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The use of photogrammetry in the survey management of utility network elements: an innovative approach to monitoring and control

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Summary

This paper discusses the potential for the use of photogrammetry in the survey management of utility network elements. Data acquired by direct measurement (tachymetric survey) was compared with data from an unmanned aerial vehicle (UAV) raid. The benefits of using photogrammetry in management systems were presented, including improved accuracy of utility monitoring, efficiency of quality control, and the possibility to better plan the location of networks and resolve claims of property owners where utility elements are located (e.g. power lines). The research shows that photogrammetry, and in particular the use of unmanned aerial vehicles, significantly increases the precision and efficiency of measurements of utility network elements compared to traditional methods. The Geomax ZOOM 90 robotic total station was used to take direct measurements. It is an electronic total station equipped with servomotors, a rangefinder and proprietary software that allows the coordinates of measured points to be calculated in real time in the field. The survey was carried out in plane coordinate system: PL-2000/7 and elevation coordinate system: PL-KRON86-NH based on a photogrammetric matrix of known coordinates. The photogrammetric measurements, on the other hand, included images taken with an Autel EVO II Pro drone, which supports a GNSS RTK module to obtain differential data in real time. This makes it possible to obtain accurate coordinates of the UAV location. The object of the study was power lines located in the town of Bielcza, Borzecin municipality, Brześć Brzeskie county, Małopolskie voivodeship. Lines located on the south side of the A4 motorway by the service road and suspended between seven poles over a length of approximately 750 m were measured and inspected.

Keywords

power lines • point cloud • unmanned aerial vehicles • tachymetric surveying • survey management

1. Introduction

High-voltage lines are an indispensable part of the landscape around us, providing a stable and secure energy supply [https://www.prawo.pl/prawo/problemy-z-liniami-wysokiego-napiecia,143539.html].

Survey management of power lines is a complex process that involves several key aspects of planning, construction and operation of energy infrastructure. Proper inspections of the infrastructure and changing conditions are crucial for the safety and efficiency of the power system. Inspections should include, but not be limited to: checking the condition of conductor insulation, assessing the condition of support structures (poles, towers), detecting faults and damage. The inspections search for areas at risk of possible failure and check that the current technical condition of the pole structure and the phase and lightning protection conductors do not pose a threat to the health and life of people and animals within the range of the line in question [https://www.eltelnetworks.pl/blog/2022/eksploatacja-energetycznych-linii-napowietrznych-problemy-i-rozwiazania/]. Along each power line, a technological strip for maintenance and a protection zone are established. Currently, the legislation does not regulate the width of these strips and zones, they are determined on the basis of the location decision. The width of a given strip, depending on the level of electromagnetic impact, can range from a few metres to even tens of metres. Surveyors measure the lines, the course of which is plotted on the base map, which serves as the reference map for the planned project. It is worth knowing, however, that these lines are plotted axially and the bases of the poles are often not plotted on the base maps at all [https://resources.geodetic.co/linie-energetyczne-w-pozwoleniu-na-budowe-jak-przysunac-inwestycje-do-linii-energetycznej/].

In response to increasing demands for aesthetics and safety, another issue relating to the management of power line metering is emerging – moving the overhead lines to underground (known as cabling). This operation may be required by local development plans or be the result of a claim by the owner of the property through which the power line runs. Managing the survey of power lines also involves compliance with legislation. Proper understanding of and following the energy and building codes is therefore key to avoiding conflicts and ensuring compliance with regulations. The majority of ground inventory work is carried out by surveying methods using a total station. The total station is a precise surveying device that can be used in the surveying of power lines, as it provides the accuracy necessary for the design, construction and maintenance of energy infrastructure. It allows the height of existing power poles to be measured, which is crucial when upgrading or inspecting the technical condition of lines. The height of individual components can be accurately determined, which is essential to guarantee the safe distance of cables from the ground and other obstacles. As part of the inventory of existing energy infrastructure, the total station is used to produce accurate maps of power lines. This makes it possible to create the documentation that is needed to plan repairs, upgrades or extensions to the network.

Inspections of power line structures of places that are difficult to access pose a challenge. One solution could be complementary measurements made using photogrammetry, which is an effective method for monitoring the condition of power lines. Photogrammetric methods allow the simultaneous registration of all objects in the images, which is particularly evident in the case of rapidly changing power line deformations. The capability to repeatedly measure line deformations at different times provides a number of functions in the management of power line measurements, influences the operation of equipment, automation of surveys and cost optimisation. One of the devices used to monitor and control power lines is drones. Drones, with their mobility, precision and ability to integrate with a variety of sensors, are becoming an increasingly popular tool in the energy sector. The applications of UAVs in this field make it possible to obtain an assessment, the condition of power lines and the degree of regrowth of plants in the vicinity of overhead lines, which can damage existing lines during their vegetation [Cieśla 2022]. Their use can significantly increase the efficiency and accuracy of management processes, offering many benefits: regular inspections of power lines can be carried out with drones. Equipped with advanced cameras and algorithms, they can automatically identify line damage such as missing insulators, corrosion or the presence of foreign objects in the protection zone. Drones can inspect and monitor areas that are difficult to access or dangerous such as tall structures or vast areas [Czapaj-Atłas 2016]. By analysing historical data and current inspections, drone systems can predict potential failures and plan preventive actions. Digital images acquired during raids allow the creation of a dense point cloud, from which a spatial model of the photographed power lines is then created [Butowtt 2010]. In recent years, technological developments have meant that a realistic 3D model, is generated automatically by computer programmes and algorithms from digital photographs. Obtaining the entire surface of the model, is only possible if the images are continuously recorded with adequate coverage [Rhee 2016, Zawieska 2013]. The low permeability of vegetation should not be an obstacle to an accurate inventory of overhead power lines, provided there are no plant obstacles in the immediate vicinity of the conductors that would impede their aerial observation. Indeed, the use of unmanned aerial vehicles allows detailed analysis of visible line components such as poles, insulators and the wires themselves [Preuss 2014].

2. Aim, scope and methodology of the study

The aim of the study was to answer the question of whether a photogrammetric survey using a UAV could provide the complete inventory necessary for the management and operation of power lines. This was achieved by comparing the data obtained through an unmanned aerial vehicle (UAV) raid with measurements obtained from a direct tachymetric survey. The accuracy of the results was also analysed in the context of permissible deviations.

The object of the study was power lines located in the town of Bielcza, Borzęcin municipality, Brzesko county, Małopolskie voivodeship. The lines located on the southern side of the A4 motorway by the service road (Fig. 1) and suspended between seven poles over a length of approximately 750 m were measured and inspected.

Source: Authors' own study based on https://mapy.geoportal.gov.pl/

Fig. 1. Location of the surveyed object on the background of the orthophotomap and the GESUT database

These are metal poles ranging from 32 m to 37 m in height and 1.6 m to 2.0 m in diameter at the base (Fig. 2).

Source: Authors' own study

Fig. 2. Image of the measured pole

The average distance of neighbouring poles is about 200 m. Fourteen power lines are suspended from each pole.

A Geomax ZOOM 90 robotic total station was utilised to carry out the direct survey. The survey was performed in the plane coordinate system: PL-2000/7 and height coordinate system: PL-KRON86-NH based on a photogrammetric matrix with known coordinates.

The photogrammetric survey, on the other hand, consisted of images taken with the Autel EVO II Pro drone. This drone is characterised by the following technical parameters: 6K resolution camera with 1′ matrix CMOS sensor from Sony IMX383, 35 mm lens, 28.6 mm equivalent f/2.8, f/11 lens range, electronic shutter speed of 8 ~ 1/8000s, ISO scale range for images 100–12800 (in manual mode). The survey of the subject was preceded by a field interview, during which the feasibility of the raid, the selection of the drone's take-off and landing site and the determination of its ceiling were defined.

3. Data preparation and methodology

3.1. Total station survey

The total station survey measured the overhang of the power line, the location of the poles, the height of the poles, the course of the power line and the hooks on the poles. It was checked by measuring the diameter of the pole using a tape measure and the distance between adjacent poles using a Leica Disto D810 BT laser rangefinder equipped with a camera to facilitate the measurement of long targets. Analysis of the observation report of the polar total station measurement allows us to conclude that the deviations during the execution of the pole alignment do not exceed the maximum permissible deviations (Table 1).

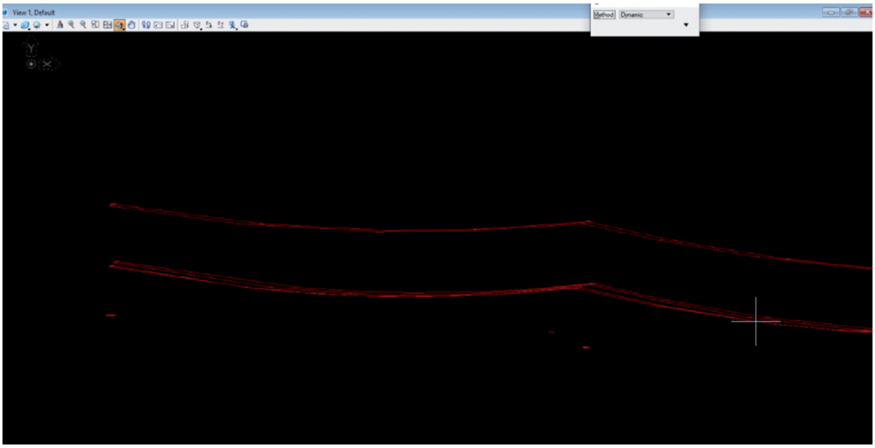
Table 1. Polar measurement deviations

Measuring points	Number of observations per point	Δx	Δy	Δz
ST_0001	7	–0.002 m	+0.000 m	–0.005 m
	6	–0.011 m	–0.026 m	–0.005 m
	8	+0.018 m	–0.013 m	+0.010 m
ST_0002	7	+0.011 m	+0.012 m	+0.004 m
	6	+0.004 m	–0.006 m	–0.002 m
	5	+0.001 m	+0.024 m	0.002 m
ST_0003	4	–0.001 m	0.000 m	+0.012 m
	5	+0.001 m	0.000 m	–0.017 m
ST_0004	2	–0.001 m	0.000 m	–0.004 m
	3	+0.001 m	+0.000 m	0.006 m

Table 2. Height comparison of pole measurements

No. of pole	Base ordinate from polar survey	Ordinate of the top from polar survey	Pole height based on total station survey	Base ordinate from photogrammetric survey	Ordinate of the top from photogrammetric survey	Height of pole from photogrammetric survey	Difference in pole base height	Difference in pole top height
Pole 71	207.88	239.83	31.95	207.86	239.81	31.95	0.02	0.02
Pole 72	206.91	243.58	36.67	206.92	243.59	36.67	−0.01	−0.01
Pole 73	206.05	238.29	32.24	206.02	238.25	32.23	0.03	0.04
Pole 74	206.00	238.23	32.23	205.97	238.22	32.25	0.03	0.01
Pole 75	205.39	242.21	36.82	205.37	242.18	36.81	0.02	0.03
Pole 76	204.96	237.35	32.39	204.95	237.34	32.39	0.01	0.01

The results of the observations at the four measuring points were labelled ST_0001, ST_0002, ST_0003 and ST_0004. The values of three deviations are given for each point: (Δx, Δy, Δz) for several observations. Next, the measurement results were visualised. For this purpose, the Bentley POWERSurvey V8i software (SELECT series 4) with the MK Power geodetic overlay was used (Fig. 3).



Source: Authors' own study

Fig. 3. Extract from the developed polar measurement of overhangs

The contours of the poles, the location of the suspensions and the overhang of the measured power lines were mapped by the same software. When measuring the poles using the polar method, the height of the poles was measured in order to compare the points from the polar method to the points from the point cloud obtained after developing the raid. The results of the comparison are shown in Table 2. The highest height deviation was 4 cm for pole height No. 73, while the lowest was 1 cm for the base of poles No. 72 and 76 and 1 cm for the top of poles No. 72, 74, 76.

3.2. Measurement using an unmanned aerial vehicle (UAV)

During the planning of the mission over the surveyed power lines, flight parameters were determined (Table 3). Based on these, a field pixel size of 1.82 cm/px was obtained.

Before the mission, the NadowskiNET account was logged in to download real-time corrections and the UAV position corrections were initiated. In addition, fourteen photopoints were stabilised prior to the raid, which were measured using a Geomax Zenith 35 PRO GPS receiver in GNSS technology (in kinetic mode) previously checked on two points of the state geodetic control network. The accuracy of the vertical and horizontal RMS measurements was ± 0.02 m. During the UAV raid, 283 photographs were taken. An orthophotomap was generated from the photographs – it gives an over-view of the situation, but does not contribute much to the measurement of the power line, with the exception of the position of the pole base, the displacement of which meets the conditions of the Regulation of the Minister of Development of 18 August 2020 on technical standards for carrying out geodetic situational and altimetric measurements and the development and transfer of the results of these measurements to the state geodetic and cartographic resource (Table 4).

Table 3. Air raid parameters

Flight parametres	Value
Flight height	80 m
Flight speed	5 m/s
Gimbal angle	90^0
Longitudinal coverage	80%
Transverse coverage	70%

Table 4. Situational displacement of poles

No. of pole	Displacement in the X axis	Displacement in the Y axis
Pole 71	0.01	0.01
Pole 72	0.03	0.02
Pole 73	0.03	0.02
Pole 74	0.04	0.02
Pole 75	0.01	0.01
Pole 76	0.02	0.03

Measuring with an UAV saves work in the field, but for measuring the overhangs, it will be safer and more efficient to take a traditional survey with a total station. A drone can photograph a much larger area in a faster time than a traditional GPS/ total station survey, but you will not always achieve the desired result.

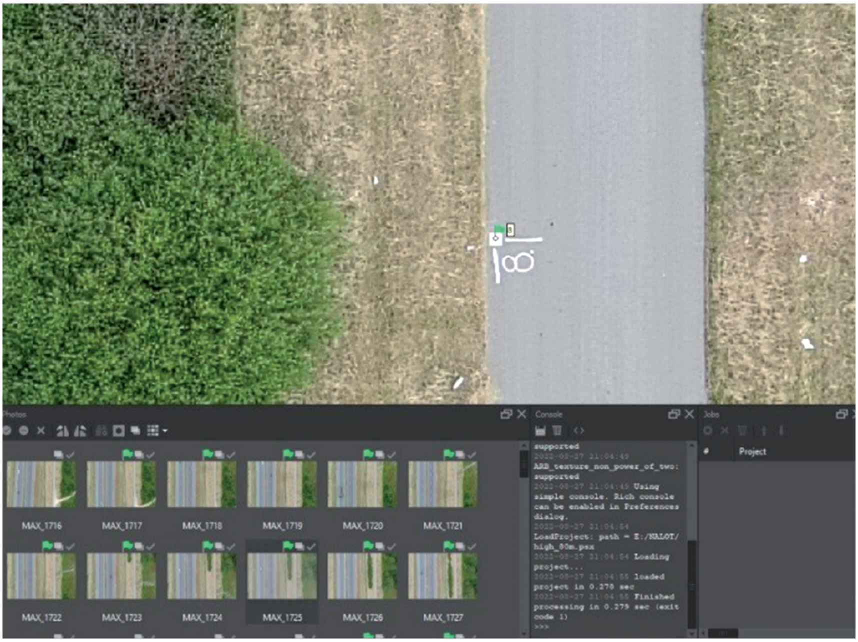
4. Processing of extracted data

The images captured from the UAV were processed using the Agisoft Metashape Professional software. The first step in processing the data from the photogrammetric raid was to import the images, along with the observation parameters of the RTK receiver placed on the UAV, into Agisoft Metashape Professional. The imported photos had ellipsoidal coordinates. However, the total station measurements were taken in the PL-2000/7 plane coordinate system and the PL-KRON86-NH height coordinates. It was therefore necessary to perform a conversion, for which a module from the Agisoft software was used (Table 5).

Table 5. Table of coordinates of raid images before and after coordinate system conversion

Cameras	Longitude	Latitude	Altitude (m)	Cameras	Easting (m)	Northing (m)	Altitude (m)
MAX_1716	20.721683	50.004963	322.778500	MAX_1716	7480049.457032	5541009.505809	285.015761
MAX_1717	20.721846	50.004987	322.831510	MAX_1717	7480061.151241	5541012.131628	285.069261
MAX_1718	20.722025	50.005015	322.826380	MAX_1718	7480073.994014	5541015.198092	285.064661
MAX_1719	20.722199	50.005041	322.811000	MAX_1719	7480086.477533	5541018.043477	285.049761
MAX_1720	20.722386	50.005070	322.802210	MAX_1720	7480099.894150	5541021.219093	285.041561
MAX_1721	20.722558	50.005096	322.792080	MAX_1721	7480112.234276	5541024.065070	285.031861
MAX_1722	20.722744	50.005125	322.804040	MAX_1722	7480125.579180	5541027.241016	285.044461
MAX_1723	20.722923	50.005152	322.806820	MAX_1723	7480138.421467	5541030.196414	285.047761
MAX_1724	20.723097	50.005178	322.832270	MAX_1724	7480150.904916	5541033.041949	285.073661
MAX_1725	20.723281	50.005206	322.805230	MAX_1725	7480164.105998	5541036.107301	285.047161

The adjacent photos were then combined into blocks of photos using the 'Align Photos' tool. Once this was done, a sparse point cloud consisting of the so-called 'tie points' was created. After merging the photos, the coordinates of the photopoints were then imported and fitted into the photo (Fig. 4).



Source: Authors' own study

Fig. 4. Fitted photopoint onto the photo from the UAV

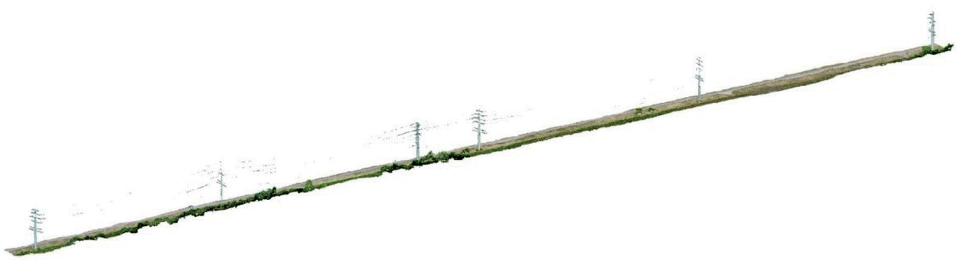
The accuracy of fitting the control points into the photographs was: X = 1.6 cm, Y = 2.8 cm, Z = 0.4 cm. Average error value expressed in pixels Image (pix) = 0.63 (Table 6).

Table 6. Fitting the photopoints

Label	X error [cm]	Y error [cm]	Z error [cm]	Total [cm]	Image [pix]
1	2.05	–1.82	–0.01	2.74	0.62
2	0.64	–2.14	–0.12	2.24	0.39
3	1.54	–3.41	0.33	3.76	0.63
4	1.11	–3.36	–0.31	3.55	0.51
5	1.72	–3.41	0.19	3.83	0.91
6	1.87	–1.04	–0.30	2.16	0.47
7	1.74	–1.83	–0.05	2.52	0.56
8	1.04	–1.43	–0.06	1.77	0.47
9	–1.53	0.95	0.02	1.80	0.61
10	–2.17	3.89	–0.10	4.46	0.72
11	–2.64	3.25	–0.52	4.22	0.66
12	0.69	4.59	0.41	4.66	0.81
13	–1.29	3.05	1.20	3.52	0.75
14	–0.36	1.28	–0.42	1.39	0.48
Total	**1.58**	**2.77**	**0.41**	**3.221**	**0.63**

Source: Authors' own study, Metashape report

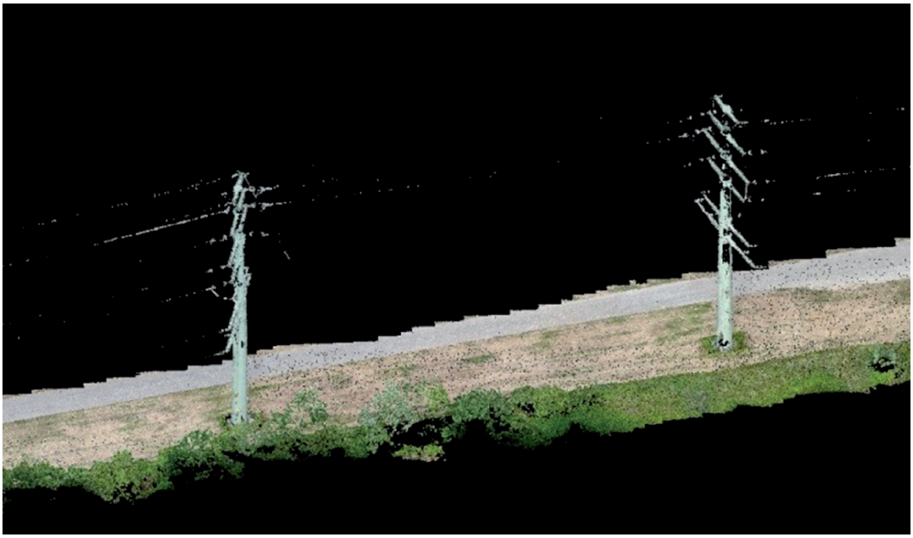
Subsequently, a dense point cloud was generated using the Ultra High quality parameter and mild depth filtering (Fig. 5).



Source: Authors' own study

Fig. 5. Dense point cloud – isometric view

This method of filtering is used when fine details are present in the study area, which overhead power lines undoubtedly are (Fig. 6).



Source: Authors' own study

Fig. 6. Dense point cloud

Once the dense point cloud was generated, a numerical terrain model was created and an orthophoto was created (Fig. 7).

Source: Authors' own study

Fig. 7. Extract of orthophotomap

The point cloud and orthophotos were imported into Bentley POWERSurvey software to compare the total station measurements with the data obtained from the CAD raid. The location of the power line poles, the quality of the line overhang measurement and the height of the poles were analysed. By precisely comparing these measurement methods, it was possible to assess the consistency, accuracy and quality of the results.

5. Summary

Surveying methods using UAVs are becoming increasingly popular. More and more surveyors are using UAVs in their work looking to save time on field measurements. However, it is important to be aware that a drone survey will not always be a better solution than a traditional polar survey. During the raid, only vertical photographs were taken of the site. The software of the Autel drone does not allow flying along a present path and taking angled photos autonomously, this has to be done manually. Therefore, in addition, it was attempted to evaluate the performed raid resulting in vertical photos and to answer the question of whether it is possible to measure overhangs of power lines using a drone. The generated point cloud shows missing points where the power line should be visible, and some of the points forming the pole are also missing (Fig. 8).

Source: Authors' own study

Fig. 8. Point cloud with scanned measurement from the polar method

Source: Authors' own study

Fig. 9. Extract from orthophotos and polar measurements

One of the better mapped elements of the power line during the raid are the pole bases, which allow us to determine the situational position of the pole and the course of the line. Unfortunately, this is the only element of the survey that we can be sure will be developed in its entirety without deficiencies and the need to complete it with a subsequent survey (Fig. 9).

A numerical terrain model was also well mapped under the poles, allowing the space between the existing terrain and the existing overhead power line to be measured. Surveying with a UAV saves field work, but for measuring overhangs, a safer and more efficient solution would be a traditional survey with a total station. A drone can photograph a much larger area in a quicker time than a traditional GPS/ total station survey, but it will not always give the desired result.

Analysing the available literature on photogrammetry and remote sensing, it can be noticed that in many articles the authors suggest taking oblique photos in order to improve the modelling of spatial elements. It is likely that taking oblique images would improve the quality of the study and allow the determination of the arrow of the overhang of power lines [Dominik 2014, Zhuo et al. 2017, Drzewicki 2018] The development of technology in recent years has meant that measurement using UAV digital imagery meets the requirements of the Regulation. According to Wicher, Banaszak, Żarnowski and Zych, it can be used as a complement to the currently existing measurement methods [https://geoforum.pl/strona/46816,46857,46954/teledetekcja-krotki-wykladfotogrametriarobimy-mape (20.08.2022)].

Following a publication by Janicka, Błaszczak-Bąk and Sobieraj and their article from the journal Civil, Environmental and Architectural Engineering, another solution may be to use airborne laser scanning (ALS). According to their study, ALS measurement meets the accuracy criteria and can be used for the inventory of overhead power lines. Usually, the ALS measurement is carried out for the entire commissioned study and the classical measurement is performed in a control manner on selected poles and spans [Wicher et al. 2016]. Measurement using UAV is much faster, but it should be taken under appropriate conditions with the use of appropriate equipment that will ensure adequate quality of images for photogrammetric studies. An unquestionable difficulty in performing a measurement with an UAV is the need for advanced computer equipment to meet the requirements of photogrammetric development software [Janicka et al. 2015].

6. Conclusions

The introduction of drones for monitoring and inspection in construction projects represents a significant step towards more efficient management of network element measurements. The technology improves safety, reduces costs and allows for more precise tracking of the progress of inventory work. Accuracy and detail should be highlighted among its advantages - the images and videos taken by the drones have a high resolution and can show details that allow an accurate analysis of the progress of the works.

Drones can perform inspections at any frequency, even on a daily basis, which is difficult to achieve with traditional methods. Using them for regular monitoring helps to quickly detect potential problems, such as delays, inconsistencies with the design or problems with the quality of manufacturing.

The data collected by the drones can be easily stored, making it easier to keep records of the progress of the work and analyse it later. This enables tracking how the location and condition of a power line changes over time. In addition, drones can reach locations that are difficult to access by humans, such as tall structures, vast areas or areas with limited space. This enables a more complete monitoring of energy infrastructure components without endangering people. Meanwhile, by quickly providing visual data, energy infrastructure managers can make decisions in real time, significantly speeding up the response to potential problems.

In conclusion, drones as a tool for regular power line inspections represent a revolutionary solution that improves the accuracy of its monitoring, increases the efficiency of its management and enhances safety during its operation.

However, despite the numerous benefits, it is also important to take into account the challenges of integrating this technology, such as the legal regulations for UAV flights and the need for proper operator training.

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