

Aerial Robotics for Inspection and Maintenance: Special Issue Editorial

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1. Introduction

The significant advances in last decade in the research and technology of multi-rotor design, modeling and control, supported by the increasing variety of commercially available platforms, components and manufacturers, have facilitated a rise in the novel applications of aerial robots, capable of not only perceiving, but also interacting with the environment, allowing the realization of diverse operations and tasks in areas and workspaces that are difficult to access by human operators or ground vehicles. Although the use of drones in surveillance and monitoring, or in aerial filming (both professional and personal) is quite extended nowadays due to the affordable cost of commercial platforms, the use of aerial robots for the inspection and maintenance of infrastructures is currently the subject of research and development, particularly when involving physical interaction during flight. The integration of sensors and robotic manipulators in these platforms, capable of easily and quickly reaching high-altitude workspaces and maintaining their position while hovering, allows us to obtain measurements of interest from cracks in bridges or corrosion in viaducts, and conduct diverse operations such as the installation of bird flight diverters on power lines. Aerial robots can also be used for the maintenance of healthy environmental conditions in urban or rural areas.

Despite the significant maturity level reached with these platforms, new research and technological challenges arise from applications demanding the benefits of aerial robots, particularly in outdoor environments, where regulation aspects must be considered. The current paradigm is to develop methods and technologies driven by specific applications and operational conditions imposed by the sensors or devices involved in the inspection and maintenance tasks, also considering general goals such as reducing costs, improving performance time, safety, and precision, or reducing energy consumption. Therefore, considerable effort is still being devoted to the mechatronic development and integration of new robotic manipulators, mechanisms, and sensor devices required to accomplish the intended task in flight, extending the capabilities of conventional multi-rotors in terms of autonomy and force interaction.

This Special Issue presents several research works focused on the use of aerial robots to conduct inspection and maintenance operations on infrastructures such as power lines, bridges, viaducts, or walls involving physical interactions.

2. Contribution and Advances

This Special Issue collects eleven papers from different research groups from Spain, Croatia, Italy, Japan, the USA, the Netherlands and Denmark, focused on the design, development and experimental validation methods and technologies of aerial robotics for inspection and maintenance. The main contributions and innovation of these works are summarized below.



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The lightweight and compliant dual-arm aerial manipulation robot presented in [1] employs one of the arms to estimate the position of the multirotor platform relative to the grabbing point, while the other arm is intended to conduct the manipulation operation in flight. This is motivated by the necessity to improve the positioning accuracy outdoors during the installation of devices on power lines, allowing the estimation and control of the interaction forces exerted by the arm, relying on the mechanical flexibility of the joints with deflection feedback. Reference [2] introduces the Cartesian aerial manipulator, a new morphology of aerial robot that exploits the benefits of a two degrees of freedom (DoF) Cartesian base (XY-axes) in terms of low weight/inertia and positioning accuracy, with a single DoF compliant joint, exploiting the deflection feedback from the flexible joint and a linear elastic link for contact force control and collision detection and reaction. The kinematic configuration of the manipulator is also applied in pick-and-store operations.

In order to increase the capability of conventional multi-rotors to generate forces along the horizontal plane, required in many contact-based inspection operations, the authors in [3] describe an add-on mechanism for multi-rotors, consisting of three ducted fans arranged in a Y-shaped structure that can be easily integrated in different types of multi-rotors, in such a way that the horizontal thrust allows the decoupling of the translational control from the attitude control. The developed prototype demonstrates how a relatively simple concept design can extend the functionalities and control capabilities of aerial robots.

The inspection and maintenance of power lines is the scope of the work in [4–6], in the context of the AERIAL-CORE H2020 project. The high altitude, high voltage, and difficult access of this essential infrastructure, comprising thousands of kilometers in any country, makes the realization of operations such as the installation of bird diverters (imposed by regulation to protect bird species from collision or electrocution) particularly risky for human operators, who have to climb the towers, using elevated lift platforms or even manned helicopters to reach the cables. This motivates the use of multi-rotor-based aerial robots and the development of new capabilities specifically for this application. In this context, reference [4] details the mathematical formulation for estimating the position and orientation of a multi-rotor platform from the magnetic field generated by the power line, measured by three magnetometers. Analytical expressions for the position of the aerial robot relative to the power line are derived, along with an exhaustive analysis of the different solutions and possible arrangements of the sensors.

Several designs and preliminary results in control, planning, and manipulation for the installation of devices on power lines, such as bird flight diverters and electrical spacers, are presented in [5], covering also the design of cognitive human–machine interfaces and the use of aerial manipulators for fast and safe tool delivery to human operators working on the power lines. The paper provides an overview of the different solutions explored as part of the AERIAL-CORE project in terms of safe local aerial manipulation. A particular technological solution for the installation of approved bird flight diverters is detailed in [6]. The main challenge here is to exert very high forces to install the device on the cable, using for this purpose a linear actuator with a customized clamp mechanism that holds the device and supports the reaction forces, so the aerial platform is isolated during the realization of the operation on flight.

The inspection of bridges [7], viaducts [8], and other civil infrastructures [9] using aerial robots requires the integration of specific sensors and devices, as well as the implementation of perception and navigation methods to conduct the operations in flight with a sufficient level of autonomy and positioning accuracy. The authors in [7] propose the deployment of a team of cooperative aerial robots to install inspection devices on bridges by spraying a resin onto the surface and applying a pushing force to keep the device attached. The paper presents the design of the control framework, covering the attitude/position and impedance controllers, the path planning, and the detection and estimation of the marked point. Two different aerial robotic solutions are presented in [8] for the visual and contact inspection of viaducts, where GNSS (Global Navigation Satellite System) positioning is not possible, requiring the integration of 3D LiDAR (Light Detection

and Ranging) combined with robotic stations to generate accurate maps of the environment. The presented work illustrates the development and integration efforts to increase the TRL (Technology Readiness Level) of aerial robots applied in real inspection scenarios.

Specific methods based on vibration monitoring for the assessment of civil infrastructure using aerial robots equipped with deployable sensor units are described in [9]. Different sensor technologies for Structural Health Monitoring (SHM) are identified, presenting the design of a sensor unit based on an accelerometer with a docking mechanism that can be attached to metallic structures using the aerial platform. Damages on monitored structures are detected as changes in their Dynamic Signature Response (DSR), relying on the B-Spline Impulsive Response Function (BIRF) for representing the time-variable system dynamics. The paper illustrates, in laboratory conditions, the deployment of the inspection sensor in a metallic structure subject to vibrations using the aerial robot, including the data acquisition, analysis and interpretation of results.

Traditional contact-based inspection methods are carried out by human operators, typically consisting of placing the sensor device in the point of interest. In this sense, the operator is responsible for determining the desired inspection point according to the observations of the environment and specific knowledge of the assessment. Therefore, in some cases it is not convenient or feasible to implement a fully autonomous inspection operation with an aerial robotic system, but it is convenient to allow the human operator to interact with the environment through the aerial robot. This is the scope of the research work presented in [10], in which a multi-rotor equipped with a passive and compliant end effector is teleoperated to exert contact forces using a haptic device that provides the user with feedback to improve his/her situation awareness. The paper is focused on the design of the bilateral teleoperation scheme and stability analysis to maintain contact forces in flight.

Although the inspection and maintenance of industrial and civil infrastructures is one of the most immediate application areas of aerial robots, reference [11] extends the scope by proposing the application of drones for releasing sterilized insects, in order to prevent the increase in insect populations that could become vectors of disease transmission in urban and rural environments. Given the capabilities of Unmanned Aircraft System (UAVs), either fixed wing or rotary wing, to cover large areas following accurately desired paths in an autonomous way, the paper considers the current regulation challenges in Europe and risk assessment when flying over populated environments, particularly when the drone operates beyond the visual line of sight (BVLOS).

3. Conclusions

The execution of inspection and maintenance operations in illustrative scenarios such as power lines, bridges, viaducts and other civil infrastructures, consisting typically of the appropriate collocation of a sensor or device in the point of interest, presents considerable risk when conducted at high altitude by human operators, and becomes a technological challenge when it is intended to be performed by an aerial robot operating outdoors. Overcoming the gap between research in indoor laboratories and practical application in realistic outdoor conditions also introduces significant difficulties, particularly in terms of positioning accuracy and reliability, requiring the integration of additional systems that reduce the effective payload. New mechatronic designs, estimation and measurement methods, control frameworks and technological solutions emerge from demanding applications that have been shown increasing interest in terms of the application of aerial robots to reduce the time, cost and risk compared with traditional procedures.

Since most of the inspection and maintenance devices currently employed in the realization of these operations are intended to be used by human operators, aerial robotics researchers and engineers face the problem of integrating or adapting these devices to aerial platforms, where the limited payload and flight time capacity are still the main constraints. It is foreseeable, however, that manufacturers will develop new inspection solutions adapted for aerial robots given the benefits and potential uses evidenced by multi-rotors.

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