FACTORY

The utilisation of high-end automation is a key idea in Industry 4.0 and this can be well observed in many large manufacturing units, such as that of Airbus, a multinational European aerospace corporation.

A fully autonomous aerial robotic system has been designed, developed and validated for manufacturing industries, particularly in the Airbus D&S factory.

This robot has the ability to navigate through predefined directions and can perform light object delivery missions within the factory. It includes reactive obstacle avoidance to ensure safety and efficiency. It uses LiDAR and visual sensors for robust and accurate measurements. For measurements of long-term localization there is a combination of ultra-wideband (UWB) and RGB-D included in its system. Employs Monte-Carlo Localization (MLC) and Iterative Closest Point (ICP) algorithms for pose estimations. The robot is equipped with a cargo mechanism for transporting components weighing up to 500g. [27]

This robot significantly increases the efficiency within manufacturing industries by deducting the time required for internal logistics operations. Productivity is boosted as it has the ability to quickly transport light components hence enhancing timely delivery. It has a robust navigation system which is capable of operating in GNSS-denied environments such as indoor factories. Allows it to handle dynamic and confined spaces with high accuracy. This adaptability makes the robot suitable for a wide range of industries for logistics, inspections and surveillance. This robot reduces the cost of operation by reducing the need for additional

ground equipment as it utilizes aerial space within factories. This also enhances the working environment within the factory.

Despite having all these advantages, the aerial robot does have some limitations. It cannot replace all ground-based logistics objects. Its payload capacity is restricted to light objects, hence while it is highly effective for certain tasks it can't carry heavier components. Extra cost might be spent due to its dependency on visual markers or other localization infrastructure for accurate navigation. Environmental factors such as lighting conditions and the presence of large, empty spaces with few visual features can affect the visual-based localization system, necessitating the use of robust algorithms to manage vibrations and motion blur. Finally, even though the robot is designed for safe operation, having aerial robots in crowded environments requires strict safety protocols to avoid accidents. [27]

IV. CONCLUSION

In conclusion, the integration of aerial robots into Industry 4.0 really does represent a step ahead in the field of automation and digital transformation. State-of-the-Art technologies, including ornithopters, drones, and all such bioinspired aerial systems, have shifted boundaries in manufacturing, logistics, environmental monitoring, and inspection. Machines whose inspirations are from the flying dynamics of birds and insects create unparalleled manoeuvrability, efficiency, and versatility.

Robots like BionicSwift, Flyability Elios, RoboBees, DelFly Nimble, Loon Copter, Parrot Anafi, SenseFly eBee X, DJI Mavic 3, and AscTec Firefly UAV showcase a diversity of applications and advantages which can be accrued from these technologies. Beginning with sophisticated surveillance through extensive mapping and inspection, these flying robots increase operational efficiency and reduce risks, thus upholding optimized and more sustainable industrial processes.

Those pioneering technologies within different industries prove that further-reaching innovations could very well take off. Though challenges persist, including payload limitations and robust navigation systems, ongoing research and development in this field presage solutions for these bottlenecks and the unlocking of more potential for aerial robotics in Industry 4.0.

In a setting of this kind, the bioinspired design principles integrated into state-of-the-art technology in aerial robots give expression to not only the spirit of Industry 4.0 but also open possibilities leading toward intelligent, agile, and efficient industrial systems. With technologies of this nature continuously evolving, they are undoubtedly going to play a huge role in shaping the future of automation and smart manufacturing.

REFERENCES

- [1] Han, Jiakun, et al. "Review on Bio-Inspired Flight Systems and Bionic Aerodynamics." *Chinese Journal of Aeronautics*, vol. 34, no. 7, July 2021, pp. 170–86. DOI.org (Crossref), <https://doi.org/10.1016/j.cja.2020.03.036>.
- [2] Phan, Hoang Vu, and Hoon Cheol Park. "Mimicking Nature's Flyers: A Review of Insect-Inspired Flying Robots." *Current Opinion in Insect Science*, vol. 42, Dec. 2020, pp. 70–75. DOI.org (Crossref), <https://doi.org/10.1016/j.cois.2020.09.008>.
- [3] Qureshi, Ghaffar. "Soaring to New Heights: The Bionic Swift — A Marvel of Robotic Engineering." *Medium*, 16 Sept. 2023
- [4] Festo's New Bio-Inspired Robots Include a Feathery Bionic Bird - *IEEE Spectrum*.
- [5] Young, K. L., Phillips, C. K., Reyes, M. D., O'Connor, T. C., Schierman, R. S., Meldem, A., ... West, W. N. (2024). Mission Results: Creating a 3D Map of a Very High Radiation Confined Space Using the LiDAR-Equipped Elios 3 Drone. *Nuclear Science and Engineering*, 1–13. <https://doi.org/10.1080/00295639.2024.2364463>
- [6] A. Norton, P. Gavriel, B. Donoghue and H. Yanco, "Test Methods to Evaluate Mapping Capabilities of Small Unmanned Aerial Systems in Constrained Indoor and Subterranean Environments," 2021 IEEE International Symposium on Technologies for Homeland Security (HST), Boston, MA, USA, 2021, pp. 1-8, doi: 10.1109/HST53381.2021.9619836.
- [7] Palomba, J. Unmanned Aerial Vehicle Inspections and Environmental Benefits.
- [8] "RoboBees: Autonomous Flying Microrobots." Wyss Institute, 5 Aug. 2016
- [9] Wood, R., Nagpal, R., & Wei, G.-Y. (2013). flight of the robobees. *Scientific American*, 308(3), 60–65. <http://www.jstor.org/stable/26018027>
- [10] Z. E. Teoh, S. B. Fuller, P. Chirattananon, N. O. Préz-Arancibia, J. D. Greenberg and R. J. Wood, "A hovering flapping-wing microrobot with altitude control and passive upright stability," 2012 IEEE/RSJ

- International Conference on Intelligent Robots and Systems, Vilamoura-Algarve, Portugal, 2012, pp. 3209-3216, doi: 10.1109/IROS.2012.6386151.
- [11] Moore, Richard, et al. Autonomous MAV Guidance with a Lightweight Omnidirectional Vision Sensor. 2014.
- [12] Karasek, Matej. "DelFly Nimble." MAVLab, 13 Sept. 2018, <https://mavlab.tudelft.nl/delfly-nimble/>.
- [13] Matěj Karásek et al., A tailless aerial robotic flapper reveals that flies use torque coupling in rapid banked turns. *Science* 361,1089-1094(2018).DOI:[10.1126/science.aat0350](https://doi.org/10.1126/science.aat0350)
- [14] S. Wang, D. Olejnik, C. d. Wagter, B. v. Oudheusden, G. d. Croon and S. Hamaza, "Battle the Wind: Improving Flight Stability of a Flapping Wing Micro Air Vehicle Under Wind Disturbance With Onboard Thermistor-Based Airflow Sensing," in *IEEE Robotics and Automation Letters*, vol. 7, no. 4, pp. 9605-9612, Oct. 2022, doi: 10.1109/LRA.2022.3190609.
- [15] Alzu'bi, Hamzeh, et al. "Loon Copter: Implementation of a Hybrid Unmanned Aquatic–Aerial Quadcopter with Active Buoyancy Control." *Journal of Field Robotics*, vol. 35, no. 5, Aug. 2018, pp. 764–78. DOI.org (Crossref), <https://doi.org/10.1002/rob.21777>.
- [16] Loon Copter: Modeling, Implementation, and Stability Control of a Fully-Featured Aquatic-Aerial Quadcopter - ProQuest.
- [17] Drews, Paulo L. J., et al. "Hybrid Unmanned Aerial Underwater Vehicle: Modeling and Simulation." 2014 IEEE/RSJ International Conference on Intelligent Robots and Systems, IEEE, 2014, pp. 4637–42. DOI.org (Crossref), <https://doi.org/10.1109/IROS.2014.6943220>.
- [18] "Parrot ANAFI | Professional Drone Camera 4K HDR." Parrot, <https://www.parrot.com/en/drones/anafi>. Accessed 11 Aug. 2024.
- [19] A. Sarabakha and P. N. Suganthan, "anafi_ros: from Off-the-Shelf Drones to Research Platforms," 2023 International Conference on Unmanned Aircraft Systems (ICUAS), Warsaw, Poland, 2023, pp. 1308-1315, doi: 10.1109/ICUAS57906.2023.10155881.
- [20] Pantos, Christos, et al. "Experimental Connectivity Analysis for Drones in Greenhouses." *Drones*, vol. 7, no. 1, Dec. 2022, p. 24. DOI.org (Crossref), <https://doi.org/10.3390/drones7010024>.
- [21] "Map without Limits – eBee X Overview." *AgEagle Aerial Systems Inc.*, <https://ageagle.com/webinars/exploring-sensefly-ebex/>.
- [22] Durmuş, Alpaslan, and Erol Duymaz. "Use of Unmanned Aerial Vehicles for Imaging and Remote Sensing." *Unmanned Aerial Vehicle Design and Technology*, edited by T. Hikmet Karakoc and Emre Özbek, Springer International Publishing, 2024, pp. 179–92. Springer Link, https://doi.org/10.1007/978-3-031-45321-2_11.
- [23] M. A. Sadenova, N. A. Beisekenov, T. B. Anuarbekov, A. K. Kapasov, and N. A. Kulenova, "Study of Unmanned Aerial Vehicle Sensors for Practical Remote Application of Earth Sensing in Agriculture", *Chemical Engineering Transactions*, vol. 98, pp. 243-248, Apr. 2023.
- [24] Tan, Chenyan, et al. "Accuracy Assessment of Mavic 3 Industrial UAV Based on DJI Terra and Pix4Dmapper." *Fifth International Conference on Geology, Mapping, and Remote Sensing (ICGMRS 2024)*, edited by Yinhe Luo and Yi Wang, SPIE, 2024, p. 13. DOI.org (Crossref), <https://doi.org/10.1117/12.3035344>.
- [25] M. Yousef and F. Iqbal, "Drone Forensics: A Case Study on a DJI Mavic Air," 2019 IEEE/ACS 16th International Conference on Computer Systems and Applications (AICCSA), Abu Dhabi, United Arab Emirates, 2019, pp. 1-3, doi: 10.1109/AICCSA47632.2019.9035365.
- [26] Omari, Sammy, et al. "Visual Industrial Inspection Using Aerial Robots." *Proceedings of the 2014 3rd International Conference on Applied Robotics for the Power Industry*, IEEE, 2014, pp. 1–5. DOI.org (Crossref), <https://doi.org/10.1109/CARPI.2014.7030056>.
- [27] Perez-Grau, Francisco J., et al. "Introducing Autonomous Aerial Robots in Industrial Manufacturing." *Journal of Manufacturing Systems*, vol. 60, July 2021, pp. 312–24. DOI.org (Crossref), <https://doi.org/10.1016/j.jmsy.2021.06.008>.