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Drones in the inspection of railway engineering facilities

Abstract: The paper shows the advantages of using drones in the photogrammetric inspection of railway engineering facilities, such as bridges and viaducts. The designs of drones dedicated to such research are presented. Methods of mapping such objects are described. Measurements of selected geometric parameters of an exemplary structure of a railway bridge were measured in a computer program based on its photogrammetric model, which creates a framework for improving the management of the inspection and maintenance process.

Keywords: Uavs, Photogrammetry; Inspection, Railway; Bridges And Viaducts

Introduction

The structures of bridges and viaducts are one of the main engineering structures of the railway infrastructure, subject to detailed inspection [6, 12]. World experience shows that the cause of serious failures of this type of structure is, as a rule, unreliable inspection and untimely completion of repair or maintenance works, which should be intensified as they age, in order to ensure their continued operational viability.

The vision method, the effectiveness of which to a large extent depends on the experience of diagnostics, is of key importance for the control and assessment of the current technical condition of such infrastructure. It is labor-intensive, costly, cumbersome, and especially dangerous when the research is carried out below the level of a bridge or viaduct. Various equipment and techniques of visual observation of the structure are used here, and the conducted inspection works usually require the closure of the railway line running after this facility.

To remedy these limitations and support such diagnostic activities, in recent years drones, also known as the English term UAV - Unmanned Aerial Vehicle, have been increasingly introduced into research. This is to significantly improve all inspection activities at railway engineering structures [6, 25]. The research is to cover places where it is difficult for diagnosticians to reach. However, this idea is at the stage of research experiments, because many issues and obstacles need to be solved and overcome to be universally integrated into practice and fully implemented into railway operation.

The basic challenges relate to the issues of accuracy and stability of flight control and its precise location. This is especially true in areas with limited space, such as under a bridge or near complex structures. There you should expect interference or loss of GPS signal.

This method is based on a huge amount of image data obtained from unmanned inspection equipment, consisting of a UAV equipped with vision and often thermal imaging cameras. By adding laser systems to this, methods of measuring the dynamics of bridges are implemented [7, 8, 19, 20].

The use of automated photo capture enables a better understanding of the situation through the 3D spatial context offered by UAV systems [3, 4, 13, 16, 23]. The created spatial vision maps enable the detection and magnification of damaged elements. The image processing techniques used further allow the assessment of the parameters of these damages in the next stage [1, 11, 26, 27, 30].

The deep learning algorithms used by the author to assess the surface defects of railway rails recognized by UAVs [2] may be helpful here. These algorithms can be used to automatically classify and locate typical damage, characteristics for bridges and viaducts, such as cracks and chipping concrete structures, corrosion and deformation of steel structures, losses of connecting elements (bolts, rivets), etc.

Therefore, more and more boldly, various railway authorities in the world introduce drones to inspect railway infrastructure, including other objects, such as electric traction structures, buildings, and surfaces, including railway rails, which was the subject of the author's considerations in the works [17, 18].

The paper focuses on the comparison of selected issues and practical experiences of inspection of bridges and railway viaducts, using the visual technique offered by drones. The geometric parameters of an exemplary truss bridge were also tested with the use of a computer program. It has been shown that the management, inspection, and maintenance of such engineering facilities are fully integrated with the results of their research by drones.

Drones dedicated to the research of railway engineering facilities

Research on complex engineering structures of railway lines, such as bridges and viaducts, in hard-to-reach places, requires special drone structures, because their direct contact with an obstacle such as a beam, pillar, support, etc., will usually end in its permanent damage [27, 28, 29].

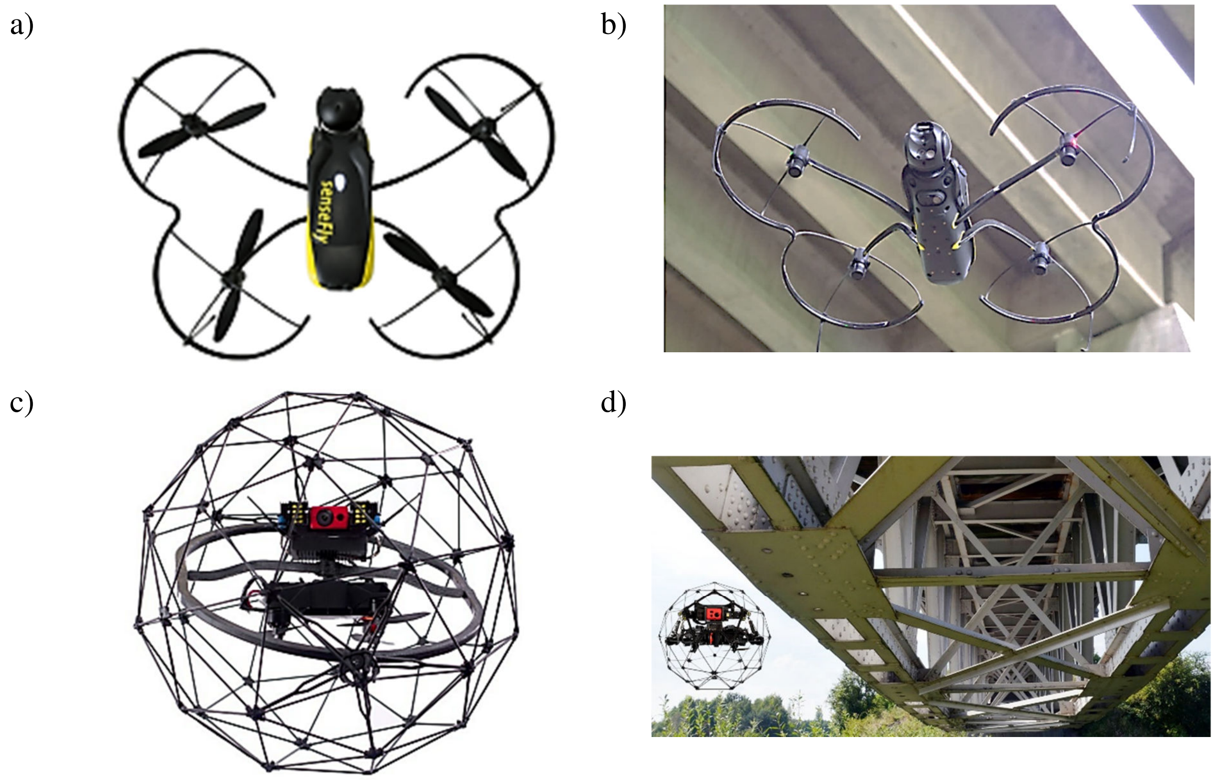
Therefore, the IT technologies of drones intended for such inspections are equipped with important intelligent functions to prevent collisions, such as detection and avoidance, and autonomous flights, without a GPS signal [15].

Despite the continuous improvement of algorithms for these specific research purposes, the equipment is still important and there is room for further improvement of its design, especially concerning various anti-damage elements (propeller guards), adapting it to work in such difficult conditions [21]. Therefore, the quality of UAV workmanship, imaging, and flight software are industry-leading and are of key importance for the proper, safe inspection of bridge or railway viaduct components.

The field of view of the drone is important for the research. No single camera angle is optimal for all aspects of the inspection. Therefore, cameras with a joint that allow you to change its aiming angle are used. This feature is very beneficial for inspection as it allows the underside of the bridge to be inspected when tilting straight up. With the lens geometry set straight down, i.e. a bird's-eye view, flights over the bridge and its mapping are performed, including surrounding areas such as the river bank. To visualize cracks in concrete, corroded bolt and rivet connections, bearing locations, it is often more advantageous to position the joint so that the optical axis of the camera is oriented horizontally [9, 14] .

Investigators need very high-resolution images to assess the condition of many of the small details of the bridge. Hence, another issue is UAV flight speed. Be aware of the effects of blurring images and skipping a fault as the speed increases.

An example may be the drone shown in Fig. **1a** and **b** [29], which can switch camera tasks during the flight, without the need to land. Equipped with integrated sensor modules, it provides the situational awareness required to operate it close to the surface to achieve image resolution below a millimeter. High flexibility allows you to select the flight mode that best suits the engineering object under study. It has an autonomous mapping function conducted without GPS or an interactive live flight.



1. Special drone constructions for vision examinations of bridges and viaducts [10, 21, 29]: a) and c) drones with special covers to prevent damage, b) and d) drones with a) and c) during inspection works under concrete and truss bridges

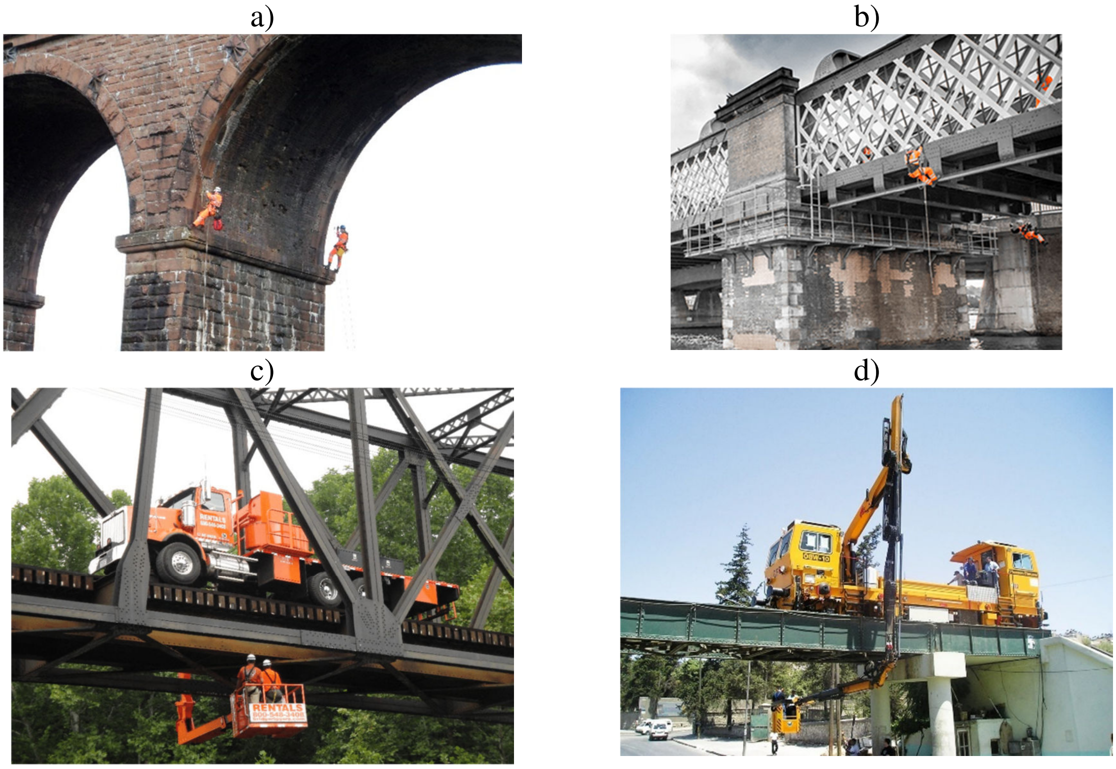
The drone shown in Fig. **1c** and **d** [10] is intended for particularly hard-to-reach places in a railway engineering structure. This professional tool is used by the most sophisticated users. It can fly in a variety of environments and perform difficult tasks. Therefore, it is especially dedicated to the inspection of areas under bridges and viaducts [29]. The drone is surrounded by a carbon fiber cage, which is a joint that rotates around it in three axes, allowing it to bounce off obstacles, rollover ceilings, and walls. During the flight, in contact with the surface, it can collect close-ups with an accuracy of a millimeter with a resolution of 0.2 mm/pixel. The video stream from the camera is recorded on an SD card placed in its head. The Full HD camera offers a resolution of 1920 x 1080 pixels, at 30 frames per second, and works well in low light. Auto default exposure value (EV) of captured images, can also be remotely adjusted from the ground station.

Despite its "collision-resistant" design, it may, like the previous one, come across protruding fragments of damaged elements, such as rods, which, while passing through the cage, will damage the drone, stopping the rotation of its propellers. Therefore, it is always advisable to review the research area in advance to identify any potential risks.

Conventional methods of railway bridges and viaducts visual research

In the current technical conditions, the assessment of the condition of railway building structures, such as bridges or viaducts, is usually carried out using conventional practices, which are mainly based on visual inspection (camcorder, camera) carried out by a human (diagnostician). For this purpose, scaffolding, ropes, or lifting platforms are used, and the research personnel requires special training and skills of climbers to collect data, Fig. **2a**, and **b**.

A better solution is to use an inspection vehicle equipped with a massive robotic arm because the tests are then carried out safely and efficiently, Fig. **2c** and **d**. It is often a heavy goods road vehicle equipped with retractable wheelsets, enabling movement on a railway track. The author had the opportunity to observe the tests with such a vehicle on the PLK line.



2. Classic methods of visual inspection of bridges and viaducts by: a) climbing teams [5] and b) [26], c) and d) vehicles with a excavator bucket [22]

Here, however, there are limitations, due to the requirements for the working space of such a vehicle, which is large and should balance the weight of a heavy robot arm. The span of the truss bridge may also be difficult to find a free space for maneuvering the arm with the excavator basket, Fig. **2c** [22].

Moreover, with such a bridge design, there is a risk of potentially missing important information on defects. This complex structure, which requires detailed inspection, consists of hundreds of load-bearing elements, subject to various load and exposure conditions.

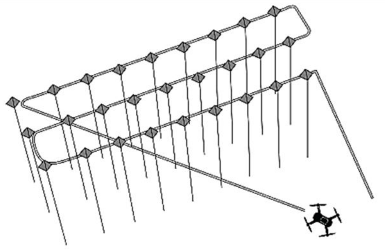
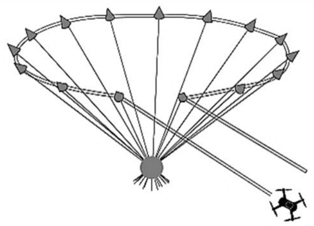
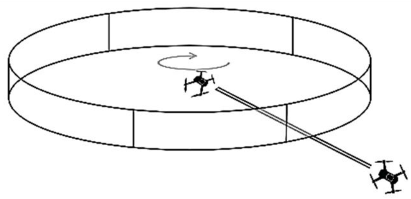
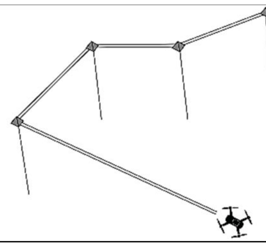
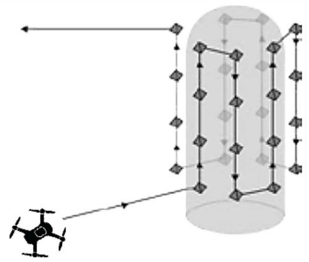
Therefore, drones are an excellent tool to reduce dangerous situations, eliminate the risks of high-altitude inspection, and also prove to be a quick and cost-effective solution, in some situations without the need to close the railroad on a bridge or viaduct.

Drone mapping for railway bridges and viaducts

Mapping is the process of finding the location and distance between points in 2D and 3D space. Based on the photos taken by the UAV, mapping is done from the air, creating orthophotos by the process of photogrammetry. These maps are mainly characterized by an orthogonal projection. They are made in the plane rectangular coordinate system and presented in real RGB colors, grayscales, or near-infrared colors. They are characterized by the lack of distortions of the images of the examined bridge or viaduct, a uniform scale for their entire surface, they reflect the distances and cubature of their elements, with high measurement accuracy. In addition, such low-ceiling photogrammetry generates images with a much greater field resolution, which translates into several times greater detail in the study.

Various methods are used for mapping the main structures of bridges and railway viaducts and their substructures, Table **1**. The choice depends on the inspection area and bridge structure, the planned flight route, the number of photos submitted in sequence, which overlap in the range of 50 - 70%.

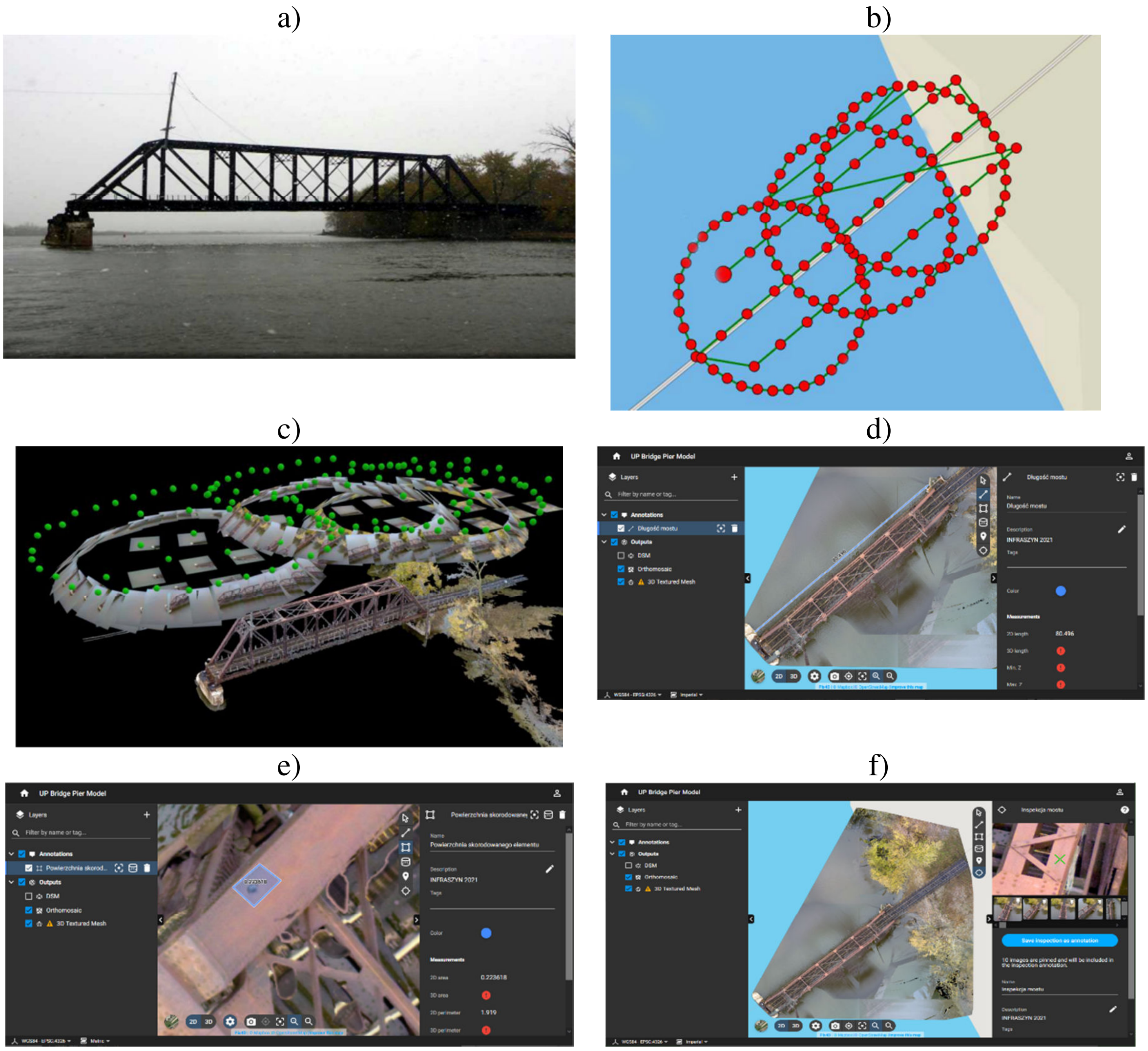
Tab. 1. Drone mapping for bridges and railway viaducts

	**Horizontal -** top-down mapping is used, that is, a "bird's eye view" of the bridge image. Several key parameters should be set here, such as the preferred resolution of the ground, and the application will do the rest by creating a flight line and setting GPS-based waypoints that are automatically adjusted to the terrain.
	**Around the Point -** where, the aircraft flight path is automatically centered around a specific point on the bridge or viaduct. After setting the resolution/distance, the application sets the image capture points. Using this method, it is easy to create a 3D model of the bridge.
	**Panoramic -** uses multiple applications. The architectural vision can be reviewed, giving an amazing effect in reporting and documentation, improving the quality of 3D models.
	**Custom route -** it is ideal for driving the drone in complex environments, which are undoubtedly truss bridge structures. By taking advantage of the superposition of individual flights, they can be combined into a non-standard route.
	**Cylindrical -** used in the control and digital modeling of tall and slender structures of bridges or viaducts, e.g. their supports, pillars. Therefore, set the height of the cylinder above the ground, plus the required resolution of the image and its extent of overlap. The application sets the drone parameters and route points required to take the required photos in overlapping layers and around the tested element of the bridge.

An example of a railway bridge computer research

In the example, a railway bridge was used, or rather its fragment in the form of a pier, situated with a bridgehead on the river bank, being a part of a drawbridge over a large river in the USA, with one track of the railway line, Fig.**3a** [29].

The superstructure of the bridge was made of a truss span, floor beams, and stringers. The substructure consists of reinforced concrete abutments and pillars erected on piles. It is widely believed that such truss bridges are the most complex structure to be inspected. The vision inspection tool that was created was to help in the preparation of reports and the development of historical documentation.



3. Example of a truss railway bridge test with a drone: a) general view of the upper part of the tested part of the bridge, b) interactive map view of the pre-planned flight of the drone (red dots indicate the photo locations), c) camera position view (green dot) at the shooting locations d) view of the orthophoto map of the bridge with its length marked by the author, e) view of the enlarged orthophoto map of the bridge with the surface of a corroded part of the truss marked by the author, f) view of the bridge divided into 10 orthophotos, intended for detailed inspection

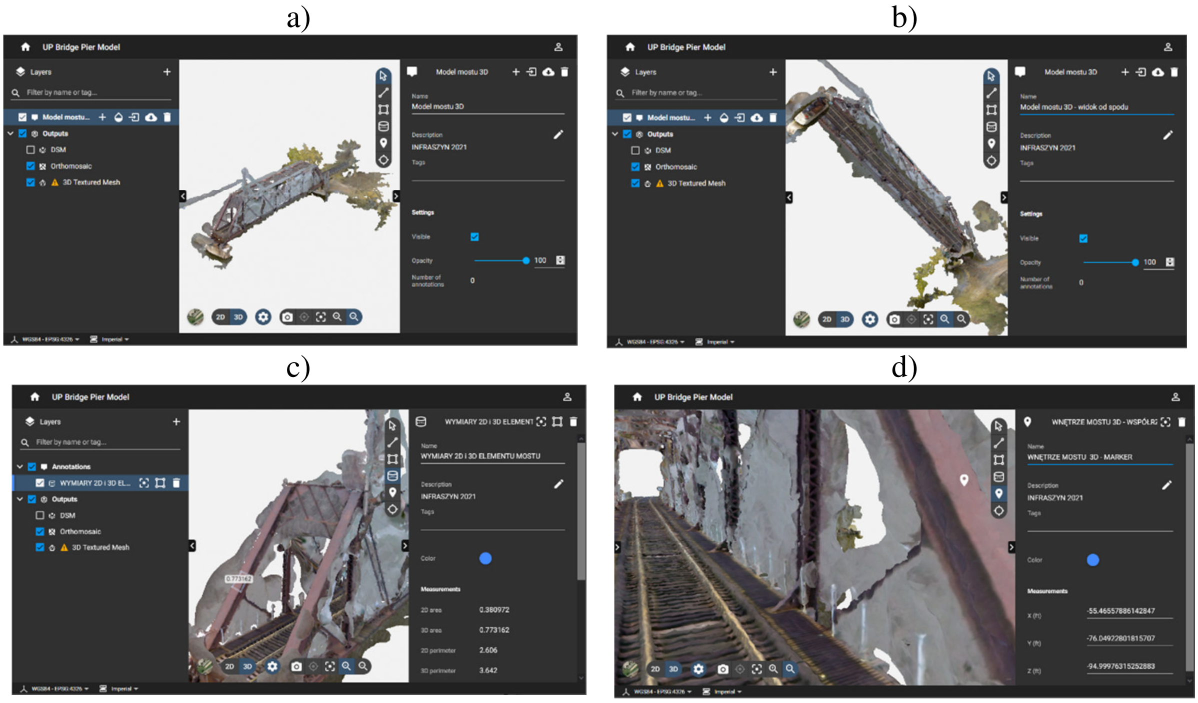
The test method consisted of a previously planned flight path at a height of about 55 m above the ground, Fig. **3b**. The UAV collected over 141 high-resolution still photos from the pier and from above. All images have been geotagged with GPS coordinates, Fig. **3c** [29].

To create orthophoto maps images, the tools offered by the Pix4D software [24] were used. The result is an image file that is used to measure the real distances (the author showed it in Fig.**3d**) and the area of the bridge areas, Fig. **3e**, and the diagnostician may additionally enlarge the defects to perform a more precise control of their descriptors.

The target process was also to create easily readable high-resolution images of many orthophotos, showing areas that a diagnostician could use for a detailed inspection and assessment of the bridge's condition, or remembered as historical documentation, Fig. **3f**.

The software used can also process all photogrammetric data into the 3D model space, creating a point cloud for digital viewing, Fig. 4. The author presented some of the capabilities of this tool, which, among other things, allows the model to be rotated in all axes.

The top and bottom views of the bridge model are shown in Figs. **4a** and **b**. By navigating this model and enlarging the interesting areas of the bridge, you can measure flat and spatial geometric parameters, such as the surface area, its perimeter, or the volume and area of the marked solid, Fig. **4c**. By marking interesting places with markers, the program gives their spatial coordinates, Fig.**4d**. For each view, you can annotate the file for archiving and comparison with subsequent measurements.



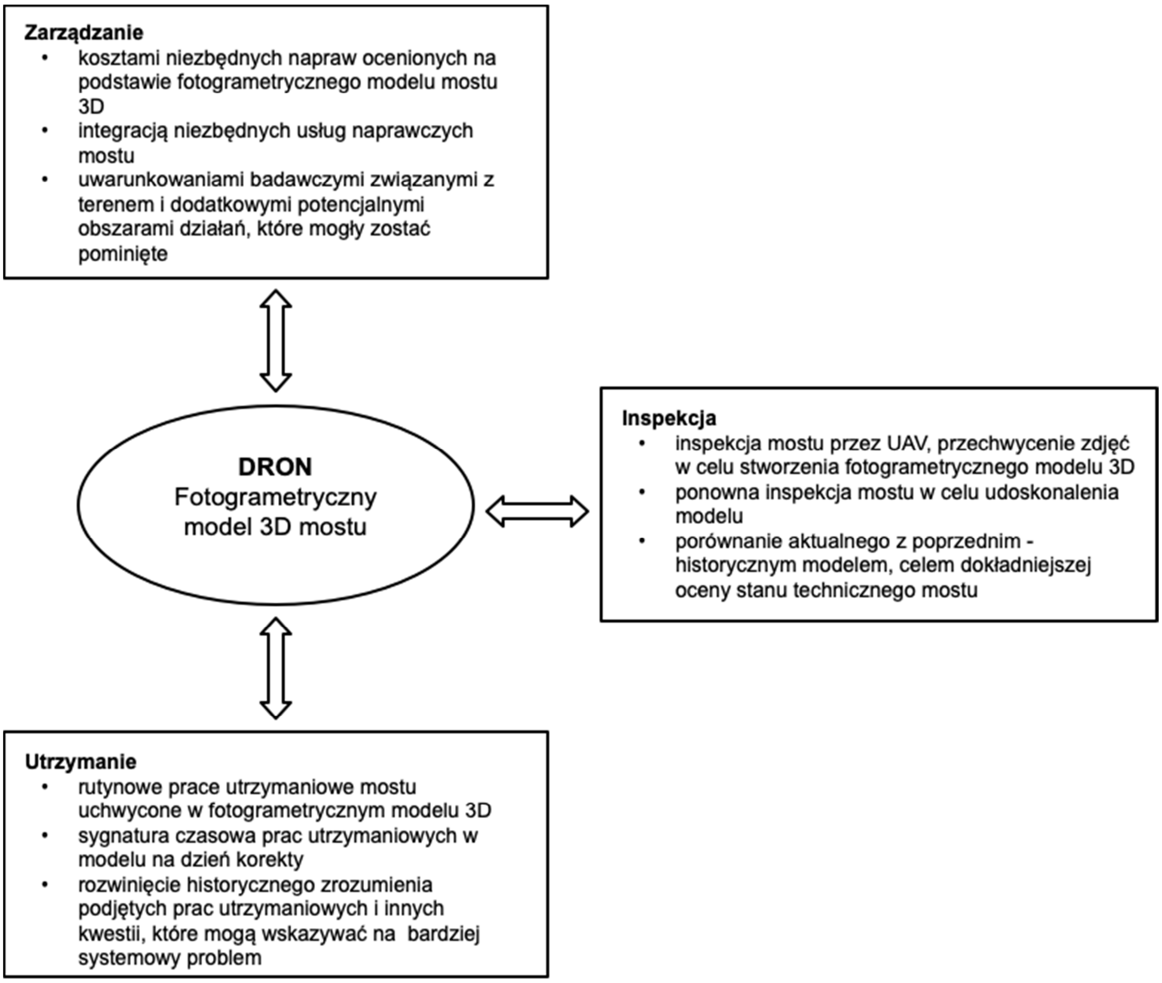
4. View of the computer program windows in the space of the 3D photogrammetric model: a) top view of the bridge, b) view of the bottom of the bridge, c) measurement of 2D and 3D parameters of the enlarged bridge element, d) view of the interior of the bridge with marked marker coordinates on the enlarged surface element of the bridge element

Benefits of using the photogrammetric model

The inspection process, based on the large amount of high-quality data collected, provides the framework for future bridge management. This is an unquestionable improvement in comparison to the tests with a handheld camera, where the preparation of inspection results often results in a time-consuming report of several hundred pages, the cost of which is estimated at 30% of the entire typical project. In addition, there is a risk that significant information about a defect may be overlooked. Therefore, an opportunity for improvement is created by the ongoing inspection carried out by the UAV in an automated manner. As a result, a photogrammetric image of the 3D model is created, which brings significant value at all main stages of maintenance and management of a railway engineering facility, Fig. 5.

Such an image can be viewed on the computer monitor along with recorded information on the condition of the bridge and the scope of its maintenance, estimating the costs of necessary repairs, and also reducing them by integrating various services. You can also manage research, terrain, and additional areas of activity that may have been missed. It is also possible to improve the model by re-inspecting the structure if there are problems overlooked in the investment, which can be implemented at a later date.

The photogrammetric model of the bridge also gives indications for its routine maintenance works, marked with timestamps, along with information about its historical condition, which may suggest a deeper system problem.



5. A framework for the management, inspection, and maintenance of a railway bridge based on its photogrammetric model

Conclusions

The area of visual inspection of railway engineering structures is significant, and bridges and viaducts are even a classic example of this. Their complicated shapes require appropriate equipment and skills because only then is it possible for diagnosticians to have direct access to places that are difficult to reach.

That is why the author tried to show the advantages of inspecting railway engineering facilities with the use of drones. The paper presents technological solutions of drones dedicated to such inspections and methods of creating photogrammetric maps, based on the collected vision tests..

Using a computer program, on the example of a truss bridge, the research of a photogrammetric model and its advantages in precise damage inspection were shown. The conducted research shows that the use of such modeling enables greater efficiency in collecting and collecting data while reducing the costs associated with ongoing research reporting. It also allows the diagnostician to better understand problems, improving decisions about necessary repairs. The model can be used during subsequent bridge inspections to create historical data of its structure and view it throughout its life cycle, providing a more accurate understanding of the current state and managing the maintenance process.

Source materials

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