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Application of unmanned aerial vehicles in construction industry

Abstract: Unmanned aerial vehicles, commonly known as drones, are widely used in many sectors of the economy, including in: mining, agriculture, medicine, ecology, transport. The systematic literature review shows that drones are also widely used in construction, including: construction inspections, damage assessment, area measurements (inventory, area mapping), safety inspections, monitoring of the work progress, maintenance buildings, as well as thermographic researches.

Keywords: Unmanned aerial vehicles; drone; Literature review, Construction industry; Occupational health and safety

Introduction

The era of the use of unmanned aerial vehicles (UAV - unmanned aerial vehicles), the so-called drones solely for military purposes is history. Over the last decade, unmanned aerial vehicles have been used extensively in the civil and commercial sectors. Currently, drones are widely used in many sectors of the economy, including in: mining, agriculture, medicine, ecology, and transport. Unmanned aerial systems are also widely used in construction, e.g. in: construction inspections [1,2], damage assessment (damage, damage), land measurements (inventory, site mapping), safety inspections, monitoring work progress [3], building maintenance, as well as thermal imaging [4].

One should be aware that unmanned aerial vehicles pose new, previously unseen threats in the construction industry. New threats are related to the constant development of new technologies, as well as the continuous automation and robotization of the construction industry. Although there are studies on the benefits that new technologies, including drones, bring to the construction industry, there is still a lack of quantitative studies analyzing the impact of the use of unmanned aerial vehicles on the health and safety of workers. The analysis of factors affecting the safety of operations with the use of unmanned aerial vehicles shows that the main causes of accidents are human errors and technical problems.

The use of unmanned aerial systems (UAS - the unmanned aerial system) allows you to achieve several significant benefits in terms of safety in construction. Firstly, drones can move faster than humans, and they can also reach places that are inaccessible or hard to reach for humans - e.g. located at a height with no access [5]. The use of drones can significantly improve work safety, e.g. near moving vehicles on the construction site, in the working area of the crane/construction crane, near unsecured edges and openings, as well as in the area of the so-called "blind spot" when using heavy construction equipment.

Systematic literature review

A systematic review of the available literature was performed. The literature review includes only Web of Science articles from the last decade (January 2011 to December 2021) to ensure that the information contained in the articles is up-to-date. For the literature review, the following keywords were selected that could be present in the title, abstract, or keywords, namely: "drone", "unmanned aerial vehicle", "construction". To assess the relevance of selected papers, a set of criteria was established to exclude publications based on their content and type of publication. First, those works that did not directly present research or analysis on the use of unmanned aerial vehicles in construction were identified and excluded. The type of paper was then verified to ensure that the publications originated from peer-reviewed journals or conference proceedings. Finally, the manuscripts were reviewed to ensure that at least one of the study's keywords was addressed in the body of the article. After incremental evaluation, 40 publications were obtained. The thematic scope of the articles concerned 5 main areas:

1. review articles (12 articles),
2. classification of drones (8 articles),
3. flight planning (4 articles),
4. occupational safety (8 articles),
5. case study analysis (8 articles).

In a situation where the article dealt with several of the above-mentioned thematic areas, it was qualified to only one leading area.

Review articles

This group of articles includes works that present the current state of knowledge in the field of the use of unmanned aerial vehicles in construction or discuss the applicable legal regulations that regulate the principles of drone movement in the air [6,7]. These articles discuss the results of original scientific research so far, e.g. in the analysis of the current state of research on the use of drones in the USA [8], as well as in India [9]. The analyzed works present the possibilities of using unmanned aerial vehicles to manage a construction site, and in particular to monitor the progress of works and construction inspections, improve logistics at the workplace, assess work safety conditions and damage caused by disasters [10,11].

The second use of drones in construction is in the literature. in addition to management on the construction site, it is possible to perform photogrammetric measurements using photos taken on the construction site. Pictures taken with the help of a drone allow you to develop, among others, orthophoto maps and digital terrain models [12]. The use of appropriate photogrammetric software allows for the integration of the collected and developed data with building information models supporting BIM technology [13] and can be used to assess the progress of the project [14], as well as to check geometric compliance in the design model [15]. Unmanned aerial vehicles equipped with a thermal imaging camera can also be used in construction thermography [16], and after appropriate preparation, they can also be used to inspect buildings in closed rooms [17].

Drone classification

Two types of unmanned aerial vehicles are commonly used in construction: rotorcraft and fixed-wing aircraft. Devices with rotating rotors (rotorcraft) are characterized by the ability to hover, vertical take-off, and landing [18]. Depending on the number of rotors, these can be helicopters or multi-rotor aircraft [19]. The lift principle of rotor-ships makes them a potentially better platform for small to medium projects or vertical types of construction. Remotely controlled devices in the form of a fixed airframe (resembling airplanes and flying wings) are characterized by the ability to stay in the air for a long time without the need to land. This translates directly into the ability to carry out raids over large areas. Such capabilities make them a better platform for large projects, especially linear ones [20]. The main limitations of fixed-wing aircraft resulting from their design are: the inability to hover and the need for a large space for take-off and landing [21]. In addition to the standard types of unmanned aerial vehicles used so far, new, innovative solutions are being designed, often combining the benefits of both types. In addition, when designing and constructing new structures, the following options are taken into account: the use of previously unused materials [22], the possibility of adding additional devices [23], or the existing structure being modified by adding additional rotors [24]. Innovative materials and techniques are used for their construction, e.g. elements made using 3D printing technology [25].

Flight planning

Regardless of the type of equipment used, it is important to properly plan the course of the flight before it takes off. The aim of the conducted research in this area is, among others, the optimization of the flight trajectory along which the drone moves while monitoring the progress of work [26]. An important issue is also the correct flight planning for a group of drones (the so-called "swarm") moving over urban areas with obstacles of various heights. The conducted research aims to find the best trajectories while ensuring collision-free navigation [27]. Another goal of the conducted research is the optimization of the flight speed, which will ensure that the drone will spend the most effective time monitoring the construction site, and will complete the route within the specified time and without depleting the battery [28]. On the other hand, when performing photogrammetric measurements, the level of detail of the collected data is important, which allows for the recognition of structural elements and the internal consistency and precision of measurements. [29].

Work safety

Unmanned aerial vehicles are effectively used to improve occupational health and safety at workplaces. The use of unmanned aerial vehicles allows e.g. eliminating the need for employees to stay in dangerous zones, enter confined spaces, or work at heights. However, it should be borne in mind that unmanned aerial vehicles may pose new threats that have not yet occurred on the construction site [30]. Possible threats and near-accident situations should be identified, their risk assessed and the necessary preventive measures taken to prevent their occurrence [31]. This is necessary to ensure the safety of employees performing work in their environment. The key role here is to identify the applied solutions, safety practices, and applicable technical requirements using air systems [32]. Unstable flight conditions, operator errors, and equipment failures may pose a potential threat to employees working nearby [33]. A wrongly selected flight trajectory of an unmanned aerial vehicle may lead to a collision, which may cause injury to people or animals, significant damage to the equipment, or even loss of the device [34]. It should also be noted that unmanned aerial vehicles are devices powered by electricity, which in turn may be a potential source of ignition for flammable materials and combustible clouds of dust [35]. In addition, unmanned aerial vehicles on a construction site can be a distraction for workers, and this can worsen the overall worker safety record, increasing the number of work accidents without the direct involvement of a drone [36]. Previous research also shows that stress and fatigue of the drone user/pilot are the main causes of accidents of these devices [37].

Case studies

The main purpose of the works belonging to this group of articles is to present the practical application of unmanned aerial vehicles in real operating conditions and applications. For example, an unmanned aerial vehicle was used to verify the quality of the collected data and the obtained three-dimensional point cloud by stakeholders with various levels of experience for a part of the curtain wall of a large healthcare facility located in the southeastern United States [38]. An interesting application of unmanned aerial vehicles was, for example, examining the possibility of monitoring surface deformations on expressway construction sites in Korea. Thanks to the use of low-altitude photogrammetry, an orthophoto map, a digital model of the terrain surface, and a 3D topographic information model of the construction site were developed [39]. Using images and photogrammetry, it is possible, for example, to detect and determine the number of vehicles working on a construction site [40]. An unusual example was the use of unmanned aerial vehicles to assemble electrical and grounding cables with fiber optics. The quoted paper describes the method of unwinding the rope (wire) used during the construction of the 400 kV high-voltage line Ostrołęka-Olsztyn [41].

Nevertheless, one of the most clearly described practical applications of unmanned aerial vehicles in the literature is their use of them for construction inspections for all types of buildings, including historical ones. For example, the purpose of the building inspection at the historic residence of Tan Swee Hoe was to assess the general technical condition of the building. An innovative solution was to perform an inspection supported by an image obtained using an unmanned aerial vehicle [42]. Similar techniques are also used in civil engineering, in particular when inspecting bridge structures [43], e.g. a three-span glued laminated timber girder with a composite deck near Keystone, South Dakota [44] or the 140-meter-long bridge in Skodsberg -m, made of prestressed concrete, in Viken county in eastern Norway [45]. As you know, bridges are a critical element of infrastructure in the road and rail transport system network. A large proportion of Europe's bridges are now reaching their design life, so regular inspection and maintenance are critical to ensuring their continued safe operation. Traditional inspection procedures and the required resources are time-consuming and expensive. The use of unmanned aerial vehicles makes it possible to reduce the time and cost of inspection of this type of structure while minimizing the risk of working at heights and in hard-to-reach places..

Literature review summary

The largest number of articles were review papers, which accounted for 30% of all analyzed publications. Frequently discussed issues, with the same number of presentations (8 articles), were works presenting the classification of unmanned aerial vehicles, occupational safety issues, and case studies. The smallest number of articles, amounting to only 4 articles (10% of all papers), dealt with issues related to the correct planning of an air operation and safe operation/flight of a drone.

The first part of the analyzed period (2015-2017) presents a small number of articles. In 2018, the number of publications almost doubled compared to the previous year (7 publications). In the following years, the number of articles is constantly growing and in 2021 it already reached the value of 10 publications. There is a clear upward trend and growing interest in the use of unmanned aerial vehicles in construction.

Most of the research results come from the United States. These articles account for 45% of all analyzed papers. Other countries publishing articles in this area are South Korea, Great Britain, Poland, Australia: and Malaysia (countries that have published at least 2 articles), which account for 45% of all articles. The remaining 10% of the articles are individual works from the rest of the world.

The use of unmanned aerial vehicles in construction

Unmanned aerial vehicles have been successfully used in construction for many years. Depending on the intended purpose, drones of different construction and weight are used. These devices can be equipped with high-resolution cameras, thermal imaging cameras, laser scanners, and GNSS receiving devices. Thanks to such equipment, drones are used in:

- inspection of building objects with difficult access, e.g. bridges, chimneys, roofs,
- assessment of the technical condition of structures and their elements. The image transmitted by drone cameras shows cracks and other defects that threaten the safety of the structure.
- monitoring the progress of construction works. Surveillance from the air allows for greater control of the progress of works on the construction site thanks to the possibility of taking photos and videos from the implementation of the investment,
- thermal imaging studies of building structures. Thanks to the use of thermal imaging cameras, it is possible to measure and identify sources of heat loss in the building,
- monitoring and control of the work environment, identification of hazards in the construction of facilities, thanks to which the risk of accidents is reduced, and thus work safety is increased,
- obtaining images for determining the 3D geometry of spatial objects, determining spatial dimensions (distance, area, volume), creating an orthophotomap, as well as inventorying object attributes.

Summary

An unmanned aerial vehicle is not only a popular gadget used more and more often by amateurs and hobbyists for private purposes, but also a modern system applicable in many areas of life, including construction, as well as in scientific research. The use of drones in construction has a wide spectrum of activities, ranging from construction inspections, damage assessment, site measurements, and monitoring the progress of works to security inspections. Unmanned aerial vehicles allow you to take not only photos from the air, but also provide three-dimensional models or orthophotos. The documentation obtained in this way makes it possible to examine the topography of the investment site with great accuracy, as well as to verify the scope of planned earthworks, e.g. to estimate the volume of excavations, the dimensions of foundations, or the depth of embedding the pipeline. This facilitates more accurate planning of the pace of work and the duration of the investment and construction project, facilitates the control of the progress, and, as a result, prevents delays at the construction site.

The use of drones in the construction industry can increase the level of safety at the construction site, but it should be remembered that unmanned aerial vehicles can also create new, previously unseen threats on the construction site. Unstable flight conditions, operator errors, and equipment failures can pose potential hazards to workers working in the vicinity. A wrongly selected flight trajectory of an unmanned aerial vehicle can lead to a collision that can cause injury to people or animals, significant damage to equipment, or even loss of the device.

Education in the safe use of unmanned aerial vehicles, as well as the proper use of drones, have a chance to improve the safety of work with these devices. Especially since the use of drones in construction, as mentioned earlier, brings many benefits. The fact that the use of unmanned aerial vehicles is rapidly expanding its range of applications is also aware of the academic community. To meet the latest trends, the international project "Virtual reality immersive safety training environment for robotized and automated construction sites" is being implemented by the consortium: University of the West of England (UWE) Bristol, (United Kingdom); CTM -Centro Tecnologico del Marmol Piedra y Materiales (Spain);

Bildungszentren des Baugewerbes e.V. (Germany); Wroclaw University of Science and Technology (Poland). The main objective of the project is to develop a highly innovative, safe, and interactive training environment based on virtual reality (VR) technology in the field of modern technologies, including unmanned aerial vehicles, to provide construction workers with the necessary skills and education in interacting with machines and materials.

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