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Revisión y perspectivas de los UAV en la evaluación de la eficiencia energética de los edificios
Review and prospects of UAVs in the evaluation of energy efficiency in buildings

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Resumen— **Las tecnologías son necesarias para perseguir un desarrollo sostenible y minimizar el actual aumento de la demanda energética. Se propone la integración de vehículos aéreos no tripulados (UAV) para tareas de inspección visual. Se utilizan imágenes térmicas para detectar defectos de pérdida de calor. La temperatura de la superficie y la geometría de un edificio se emplean para garantizar una evaluación fiable. El uso combinado de ambos permite la inspección no destructiva de componentes, así como la evaluación de la eficiencia energética.**

La supervisión periódica de espacios y la identificación automática de errores de construcción mediante IA es la dirección futura de los dispositivos UAV. Esto es de gran importancia teniendo en cuenta las importantes pérdidas de energía que podrían evitarse con una identificación temprana y, en consecuencia, el ahorro económico que supondría.

Palabras clave— UAV; eficiencia energética; termografía; fotogrametría.

Abstract— **Technologies are necessary to pursue sustainable development and minimize the current increase in energy demand. The integration of Unmanned Aerial Vehicles (UAVs) is proposed for visual inspection tasks. Thermal images are used to detect heat loss defects. The surface temperature and geometry of a building are employed to ensure a reliable assessment. The combined use of both allows for non-destructive inspection of components, as well as the evaluation of energy efficiency.**

The regular monitoring of spaces and automatic identification of construction errors through AI is the future direction of UAV devices. This is of great importance considering the significant amounts of energy losses that could be prevented with early identification, and, consequently, the economic savings it would entail.

Index Terms— UAV; energy efficiency; thermography; photogrammetry.

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I. Introduction

Currently, there is a rise in energy consumption to meet the growing needs and comfort of society. This underscores the increasing urgency of sustainable development in energy policy (López et al., 2018).

Urban sustainability to mitigate climate change holds great importance for the EU. The energy sector is responsible for 80% of the European Union's greenhouse gas emissions. The construction sector accounts for 40% of final energy consumption and 36% of emissions. Consequently, it is assigned a strategic role in savings due to the untapped energy potential it presents (Commission et al., 2021).

For this reason, the European Commission promotes energy savings in buildings through the Energy Performance of Buildings Directive (EPBD), which incorporates the concept of "Nearly Zero Energy Buildings" (NZEB) as a minimum level of energy performance to be met. Various mandatory information systems are applied to the current real estate portfolio, such as energy certificates, boiler and air system inspections, and optimal profitability methodology (Chapter 3 - From Efficient to Sustainable and Zero Energy Consumption Buildings. 2019).

The overall longevity of buildings involves assessment throughout their life cycle. Limiting conditions lead to poorer results compared to empirical ones. The implementation of energy efficiency is an ongoing process (Troi et al., 2014). This is where the importance of new technologies comes into play. Regular monitoring involves early identification of errors, leading to immediate energy savings.

Therefore, this document reviews various data acquisition approaches using unmanned aerial vehicles (UAVs) for energy studies. The emergence of this new data acquisition method facilitates energy studies. The existence of systems with fast processing capabilities and different design software with simulations highlights the importance of using these drones as auditing tools due to their speed, accessibility, economic savings, and efficiency.

A. UAV

"UAV" is an abbreviation for "Unmanned Aerial Vehicle." It is an aerial system composed of an unmanned aircraft that can be remotely controlled or follows a preprogrammed flight path.

A UAV is a set of technologies that perform a specific task. Three fundamental components are identified: the unmanned aircraft, the ground control station, and communication data. In addition to this, they are equipped with different components depending on the drone's mission. These may include autopilots, image sensors, and wireless systems. In this communication, these technologies are considered, which are of interest for the energy field and monitoring (Colomina and Molina, 2014).

In this study, the term "UAV" is used to refer to the set of elements that includes an Unmanned Aircraft (UA), a Ground Control Station (GCS), and a data communication link for commanding and controlling the UA (C2) from the GCS.

B. Energy Efficiency

The development of these new technologies is driven by the current increase in energy demand. It currently requires a high energy consumption to maintain the comfort and quality of life in society. As mentioned, the current challenge focuses on seeking a sustainable transformation, considering that existing resources are finite. Energy efficiency is introduced with the aim of avoiding energy waste, and enhancing it is the cheapest and most effective way to address this situation (Rey Martínez and Velasco Gómez, 2006).

The UNE-EN ISO 50001:2018 standard is applied to conduct an energy audit of spaces. This standard specifies requirements for implementing, maintaining, and improving an energy management system. These audits help identify the systems that consume the most energy to implement improvements. The standard provides a systematic and documented approach to optimizing energy performance. The acquisition phase is where drones are implemented (Asociación Española de Normalización, 2018).

Energy audits are crucial for identifying energy-saving opportunities, complying with regulations, improving the efficiency of systems and equipment, promoting energy awareness and education, and assessing the feasibility of renewable energies. These actions contribute to reducing energy consumption, operational costs, and greenhouse gas emissions.

C. Photogrammetry

Photogrammetry is a non-destructive technique (NDT) that aims to determine the dimensions and location of objects in a specific area by measuring the intersection of two or more photographs or a photograph and a digital terrain model. To obtain an accurate model of the represented location, it is necessary to generate the intersection of several photographs.

The use of a UAV device can assist in obtaining images for the proper application of photogrammetry. The aerial vehicle, with a programmed flight, allows for capturing detailed images from heights inaccessible to a human, thereby obtaining the necessary data to graphically reconstruct a three-dimensional image of the building under study.

D. Thermography

Thermography is a non-contact measurement method that utilizes a thermal camera to record the temperature distribution on surfaces. It measures the long-wave infrared radiation in the field of view to calculate the average temperature of the object. Subsequently, this data is transformed into a thermal image, allowing visualization of the temperature distribution. Each pixel represents a surface temperature point. Emissivity and the reflected temperature from the object's surface are considered for obtaining the image.

The combination of this testing method on a UAV can contribute to the speed of error detection in large spaces. In a remote or planned flight, differences in temperature on the building surfaces, identified with the thermal camera attached to the drone, can reveal construction issues. Leaks, anomalies, cracks, poorly sealed areas, among others, can be identified due to the difference in tone represented in the digital image.

E. Research methodology

Choosing to conduct a review of UAV devices takes a multidisciplinary approach, considered the best way to gain in-depth knowledge about the use of this technology. To understand the state of the art of UAVs, Scopus is employed, which is a bibliographic database and abstracts of academic and scientific literature managed by Elsevier.

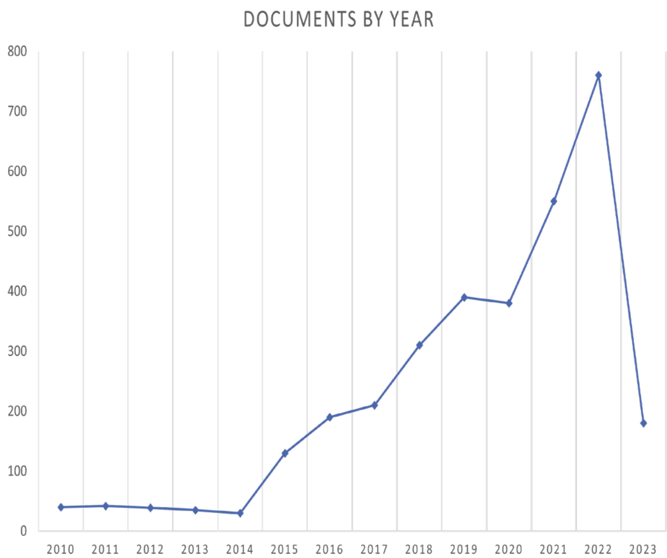

Fig. 1 Chart showing publications of articles related to UAV by year. (Source: Scopus, Elsevier)

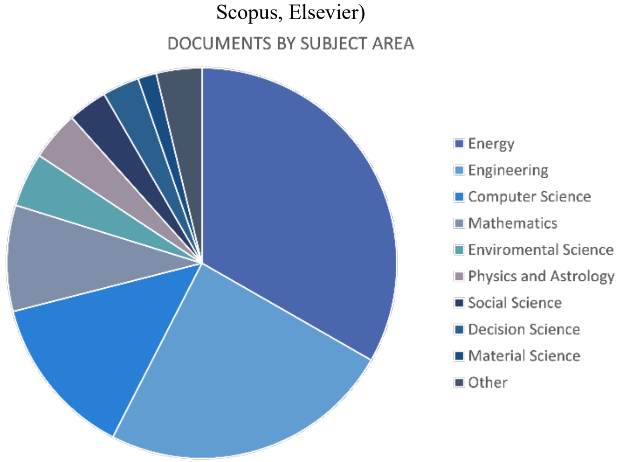

Fig. 2. Chart of research area related to UAVs. (Source: Scopus, Elsevier)

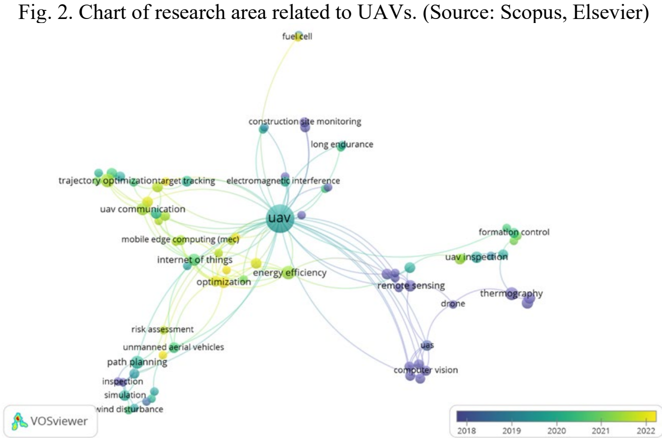

Fig. 3. Overlay visualization UAV VOSviewer (Fuente: Scopus Elsevier)

The increasing interest in recent years is readily apparent; the initial illustration portrays the exponential surge in the quantity of research documents pertaining to Unmanned Aerial Vehicles (UAVs), with 756 articles published in the year 2022. In terms of thematic focus, 32% of the publications revolve around the field of energy.

To identify the domains in which UAVs are utilized, Scopus publications were employed, followed by the application of VOSviewer. This software enables the correlation of drones with themes based on keywords from publications over the last 13 years, using 'UAV' as the keyword. Furthermore, it facilitates the identification of future trends due to the chronological option it provides. With this information, the methodology of the subsequent document is bifurcated into two parts.

Firstly, the applicability and functionality of UAV devices are examined in relation to the energy analysis of buildings. To achieve this, various types of drones, programming techniques, and existing wireless connections are explored. Additionally, combinations of drones with different sensors are scrutinized, with a particular focus on those highly regarded in the energy sector, namely photogrammetry and thermography. Along this line of investigation, 38 outcomes are obtained, comprising scientific articles, doctoral theses, and books. The timeline spans from 2010 to 2023. In conclusion, findings are drawn, encompassing new challenges and prospective avenues that may emerge in the realm of drones, along with the introduction of technologies associated with this future perspective.

II. Experimental

A. Use of Drones in Engineering

In the field of engineering, drones have multiple applications. They are used for topographic surveys, infrastructure inspections, construction site monitoring, among other applications. Their ability to quickly capture data and perform inspection and monitoring tasks makes them an indispensable tool in the industry. Despite these general uses of drones, it should be noted that the application depends on the type of sensor or camera with which they are equipped.

In the visible spectrum, RGB sensors are utilized to document events and develop technologies based on human perception, particularly in photogrammetry and 3D modeling.

Applications in reflected infrared involve the use of technologies to analyze the infrared radiation reflected by objects. This region of the electromagnetic spectrum extends from 700 nm to 2500 nm, beyond the visible region. It is used primarily in material identification, agriculture, and geology.

Thermal infrared applications deploy sensors capable of quantifying temperature accurately without physical contact. The data obtained is converted into images with information about the material's temperature. This allows for infrastructure inspection, detection of geothermal anomalies, and search and rescue operations even in conditions of limited visibility.

The unmanned aerial vehicles (UAV) industry is constantly evolving. Regarding the typology of UAVs available in the

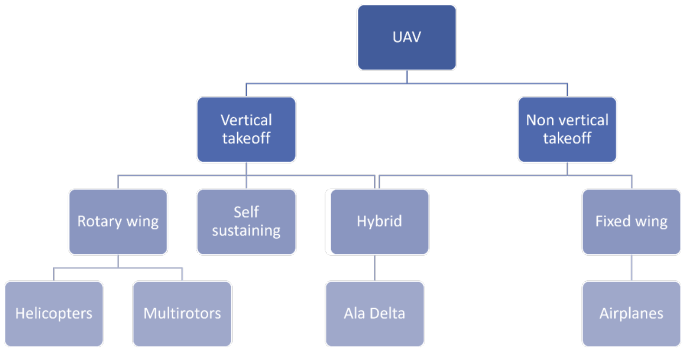

Fig. 4. Classification scheme of drones.

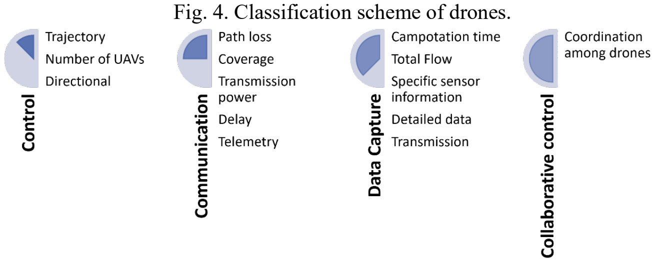

Fig. 5. Classification of UAV transmissions according to control type.

market, it depends on their characteristics and capabilities. The choice is based on specific mission requirements. They are classified based on takeoff; if the ascent is vertical, they are drones equipped with rotary wings or self-sustained. They are characterized by the ability to hover in flight and limited autonomy. Conversely, drones with fixed wings allow for lift generation and are efficient in long-range, long-duration flights due to their aerodynamic shape. Lastly, there are hybrid drones, which are efficient in long-range, long-duration flights due to their aerodynamic shape and can also take off and land vertically.

UAV drones utilize various wireless connection technologies to provide different types of data necessary for subsequent analysis. Additionally, the connections may vary in terms of the number of main components that can be controlled or communicated through the connection. This connection can be achieved through radiofrequency (RF) or technologies such as Bluetooth or Wi-Fi (Gu and Zhang, 2023). For live telemetry and video transmissions, 4G/5G is employed. Depending on the number of components that can be controlled or communicated through the connection, concepts such as 2C (Control and Communication), 3C (Control, Communication, and Data Capture), and 4C (Control, Communication, Data Capture, and Collaborative Control) are incorporated (Shahzadi et al., 2021).

With the anticipation of the upcoming generation of wireless network, 6G, significant research has been conducted on the integration of UAVs into cellular communication systems. This aims to support reliable UAV control as well as mission-related payload communications (Europea, a). Currently, Real-Time Kinematic (RTK) drones are being introduced, which are high-precision positioning systems used in mapping and topography applications. These drones are equipped with Global Navigation Satellite System (GNSS) receivers that enable real-time centimeter-level position data (Taimoor et al., 2022).

As of December 31, 2020, the regulations (EU) 2019/947 and Delegated Regulation (EU) 2019/945 are in effect (Europea, b). These regulations apply to all drones regardless of their use or size, with the only exemptions being drones for military, rescue, police, customs, border control, and other security-related purposes.

B. UAV and thermography

The use of Unmanned Aerial Vehicles (UAVs) equipped with Infrared Thermography (IRT) has revolutionized the way inspections are conducted. This combination of technologies allows capturing thermal images from the air, providing a panoramic and detailed view of temperature distribution in different environments.

UAVs equipped with thermography find applications in various fields, primarily in construction and rehabilitation to detect construction defects. Additionally, this technology is employed in industrial inspections due to noticeable variations in infrared energy patterns in different electrical systems and/or industrial processes. Its application extends to the realm of safety and rescue, where sensors enable the detection of individuals in hard-to-reach areas during critical situations. Finally, thermographic cameras play a significant role in precision agriculture, as insect infestations cause temperature increases.

Regarding drones compatible with thermographic cameras, the commercial drone market is currently dominated by the Chinese company DJI (Da Jiang Innovations). The industry-leading brand offers models like DJI Matrice 300 RTK and DJI Matrice 210 RTK suitable for thermographic cameras. These drones utilize GPS and GLONASS navigation modules, two Inertial Measurement Unit (IMU) modules, and a front and downward vision system to automatically stabilize and navigate around obstacles (Burdziakowski, 2018). When choosing a thermographic camera, factors such as the thermographer, lens focus, resolution, sensitivity, scene range, among others, must be considered. For image processing, there is a wide range of thermal image management software, with FLIR Thermal Studio being the most recognized .

Early experiments with UAVs focused on thermophysical sampling to explore vast and inaccessible territories. Mavromatidis et al. equipped UAVs with an active pulse infrared camera to obtain thermal data not achievable with passive pulsing from the surface. A year later, Krawczyk et al. conducted an analysis to assess the energy consumption of buildings using infrared thermography on UAVs. Spatial resolution deficiencies were identified in the results, and areas for development included asymptotic behavior and the limited adaptability of UAVs to operate in various weather conditions and high turbulence. While the effectiveness in detecting issues such as thermal losses and insulation leaks is optimal, technical improvement of the results is necessary for a proper enhancement of energy performance in buildings.

Nevertheless, the focus shifted to the development of new connectivity ports and additional power options to support sensors and enhance control software. Specific changes in features, such as resolution, which was the initial focus, evolved towards creating products that generate demand in the market (Rakha et al., 2018). This implies referencing existing technological capabilities and carrying out more parameterization of processes, allowing a more comprehensive view through the validation of replicated experiences. Additionally, the need for standardized methodologies to facilitate presented work arose.

Following a study, OMAR, T et al. adopted new imaging tools and AI-based approaches for infrared thermal data to achieve complete automation of the analysis process and improved decision-making. Their study explores the possibility of using infrared temperature measurements taken from a UAV to detect subsurface segregation in concrete bridge decks.

In line with standardization, Waqar Akram et al. (2021) investigate thermography and subsequent infrared image processing to automate the detection of defects in solar panels intended for housing. They conduct experiments on faulty and normally functioning photovoltaic modules and present an image processing scheme applicable in different cases, offering a better visualization of defects.

On the other hand, K. Hossain et al. propose using thermal images taken by drones to detect energy leaks in underground pipes of urban heating systems, as part of their focus on new technologies and automation. To identify potential leaks, a land region extraction algorithm is utilized. Subsequently, a Convolutional Neural Network (CNN) and eight conventional machine learning classifiers are applied to these regions to determine whether they are leaks or not.

Liu et al. conducts a study using deep learning and infrared thermography to detect and classify the severity of cracks in asphalt pavement, aiming to investigate new segregation patterns and automate this process. They use a UAV equipped with an Infrared Thermal (IRT) measurement method to collect data. By using Convolutional Neural Network (CNN) models, they achieve satisfactory performance in crack detection, but errors are observed in classification. It is concluded that further research on different crack types is necessary to better assess deep learning performance.

These results demonstrate that deep learning, especially Convolutional Neural Networks (CNN), is becoming a powerful tool for automating this process. With the need for regularization and the advent of better technologies, efforts are directed towards improving performance, including the robustness, computational intelligence, and flexibility of UAV systems, aiming to enhance energy efficiency in a faster, cleaner, and more economical manner.

C. UAV, photogrammetry and laser scanning (3D)

As previously mentioned, photogrammetry is a technique employed to obtain precise measurements and positions of objects in space through the analysis of images captured from various locations. There are three main approaches to photogrammetry. Firstly, there is analog photogrammetry, which relies on mathematical models. Next is analytical photogrammetry, which applies mathematical models to physical objects with the aim of obtaining precise measurements. Lastly, there is digital photogrammetry, which is the most common and updated, relying on the use of computer programs to process digital images. Regarding image acquisition, this can be done both from the air, using a camera mounted on an aircraft or drone, and from the ground, using a portable camera mounted on a tripod (Sancho Gómez-Zurdo et al., 2021).

Photogrammetry using drones has multiple applications, with 3D terrain modeling and orthophoto generation being particularly noteworthy. Additionally, it is applied in infrastructure analysis and architecture through the creation of a feasible digital model to obtain curves and profiles. Finally, it is highly useful in mining exploitation, as it allows for the study of the state of material quarries.

The choice of drone model depends on the specific requirements of the photogrammetry project, such as camera resolution, flight autonomy, and stability in the air. Regarding the leading drone brand, DJI Phantom 4 Pro and DJI Mavic 2 Pro are suitable models for photogrammetry. These drones are compatible with different cameras or photogrammetric sensors and support various flight planning applications.

Photogrammetry-enabled drones have garnered much interest due to their economic accessibility and their ability to rapidly generate digital data thanks to their navigation, control, and recording devices. The main advantage of drones is their capability to provide high-resolution information in terms of time and space, enabling a quick response in critical situations where immediate access to 3D geospatial information is required.

In 2011, Remondino et al. reviewed current optical sensors and 3D modeling techniques, showcasing examples of measurements on buildings and objects to generate 3D models. Two years later, Roca et al. proposed the use of a UAV platform with a Kinect sensor to acquire geometric data from inaccessible areas from a terrestrial platform. As the generated model has limitations due to the sensor, the resulting point cloud is not uniform. Hence, it is suggested to mount different sensors on the platform to achieve better results. The focus should be on analyzing the performance of different sensors on the platform to find the optimal system configuration. These studies are crucial for analyzing the energy balance of buildings and detecting conditions economically and reliably across large surfaces.

In the same year, Siebert & Teizer presented an approach to evaluate the performance of UAV systems. This document describes hardware components and introduces a new flight route planning software tool for automated test missions. They demonstrate how to capture a georeferenced image taken by a camera connected to a drone. The results indicate improvements compared to previous studies, although limitations such as battery duration should be considered. Subsequently, future works of similar case studies used in more hostile work environments and equipped with additional sensors, such as rangefinders and infrared, will be mentioned, complementing this work.

Aicardi et al. conducted an article with the intention of evaluating the possibility of acquiring and processing oblique images for the 3D reconstruction of a historic building, obtained through UAVs and traditional commercial off-the-shelf (COTS) digital cameras for high-detail architectural surveys.

This proves to be an effective tool for inspecting objects characterized by limited accessibility, detailed requirements, and speed in the acquisition phase, often within reduced budgets. The software tools used can produce a similar product, albeit with slight differences in results, including open-source and open-code software.

To conduct a comparison with market technologies, Inzerillo et al. presented a study of 3D reconstruction based on images using traditional and UAV datasets for the analysis of road pavement deterioration. The Structure from Motion (SfM) technique was used to analyze geometric relationships between visual features detected in images. It was observed that the 3D model obtained from UAVs was less accurate, concluding that UAV-SfM results are useful for understanding general conditions and immediate action. However, for specific improvements, a more detailed analysis is necessary.

Freimuth & König investigated an application that enhances inspection tasks by combining BIM and Dronecode. The innovation is a system that maximizes automation to control UAV inspection tasks, eliminating the need to manually create flight routes, thereby increasing inspection efficiency. The analysis of georeferenced BIM geometry has proven to be a reliable method for navigation in confined spaces, such as construction sites. However, researchers suggest integrating a GPS navigation method to account for location-specific features, as distances to structures may vary.

Given that distance is a barrier, the possibility of calculating the navigation volume, considering the height of facades and sky occlusion in future versions of the mission planning solution, is proposed. The integration of advanced autonomous methods to actively avoid obstacles is suggested. These technological advances enable a highly useful photogrammetric workflow in the fields of architecture and engineering.

Andaru et al. discovered that to create a complete 3D point cloud of a building, an iterative algorithm (ICP) can be used to merge point cloud data generated through terrestrial laser scanning (TLS) and UAV with photogrammetry, integrating them into a reference system, making this method more efficient. Unity 3D technology was used for representation.

Rizo-Maestre et al. presents a novel perspective, looking from inside the object outwards. This methodology, based on the use of drones, integrates terrain capture, 3D mesh generation, and overlay of environmental reality with architectural design using modeling techniques such as Building Information Modeling (BIM).

In another study by Zhao et al., a model for emergency dam monitoring is proposed using unmanned aerial vehicles (UAVs) and a three-dimensional (3D) model of the dam with real texture of the surroundings and scale information. A study was conducted on a small-scale dam to detect damages by comparing point clouds before and after destruction. The method is efficient and cost-effective, and the results demonstrate that basic and low-cost UAVs can generate suitable models for monitoring construction health. Considering the economic costs and time investment of the proposed method, it is suitable for widespread use. There is an intention to integrate recognition algorithms to automatically identify existing defects in the dam model.

In a recent publication, Ali et al. present the development of a near-real-time damage detection method using convolutional neural networks (CNN) as a base network combined with an autonomous UAV for automatic detection of structural issues. The study used a structure with defects such as cracks, corrosion, and loose bolts.

In conclusion, further research is needed to continue improving accuracy for real-time damage detection in large-scale bridge systems. Developing optimized training data for high-performance damage detection is a significant challenge using small and cost-effective UAVs.

D. Combining UAVs with Three-Dimensional Imaging and Infrared Thermography

The combined use of three-dimensional imaging and infrared thermography is of great interest in many fields of engineering, science, and construction. This combination is commonly employed in the construction sector, enabling non-destructive inspection and testing of components, as well as the evaluation of energy efficiency.

The automated generation of a 3D model of buildings from photogrammetric data and thermal images can be a powerful tool. Thermal images obtained through infrared thermography from an Unmanned Aerial Vehicle (UAV) can be used to determine the energy efficiency of a construction and detect defects such as thermal bridges and heat losses. However, reliable evaluation requires surface temperature and geometry information.

Applying the mentioned combination, Bang et al. studied a preprocessing method to enhance the quality of image stitching. This is the first attempt to apply deblurring and key frame selection techniques to images obtained by UAV. The specific contributions of this study are twofold: first, the use of a moving average of blur values from adjacent images in the deblurring module, unlike existing techniques; and second, the use of altitude and horizontal speed information in the key frame selection module. These improvements allow the proposed method to generate panoramas accurate and detailed enough for construction management applications.

This system has various applications depending on the pursued objective, as it can be used to analyze vast environments. Webster et al. employed matching thermal and RGB images taken from a UAV to produce a 3D model in both RGB and temperature terms for individual trees and forest stands. The thermal structure of the forest canopy in 3D was obtained from thermal images. 3D point clouds generated from thermal images accurately captured the complex structures of both individual trees and the forest. RGB and thermal images were acquired from two UAV flights over a forest in a single morning during the thaw season.

On the other hand, to ensure real-time inspections, Entrop & Vasenev demonstrated how thermal sensors and drones can be combined to measure heat for monitoring, assessing, and detecting structural damage remotely in real-time. This innovative technology addresses time and cost issues. A drawback of this new technology is the lack of a 3D map, so the pilot cannot guarantee the detection of every part of the building. Once an error is identified, there is no way to save or re-implement.

Obstacle identification represents most of the challenges in this field, as capturing subsequent changes after obtaining a result proves difficult. In a recent study conducted by Garibeh et al. and collaborators in 2022, a motion planning system was implemented in a dynamic 3D space for the control of Unmanned Aerial Vehicles (UAVs). In this system, the UAV is assumed to move in a three-dimensional environment under the simultaneous influence of attractive and repulsive forces. This allows the UAV to adjust its altitude and position in real-time when both the target and obstacles are dynamic. Simulations and experiments were conducted to validate this system in dynamic 3D environments. Additionally, an optical tracking system with six Vicon cameras was used to obtain accurate information about the position of moving objects during real-time tests. The obtained results demonstrated the effectiveness of the motion planning system in this context.

E. Future perspectives

The use of UAV technology in combination with the non-destructive techniques makes a significant contribution to the automation of energy audits by integrating them into data sciences such as deep learning (DL) or artificial intelligence (AI). The focus is on endowing machines with the capability to analyze and interpret images or videos based on previous case studies. This encompasses tasks such as recognition, detection, image segmentation, among others. The automation of the process facilitates the inspection task in terms of time, money, and, consequently, energy savings in this case.

The DL method employs artificial neural networks with deep structures and hidden layers, providing it with greater robustness and intelligence. Its development is currently in a limited stage, with the adoption of DL-based approaches being studied to optimize the photogrammetric processing task of UAVs. The primary goal is to generate a point cloud and an orthomosaic, using techniques such as Structure-from-Motion (SfM) and Multi-View Stereo (MVS) (Ma et al., 2021). While this field is still an open challenge, the potential of deep learning in this task is highlighted. Methodologies based on this are primarily used for the detection and description of attributes, and further research is needed in the field of feature matching (Osco et al., 2021). This will open new opportunities to optimize photogrammetric processing, improving the quality of generated products and reducing the need for manual intervention in the workflow.

In addition to the mentioned challenge, real-time decision-making or the rapid identification of users is one of the current key research topics intended to be addressed with artificial intelligence (AI). Traditional optimization methods fall short when it comes to a solution that can offer continuous learning and operate in real-time dynamic environments with total autonomy and low computational complexity. With the 4C connections available in UAV wireless systems, AI-based models can learn on cloud platforms with the required precision. Furthermore, the possibility exists to perform inference on edge nodes based on usage or user requirement conditions (Gu eta Zhang, 2023). The concept of the Internet of Things (IoT) applied to drones is introduced to enable the interconnection of everyday objects for data transfer and communications. Thanks to AI, drone capabilities would significantly expand, allowing for real-time monitoring, remote tracking, route and operation optimization, integration between systems of different drones, and decision-making based on AI algorithms, such as pattern detection (Pan eta Fu,2023).

III. Results and discussion

The communication has provided an overview of UAV systems and applications, with particular attention to the fields of photogrammetry and infrared thermography. The reported examples showcase the current state of the art in UAV technology across various application domains. Data acquisition remains a critical task for obtaining images with suitable geometry in the photogrammetric process, especially in non-planar and large-scale projects. While flight programming for nadir images is straightforward, the same task becomes more complex for 3D studies that require convergent images. Nevertheless, the achievements outlined in the document demonstrate a high level of photogrammetric processing capability, with real-time acquisition and transmission capabilities. However, there is a lack of discussion on data collection and processing modes using UAVs.

UAVs offer numerous advantages compared to traditional airborne platforms. In addition to reducing operational costs, they decrease the risk of access in hostile environments while maintaining a high level of precision. To fully capitalize on these advantages, it is highly recommended to use automated and reliable orientation software. Currently, various robust solutions are available, including open-source and low-cost options for 3D building modeling. However, it's important to note that algorithms for sensor fusion working under the same software have not been discussed in detail. To maximize the potential of UAVs in remote sensing applications, research and development should focus on algorithms that efficiently integrate diverse sensors to facilitate better understanding and analysis of collected data.

This is where artificial intelligence comes into play. The latest 5G mobile networks have enabled IoT applications in drones. However, the AI methods used must be capable of processing data and making decisions efficiently while minimizing energy consumption. The existing cloud-based AI paradigm still struggles to meet the specific requirements of UAVs. For this reason, research is focused on developing solutions that better adapt to the needs and limitations of these aerial systems.

IV. CONCLUSIONS

In the energy sector, the initial experiments with UAVs equipped with different sensors and cameras were carried out with the intention of reaching areas that were inaccessible using traditional methods of data acquisition. Initially, the goal was to improve the image quality of the results and further explore the technique for accurate auditing. However, as research in the field progressed, a broader vision emerged, recognizing the opportunities that this technology can offer. Consequently, there arose a need for greater parameterization and standardization of UAV technology.

This communication proposes a literature review on the integration of UAVs in visual inspection tasks. An overview of research related to inspection and the application of autonomous UAVs shows that many industries are looking to employ UAVs for remote sensing tasks. The combination of new advanced technologies and open-source autopilot technology forms the basis of a systematic approach to automate flight behavior in a safety-conscious manner and aerial photography.

UAV platforms, as observed in the review, offer advantages compared to traditional data acquisition methods. Hence, their popularity in commercial and industrial applications. However, the main challenge lies in considering the process as subject to biases and potentially imperfect. Currently, the focus is on remote sensing, aiming to obtain fast and precise information from data collected by UAVs. In this context, the development of deep learning (DL) and artificial intelligence (AI) techniques has emerged as a promising solution to enhance the process.

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