ГЕОДЕЗІЯ

GEODESY

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THE USE OF MODERN TECHNOLOGY IN THE CLASSICAL SURVEYING

Purpose. The article presents examples of usage of modern technologies to improve classical geodetic measurements. Modern technologies such as 3d scanners or unmanned aircraft vehicles (UAV) can be applied to increase the accuracy of complex monitoring of tall and unreachable objects. There was shown an example of measurement of the wind speed impact on the Gliwice Radio Tower deflection. The Tower is one of the oldest and highest wooden (non-impregnated) towers in Europe and because of the historical past it's very important object in the worldwide culture. The Tower is located in the open and undeveloped terrain. This means that it is exposed to strong winds. Unfortunately the life of the Tower is estimated at about 15–20 years and because of the fact that it's very hard to mount on any additional sensor there was an idea to use the UAV to measure the wind speed. So far there was proved by classical tachometric observations and wind speed data adopted from publicly available information that the tower deflects in order to the wind speed and also that the average deflection from several levels of the Tower clearly correlate with the direction of the wind. Another example of utilization of modern technologies relate to the unreachable or hard to reach objects. There was shown an example of usage of UAV with mounted non metric camera to improve monitoring water basins surface in regions where coal extraction took place because of its significant impact on the landscape or agriculture. This paper demonstrates the idea of continuous monitoring of impacts of mining exploitation on location and reach of water bodies shoreline or shape and condition of river channels situated within the mining areas by appropriately equipped quadrotor. The last example presents the usage of 3d scanner and GNSS method to generate spatial map of underground labyrinths of the Fortress Klodzko. The fortress is a historical monument available to tourists, however underground there is a several-kilometer network of walkways. It's important to inventory them in order to the safety, historical and tourism aspect. Some parts of these walkways are very hard to reach or sometimes even unreachable. By the usage of 3d scanner it was easy and fast to measure ale the nooks and crannies with millimetre accuracy and by binding the underground geodetic traverse with the reference points on the surface by GNSS technology it was easy to orientate the network of measured walkways. The aim of the article is to present possibilities of utilization of modern technologies in typical geodetic measurements on the basis of few examples. They were respectively selected to show that correctly applied technology can significantly improve the accuracy, reduce the time or costs of measurements or even both of them defined as efficiency.

Key words: Surveying, Unmanned Aircraft Vehicle, 3D Scanner.

Introduction

On the market can be found many new technologies that seems to be very attractive in order to possibilities for use in surveying. Usually after short analyse can be found that classical methods and existing solutions of surveying are more accurate or even cheaper and faster to apply. Basing on own experience can be stated that more often so called modern technology are rarely used in classical surveying mostly because of the unclear data about internal accuracy of the technology and its impact at overall accuracy of observations. Also instruments like 3D scanners are relatively expensive and it's really hard to find a reasonable use for this technology in surveying.

In the article there were presented three different cases of application of modern technologies in typical surveying tasks. Examples were respectively selected to justify usage of expensive instruments. Examples demonstrates cases of application of Unmanned Aircraft Vehicles (UAV) and 3D scanner. Instruments were used combined with classical surveying tools as well as individual solutions. However there weren't done any accuracy estimations of presented technologies, also in the article there'll be not presented specific digital results of multiple observations.

Gliwice radio tower deflection

The Gliwice Radio Tower located in the southern part of Poland built in 1938 of not impregnated larch wood, which is about 111 meters high, is one of the highest objects of such a type in the World. [www.muzeum.gliwice.pl (in Polish)] To the highest platform, with dimensions 213 x 213 centimeters and installed at an altitude of about 109,5 meters, leads the ladder consisting of 365 rungs. By 2007, the tower in the shape of paraboloid, was the world's tallest structure built entirely of wood, which has been certified entry in The Guinness World Records. The structure is now a part of the Museum of Radio and Media Arts complex. Since 2012, the Museum in Gliwice is trying to place this object in the list of United Nations Educational, Scientific and Cultural Organization (UNESCO).

The Gliwice Radio Tower is located in the open and undeveloped terrain. This means that it is exposed to strong winds. Since this is a wooden structure that resistance element is considerably smaller than similar metal structures. Therefore authors analyzed results of measurements of the tower's deflection, whose purpose was to determine how much the structure is susceptible to the wind.

To this aim there were done a conventional measurements with usage of the precise Total Station Topcon GTS − 601. The accuracy of the electronic angle measurement was at the level of 1 second.

Deflection at individual levels, from the specified position, was determined as the average value value of the measured horizontal angle to the left and right edges of the Tower (Fig. 1) in relation to the reference level (base of the tower). The height of different levels was calculated on the basis of known distance to a point on the tower, determined by the method of linear indentation and the value of the vertical angle (trigonometric leveling) [J. Gocał, 2010].

Due to the inability to mount anemometers at various levels of the Tower and due to the economic reasons for the measurements of the air flow there was used UAV. The concept of the measurement from single tachometric station including wind measurements was presented in the Fig. 2.

In order to address problem of wind speed vector estimation, there was developed solution based on slung load attached with a long string to the quadrotor frame. Slung load consists of a sphere body with inertial measurement unit (IMU) inside.

Inertial measurement unit is basic instrumentation found in unmanned aerial vehicles, because of its small size and cost reduction due to progress in electronics manufacturing, applications using IMU are becoming more and more popular [Spinka, Holub and Hanzalek, 2011]. Sample application besides avionics include movement tracking, surgical tools stabilization, human movement classification etc. [Fourati, Manamanni, Afilal and Handrich, 2011;Wu, Zeng, Shao and Feng, 2012].

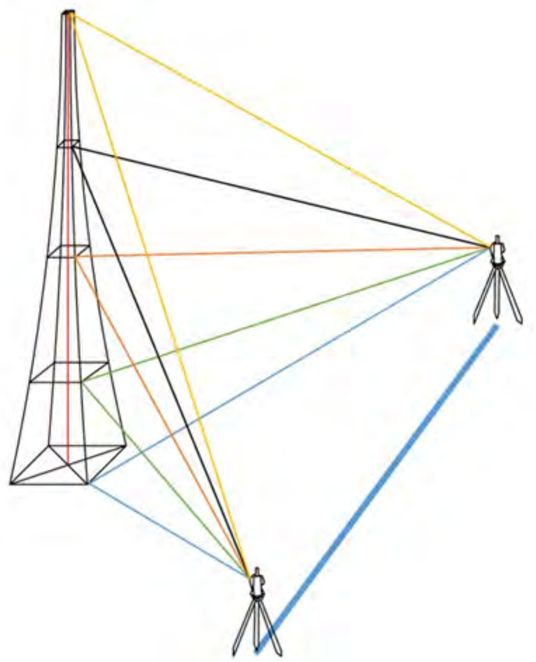

Fig. 1. The measurement of angles and distance of individual levels with usage of Total Station

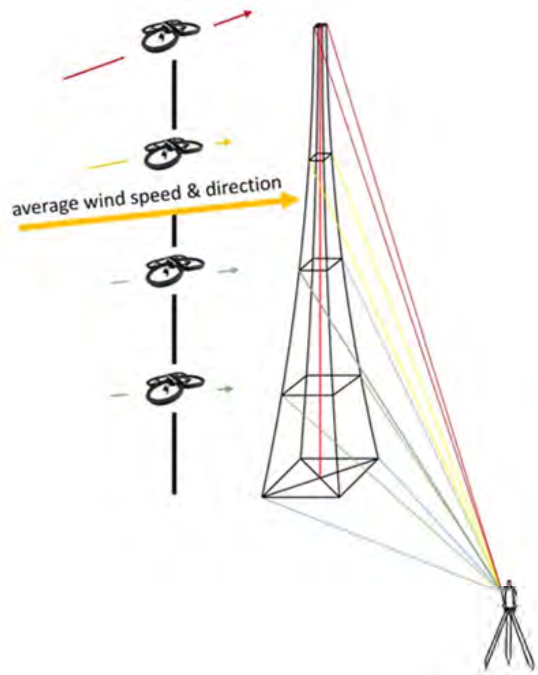

Fig. 2. The concept of angles measurements including measurement of the wind (speed and direction) by UAV

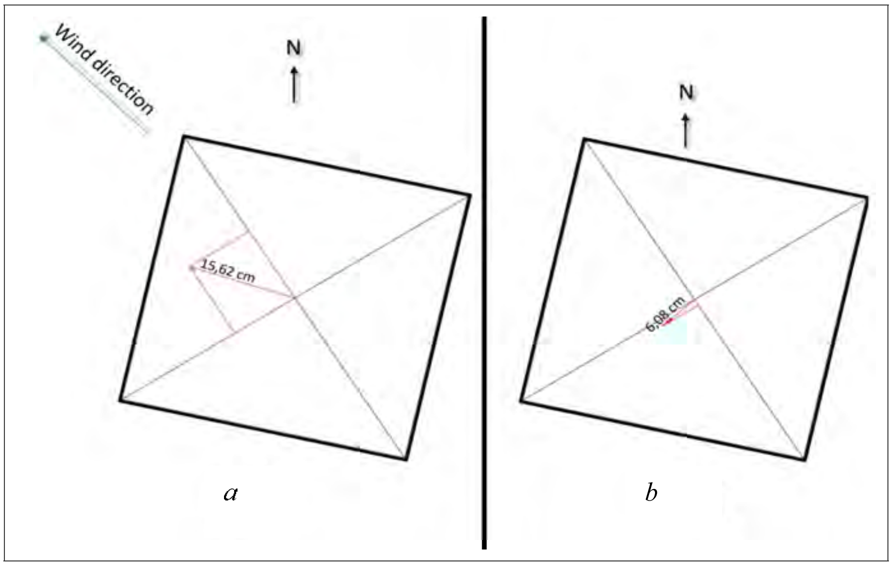

Fig. 3. Average Tower's deflection and its direction at average wind speed of 7 m/s ; b) Wind speed at the level of 1 m/s considered as no-wind weather

Inertial measurement unit is built from three sensors:

1) accelerometer measuring external accelerations;

2) magnetometer measuring components of Earth magnetic field vector;

3) gyroscope measuring angular rates in the IMU body frame.

Because forces acting on the sphere are directly measured by IMU, it's possible to estimate wind speed vector based on these measurements and knowledge about the rigid body dynamics and aerodynamics of hanged sphere.

Based on use of quadrotor and presented measurement method, it was possible to estimate wind vector on different altitudes and arbitrary close to the tower. In a result there was possible to determinate the Tower's deflection in order to the wind speed and its direction. First results were presented in following graph (Fig. 3).

Presented results rely to two observation cycles in calm time and in windy day. In case of windy day, where the average measured wind speed was at the level of 7 m/s it was observed average Tower's deflection that was much heavier than during observation in no-wind day (at the level of about 1 m/s). Also the deflection was clearly correlated to the wind direction.

Performed observations prove the earlier assumptions to use the UAV for wind speed measurement. However the method must be still improved because of the unclear data about internal accuracy of UAV's wind speed measurement and its impact at overall accuracy of observations.

Surface monitoring of water basins based on use of UAV

Underground mining operations impact isn't neutral to the environment and objects located on the lands surface. Underground mining of coal can cause the irreversible, adverse changes inside the rock mass and on the land surface. These changes may be disclosed during the mining extraction which is currently being conducted or after its completion (2 − 3 years) [Popiołek, 2009].

Land surface deformations, especially in the highly urbanized terrains, are thoroughly and often monitored not only by mine industries but also by local authorities and even private owners of land parcels, mainly farmers. There are multiple methods of measurement of the mining impact on the land surface, but most of them depend on the need of reference to the control points being outside the region of mining influences. Usually it's a time consuming process in order to the large-area nature of the deformation.

In case of relatively small water basins that can be caused by formation of subsidence trough on the surface there can be used a new method depending on simple photogrammetric rules and usage of small UAV's equipped with the non-metric camera [Janusz, Mielimąka, Niezabitowski, Orwat, Sikora, 2015]. The method can be applied eg. by farmers on agricultural regions to check if the lack of drainage zones are changing the size, especially when the water begins to accumulate therein. This could suggest that the region is under impact of underground mining operations. Described situation very often can be met in the both urbanized and characterized by presence of farmlands area of Upper Silesian Coal Basin.

The main idea of the method was to use the UAV with mounted digital camera to fly over the water level and pick up the set of images [Zhang, Wu, Liu and Chen, 2010]. Similar solutions of applying the UAV's are already documented, e.g. monitoring soil erosion [d'Oleire-Oltmanns, Marzolff, Peter and Ries, 2012].

The process of flight planning is well known since the earliest works with analogue aerial images and can be found in the literature [Eisenbeiss, 2009; Kurczyńki and Preuss, 2011; Wu, Zeng, Shao and Feng, 2012]. There have been determined values of sidelap and overlap in order to the value of the speed and fly height of the UAV.

Because of the usage of non-metrical cropped camera there has to be determined focal length of the camera. It can be determined with usage of scale. The scale should be placed horizontally on the ground under the camera. After taking photo the focal length can be estimated from the simple ratio showed in the Fig. 5 [Heikkila, Silven, 1996].

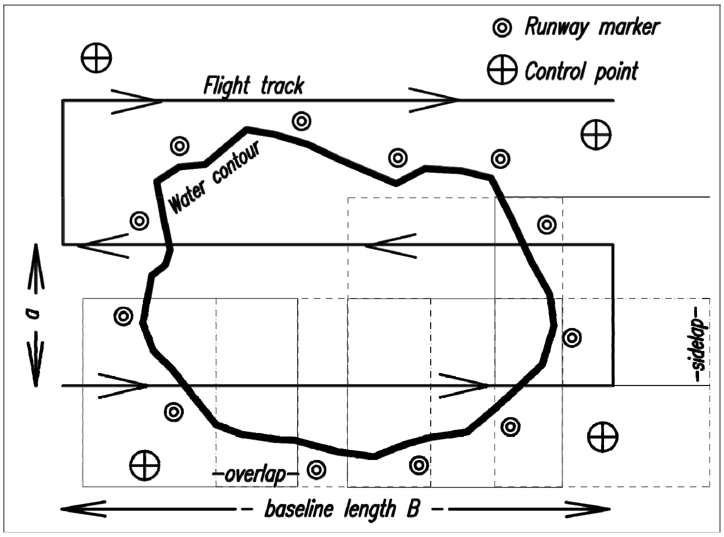

Fig. 4. The concept of the flight plan over the water basin including estimated length of baseline, distance between neighboring flight lines, side lap, overlap and the set of runway markers and control points for further images orientation process

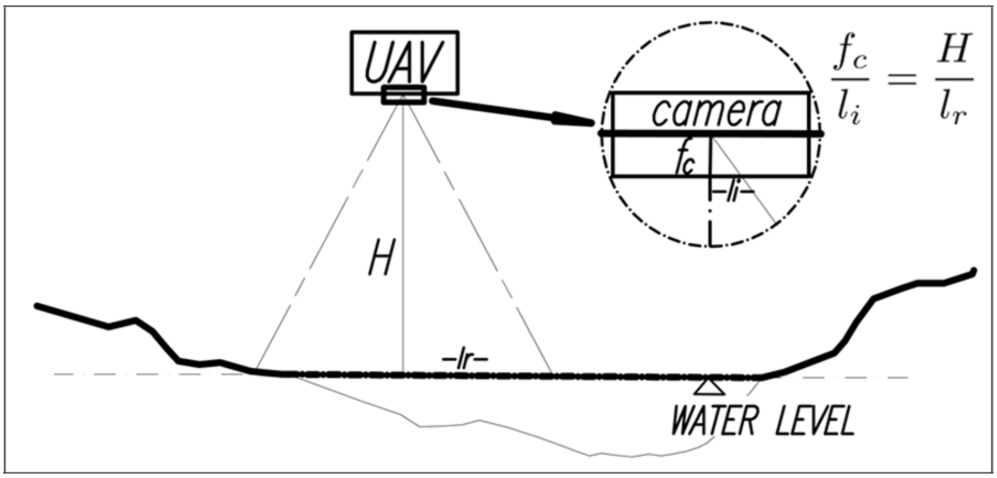

Fig. 5. Image scale factor is defined by the flight height and the camera focal length fc

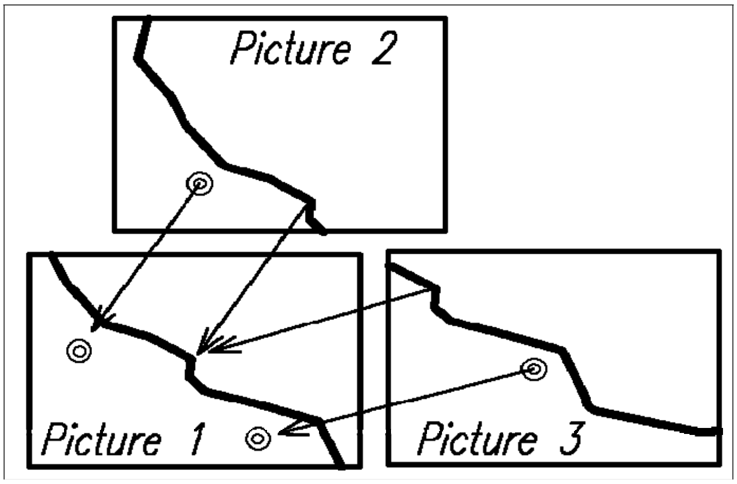

Fig. 6. Alignment process with usage of runway markers and terrain details

That allow to create the block configuration of the pond in the calibration process. Using some reference points settled out on the border of the pond, tied to the geodesy control point determined by GNSS RTK observations allow to orientate the raster map in unified coordinate system.

After all it was possible to trace images getting the vectorised contours of the water basin. Comparing contours created in different moments it will be able in the future to check the progress of land deformation in time and its impact on the environment.

The method uses modern technologies and finally is cost-effective, however like in the previous example it's hard to state about the absolute accuracy of the method because of unknown accuracy of UAV position in the moment of taking photo.

Inventarization of underground labyrinths of the fortress klodzko

Klodzko Fortress is another Polish monument frequently visited by tourist. [www.twierdza.klodzko.pl (in Polish)] The Fortress is a place shrouded in an aura of mystery, which collects many historical events from the past and various legends and stories. It was opened for tourism in 1960 and since that moment can be visited by tourists only about 10 % of the entire facility. This medieval fortress located in the Lower Silesia hides among other things, an extensive network of underground sidewalks whose task was to destroy, by blowing up explosive, enemy positions during the siege. Some small part of them can be visited by tourist and most of them never was inventoried.

Because it's estimated that overall length of the network can be longer that 30 km it was assumed that the best method for complex measurement of the sidewalks will be usage of 3d scanner. By the method it's possible to inventory the object as well as create spatial map of the underground cavities.

Hopefully the sidewalks are well ventilated (naturally) and there were no other hazards limiting the possibilities of usage of surveying tools. In the first part of observations there was used FARO FOCUS3D X 330 (Fig. 7) characterized by a range of measurement at a level of 300 m with the accuracy of distance measurement at the level of +/- 2 mm. The accuracy of observations is enough to obtain detailed model of underground sidewalks.

Fig. 7. Faro focus3D x 330 in the underground sidewalk

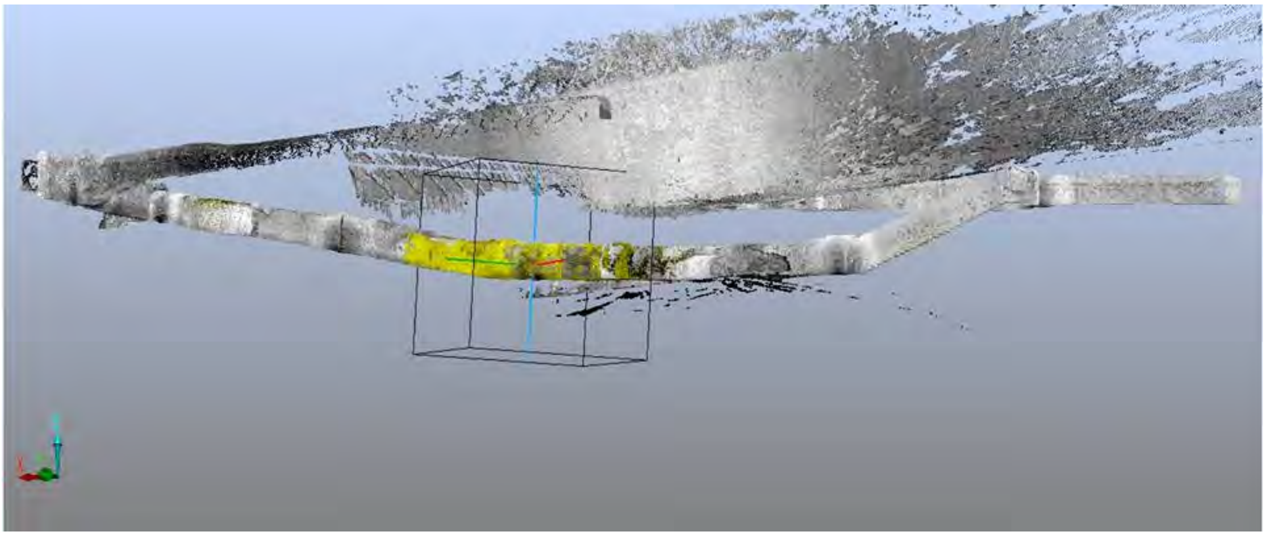

Fig. 8. Part of the points cloud showing the spatial model of underground sidewalks.

So far there was done only one series of measurements covering a total of 33 underground control points. It is estimated that so far it was inventoried approx. 5 % of the entire network of cavities. Unfortunately, it turned out that some of them are currently unavailable, among others, due to the complete inundation by a water.

The underground traverse was tied to reference point on the surface by GNSS measurement. It allows in a consequence to create the spatial map of walkways in unified reference system.

The advantage of the applied method is its speed in order to typical tachometric method. It also allows in a easy way to monitor the natural phenomenon of convergence, which involves the gradual tightening of the side walls of excavations by advancing rock mass from the environment.

Conclusion

In the article were shown three examples of application of so called modern technologies in typical surveying tasks. There was shown an example of measurement of the wind speed impact on the Gliwice Radio Tower deflection. The Tower is one of the oldest and highest wooden (non-impregnated) towers in Europe and because of the historical past it's very important object in the worldwide culture. The Tower is located in the open and undeveloped terrain. This means that it is exposed to strong winds. Unfortunately the life of the Tower is estimated at about 10–15 years and because of the fact that it's very hard to mount on it any additional sensors there was an idea to use the UAV to measure the wind speed. So far there was proved by classical tachometric observations combined with wind speed value measured by sensor mounted on UAV that the tower deflects in order to the wind speed and also that the average deflection from several levels of the Tower clearly correlate with the direction of the wind.

Next there was shown an example of usage of the UAV with mounted non metrical camera to improve monitoring of water basins surface in regions where coal extraction took place because of its significant impact on the landscape or agriculture. This paper demonstrates the idea of continuous monitoring of impact of mining operations on location and reach of water bodies shoreline or shape and condition of river channels situated within the mining areas by appropriately equipped quadrotor.

The last example presents the usage of 3d scanner and GNSS method to generate spatial map of underground labyrinths of the Fortress Klodzko. The fortress is a historical monument available to tourists, however underground there is a several-kilometer network of walkways. It's important to inventory them in order to the safety, historical and tourism aspect. Some parts of these walkways are very hard to reach or sometimes even unreachable. By the usage of 3d scanner it was easy and fast to measure ale the nooks and crannies with millimetre accuracy and by binding the underground geodetic traverse with the reference points on the surface by

GNSS technology it was easy to orientate the network of measured walkways.

The article focuses mainly on practical significance of modern technologies, not in determining their accuracy. Only three cases show, however, that the justified application of this type of technology is incidental, but shows that with a relatively simple solutions can be obtained results yet difficult to realize.

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WYKORZYSTANIE NOWOCZESNYCH TECHNOLOGII W TYPOWYCH POMIARACH GEODEZYJNYCH

W artykule przedstawiono przykłady wykorzystania nowoczesnych technologii do zwiększenia szeroko pojętej efektywności typowych pomiarów geodezyjnych. Nowoczesne technologie pomiarowe jak np. skaning trójwymiarowy lub zastosowanie bezzałogowych obiektów latających (UAV) mogą być wykorzystane z powodzeniem do zwiększania efektywności, w tym także dokładności, kompleksowych pomiarów obiektów wysokich lub obszarów niedostępnych. W artykule został przedstawiony przykład pomiaru wpływu prędkości wiatru na wychylenie Gliwickiej Radiostacji. Radiostacja jest jedną z najstarszych i najwyższych w Europie wież drewnianych (nieimpregnowanych) a ze względu na swoją przeszłość historyczną jest także ważnym obiektem dziedzictwa kulturowego. Wieża zlokalizowana jest w terenie otwartych i słabo zabudowanym. Oznacza to, że jest podatna na działanie silnych wiatrów. Niestety, z obecnych ekspertyz wynika, że trwałość konstrukcji szacowana jest na zaledwie 15-20 lat. Potencjalne wychylenia wieży z uwagi np. na wiejący wiatr dodatkowo osłabiają konstrukcję. Z uwagi na stan obiektu nie jest możliwe częste wchodzenie na obiekt lub montowanie dodatkowych czujników. Z uwagi na wymienione ograniczenia powstała idea pomiaru wychylenia wieży pod wpływem prędkości i kierunku wiatru z wykorzystaniem UAV, jako elementu kompleksowego pomiaru. Dotychczas wykazano pomiarami tachimetrycznymi oraz informacjami o sile wiatru z ogólnodostępnych źródeł informacji, że wieża wychyla się zgodnie z kierunkiem wiatru oraz wychylenie jest większe w zależności od średniej prędkości wiatru. Zaobserwowano jednak, że wychylenia są różne na różnych poziomach wieży.

Kolejny przykład wykorzystania nowoczesnych technologii pomiarowych, przedstawiony w pracy, dotyczy monitoringu obiektu niedostępnego lub trudnego do pomiaru klasycznymi metodami. Przykład przedstawia pomiar konturów zalewisk wodnych powstałych jako skutek podziemnej eksploatacji złóż pokładowych. W wyniku obniżeń terenu na powierzchni mogą się tworzyć niecki bezodpływowe, które mają duże znaczenie z uwagi na np. rolnictwo i krajobraz. W artykule przedstawiono sposób systematycznego monitoringu polegający na zastosowaniu bezzałogowego obiektu latającego wyposażonego w kamerę niemetryczną. Z wykorzystaniem prostych zasad fotogrametrycznych w relatywnie prosty sposób można utworzyć metryczną ortofotomapę w celu wyznaczania ewentualnych zmian kształtu i rozmiaru powstałego zalewiska.

Ostatni przykład przedstawia wykorzystanie skanera 3d oraz pomiarów GNSS do utworzenia przestrzennej mapy sieci podziemnych korytarzy minerskich w Twierdzy Kłodzkiej. Obecnie Twierdza jest w Polsce znanym zabytkiem historycznym. W podziemiach znajdują się wielokilometrowe chodniki, które udostępnione są turystom tylko w marginalnym stopniu. Kluczowe jest zinwentaryzowanie pozostałej części z uwagi na turystykę oraz aspekt bezpieczeństwa i historyczny. Część z tych chodników jest niemalże niedostępna lub niebezpieczna do wejścia. Z pomocą nowoczesnego skanera 3d o skutecznym zasięgu pomiaru ok. 300 m możliwe było zinwentaryzowanie chodników z dokładnością milimetrową. Natomiast poprzez dowiązanie podziemnej sieci pomiarowej do powierzchniowego układu współrzędnych z zastosowaniem pomiaru GNSS możliwe było dalsze zorientowanie sieci korytarzy w przyjętym układzie odniesienia.

Celem artykułu było przedstawienie możliwości wykorzystania nowoczesnych technologii, często droższych od klasycznie stosowanych, w typowych pomiarach geodezyjnych na przykładzie kilku realizacji. Przykłady zostały tak dobrane aby wykazać, że prawidłowo dobrana technologia pozwala znacząco zwiększyć dokładność końcowego opracowania, zredukować czas lub koszty pomiarów co w sensie artykułu rozumiane jest jako efektywność pomiarów.

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ВИКОРИСТАННЯ СУЧАСНИХ ТЕХНОЛОГІЙ ГЕОДЕЗИЧНОЇ ЗЙОМКИ

Наведені приклади застосування сучасних технологій для підвищення ефективності геодезичної зйомки. Сучасні технології, такі як сканування тривимірних об’єктів або використання безпілотних літальних апаратів (БПЛА), можуть бути успішно впроваджені для підвищення ефективності, зокрема точності комплексних вимірювань високих будівель або недоступних районів. Наведено приклад вимірювання впливу швидкості вітру на коливання радіостанції Глівіце. Радіостанція є однією з найстаріших, найвищою дерев’яною вежею в Європі, а також є важливим об’єктом культурної спадщини. Вежа розташована у відкритому і погано забудованому районі. Це означає, що вона схильна до дії сильних вітрів. На жаль, поточні звіти показують, що стабільність конструкції оцінюється в 15–20 років. Коливання вежі, спричинене вітром, додатково послаблює конструкцію. З огляду на це, виникла ідея виміру коливань вежі під впливом швидкості і напрямку вітру із застосуванням безпілотних літальних апаратів. Досі вимірювання проводили тахеометрами, а інформацію про силу вітру черпали з публічних джерел про те, що вежа нахиляється в напрямку вітру і відхилення буває велике, залежно від середньої швидкості вітру. Зауважено, що коливання різні на різних рівнях вежі. Інший приклад використання сучасних вимірювальних технологій, поданий в роботі, стосується моніторингу недоступного об’єкта або такого, що важко виміряти класичними методами. Подано приклад виміру контурів переливання води внаслідок підземних гірських робіт. Просідання ґрунту може спричинити відтік басейну, що має велике значення для сільського господарства та ландшафту. Подано спосіб систематичного моніторингу, що ґрунтується на застосуванні безпілотних літальних апаратів, споряджених неметричною камерою. За допомогою простих засад фотограмметрії створено ортофотоплан для визначення зміни форми і розміру отриманої заплави. Останній приклад демонструє застосування 3D-сканування і вимірювання GNSS для створення просторової карти мережі підземних коридорів Клодзької фортеці. Сьогодні це добре відомий історичний пам’ятник у Польщі. У підвалі є багато-пішохідних доріжок, чимало коридорів фактично недоступні або небезпечні для входу. За допомогою сучасного 3D-сканера з ефективним вимірюванням дальності близько 300 м можна провести інвентаризацію коридорів з точністю до міліметра, а з використанням вимірювань GNSS – зорієнтувати мережу коридорів у прийнятій системі відліку. **Мета** – подати можливості застосування сучасних технологій і показати, як правильно обрана технологія дає змогу значно підвищити точність дослідження, скоротити затрати часу і коштів.

Ключові слова: геодезична зйомка, безпілотні літальні апарати, 3D-сканер.

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