the distortion coefficients of radial and tangential distortion); rectification of images (the calculation of disagreement of each frame from stereo camera); spatio-temporal filtering of images (frames of a video sequence processing for digital noise suppression). Much attention is given to factors mismatch stereo cameras and methods of calibration. Also presented a method for accelerating the rendering of depth maps by using threading GPU, which enables the 3D-reconstruction in real time using the video stream.

***Key words**: 3D-reconstruction, calibration, depth map.*

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THE USE OF UAVS FOR GEOSPATIAL DATA COLLECTION

In this article, the use of UAVs for geospatial data collection was analyzed. Nowadays, inexpensive UAVs equipped with high-resolution cameras, laser scanners, GNSS/RTK receivers and sensors are capable of making sophisticated and spatially correct maps of survey-grade accuracy with minimum human control. UAVs are bringing the revolution to cartography making it truly real-time. This article contains the information about the workflow, analysis of factors, which influence accuracy, accuracy assessment of one of the most popular drones, comparison of GPS ground topographic survey and aerial UAV topographic survey, suggested improvements to the modern civilian drones and skills that professionals in GIS, geodesy and cartography have to acquire nowadays.

***Keywords**: UAV, drone, accuracy, GIS, cartography, geodesy*

Introduction. Nowadays, inexpensive UAVs equipped with high-resolution cameras, laser scanners, GNSS/RTK receivers and sensors are capable of making sophisticated and spatially correct maps of survey-grade accuracy with minimum human control. Mapmaking takes much less time than ever before. UAVs are bringing the revolution to cartography making it truly real-time.

The Analysis Of Recent Research And Publications. The most recent research and publications about UAV technology were analyzed in this article. The analysis shows that UAVs are already widely used in various fields. Their high accuracy was tested and proved not only by venders, but also by companies that specialize in surveying. Their time- and cost-efficiency was proved by comparison of the ground topographic survey and UAV topographic survey of the same land parcel.

Statement of the problem. The aim of this article is to present the workflow, the accuracy assessment of one of the most popular UAVs and to show that the provided accuracy allows us to use UAVs for topographic surveys in Ukraine, which are regulated by legal acts, compare the accuracy of UAV aerial topographic survey and GPS ground topographic survey of the same land parcel, suggest extraordinary applications of UAVs including those applications which became possible with the occurrence of real-time cartography, to suggest improvements to modern civilian drones and to analyze new skills, which professionals have to acquire nowadays.

The exposition of research results. Working with UAVs is relatively easy and fast. The first step is flight planning. A first-order decision is whether the flight will be done under autonomous control or will be controlled manually. Manual control is generally more useful for inspections (say beneath a bridge) that aim to react to information in real time, while autonomous control is, as a rule, more useful when one is trying to fly in a systematic pattern to create a map. Using an autopilot is in fact safer because it reduces the possibility of human error and of radio interference disrupting the signal between a manual controller on the ground and the drone. In either case, it is important to analyze the area to be mapped before liftoff. It is good practice to use existing satellite imagery to plot out a flight before takeoff [5].

The design of flight paths is an important component of UAV mapping. This is typically done using software packages. UAV mapping missions are usually flown in a specific pattern of parallel lines, commonly described as “transects,” which are connected to a series of “waypoints”–think of a connect-the-dots pattern of parallel lines, or the pattern in which you might mow the lawn. A transect flight pattern is a method of ensuring that the UAV captures an adequate quantity of images that overlap to the degree required for the processing software to create a high-quality and accurate map. For maximum quality, some UAV mappers suggest flying two different overlapping patterns over the same area but at different heights. The pilot opens the software and defines an area to be mapped with a polygon, then specifies the desired operational altitude, image overlap and other parameters. When complete, the mission file is saved to the computer and can also be saved to the UAV’s flight controller. If there is a working Internet connection available, missions can be planned at the site of the anticipated fieldwork [5].

UAV flight paths or mapping projects should be designed to ensure a sufficient amount of both forward and lateral photographic overlap, which will better allow postprocessing software to identify common points between each image. There is no universally accepted overlap standard. As an example, Walter Volkmann of Micro Aerial Projects suggests overlaps of 80 percent (forward) and 70 percent (lateral/side). Pix4D on its website suggests at least 75 percent forward overlap and 60 percent lateral/side overlap. To achieve a certain image overlap, pilots need to balance the speed of flight with the interval at which the camera is taking pictures, as well as the altitude of the flight. Today’s flight planning software will automatically calculate all these figures [5].

Image resolution is an extremely important consideration. Achieving good resolution in UAV photography depends on how high the drone is flying and camera settings. Resolution in aerial photography is measured as ground sampling distance (GSD)–the length on the ground corresponding to the side of one pixel in the image, or the distance between pixel centers measured on the ground (these are equivalent) [5].

Of course, image quality is not purely a function of the theoretical resolution. A higher altitude will not be useful if there are clouds between the camera and the ground. Also, images can be made blurry by the motion of the drone. Another negative factor is turbulence, which can be ameliorated by gimbal systems that stabilize the camera's motion with respect to that of the airframe [5].

Collected imagery must be processed on a computer to generate a map. Processing big batches of high-definition aerial imagery can be slow, and depending on how many images are being used, this can require a powerful computer processor. Some field workers will do low-quality image processing in the field to check that they have shot an adequate number of images with adequate overlap, then create a higher-quality model when they return to their computing workstations. Factoring in the time required to process data is an important consideration for fieldwork, as processing presents a technical barrier to projects that require a swift turnaround. To avoid unpleasant surprises, it is best to get a clear sense of how long processing will take with the computing equipment available before heading into the field. Some companies now offer UAV mapping software that carries out real-time image processing on their servers, such as DroneDeploy, DroneMapper, and Airware. Outsourcing the computing power to process detailed UAV imagery lessens the lengthy processing time required by other photogrammetry software, and it can also provide output quickly while a team is still in the field. However, using these services requires access to mobile data or the Internet, which is often unavailable in remote areas or during disasters. Some services, such as DroneDeploy, require the purchase of a separate unit that is mounted on the UAV to function [5]. The technology will change and the processors will be fast enough.

The accuracy assessment of the senseFly's eBee RTK supplied with PostFlight Terra 3D post-processing software was completed by senseFly team. To calculate the accuracy the Root Mean Square Error (RMSE) was used. RMSE is the standard error measure used in geo-correction. The team set out 19 reference points spread over the 0.20 km^2 area. The references were taken by surveying the zone with the double-frequency GPS/GLONASS receiver taking RTK corrections from swisstopo's Automated GNSS network for Switzerland (AGNES). The team did two flights using eBee RTK along with eMotion for the flight planning and monitoring, and PostFlight Terra 3D for image post-processing. Accuracy of point cloud, orthomosaic and DSM were studied. During the first flight RTK corrections were provided by the VRS, GSD was 2.5 cm, altitude was set to 81 m and image overlap was 80 %. The weather conditions: bright sunny day. The analysis first focused on the point cloud accuracy. The eBee RTK achieved high level of accuracy both horizontally ($RSME_{XY}$ = 2.6 cm) and vertically ($RMSE_Z$ = 3.1 cm). The accuracy of all the points is within the range of 1 to 3 times the GSD. Second, analysis focused on the orthomosaic and the DSM. The quality of both was checked by using ESRI ArcMap 10.1 software to compare the horizontal distances and the vertical offsets between the verification points, computed by Postflight Terra 3D, and the original position of the these points in the field. For the orthomosaic $RSME_{XY}$= 3.3 cm and for the DSM $RSME_Z$ = 3.5 cm. The next analysis focused on the conditions when the uplink between the base station and the eBee RTK is lost for short periods, preventing RTK corrections from reaching eMotion. The GPS positions of 10% of the images were edited. Incorrect geotags were entered randomly. In this way, the SenseFly's team validated Postflight Terra 3D's ability to correct such positions. The accuracy of the entire dataset was still maintained: $RSME_{XY}$= 2.8 cm and $RSME_Z$ = 4.8 cm. The last analysis focused on the ability of eBee RTK to maintain the accuracy in bad weather conditions. Even in windy, low light conditions eBee achieved one to three GSD accuracy: $RSME_{XY}$= 8.9 cm and $RSME_Z$ = 7.0 cm [1].

Topographic surveys are one of the most common surveys in Ukraine and their accuracy is regulated by legal acts. Based on the accuracy assessment, which was described previously, I can make a conclusion that surveying with UAVs provides the required accuracy.

The company “Geocom” in Charkov, Ukraine conducts geodetic surveys using UAVs “Tornado”. They also offer postprocessing of the acquired images into orthophoto maps of the following scales: 1:500, 1:1000, 1:2000 and into digital models. The company offers to conduct a survey at any location within Ukraine. They promise that their UAV can stay in the air up to two hours. Surveys can be conducted at hard-to-reach areas.

So, can UAV topographic surveying replace ground topographic surveys? McIntosh Perry Surveying Inc. collaborated with UKKO to conduct a test of an eBee. The purpose of the test was to compare the accuracies of horizontal positions and vertical elevations against a topographic and site detail survey. First, the farmland set on 40 hectares was surveyed with Trimble R8 base station and rover RTK GPS units. The survey of the site was completed by visually identifying and taking RTK GPS observations at break lines and physical features. The field topographic survey resulted in the acquisition of approximately 1800 data points with x, y, z coordinates. A digital terrain model was prepared using CAD software. Field accuracies were observed to provide results between 3 and 8 cm in each of the three axes over 95%+ of the observations, with combined accuracies averaging 5 to 6 cm. These results were achieved by using a fixed base station. Later, the same farmland was surveyed with an eBee RTK UAV. A Trimble R10 RTK GPS unit set on a point with known coordinates was used as base station for that survey. The known latitude, longitude and ellipsoid height were entered through the eMotion software on the laptop controller, and the base was connected to the UAV through the laptop, where real-time corrections could be pushed to the UAV during the flight. The onboard GPS receiver in the aircraft constantly updated the laptop with the calculated deviation of its ‘fix’ from the base station, a value which averaged <2 cm throughout the flight. For accuracy comparisons, McIntosh Perry had previously set 6 GCPs, which were not used in the post-processing, but were used only as a check on the accuracy of the positioning determined by processing the data acquired by the UAV. The photographs were taken with a lateral overlap of 70% and a longitudinal overlap of 85%. The maximum altitude for the mission was 100 meters. Resolution was 3 cm/pixel. Setup took 10 minutes. The eBee was simply hand-launched and flew a predefined path in 28 minutes. The camera took 314 photographs in total. The highest wind speed during the flight peaked 18 km/hour, but the UAV managed to adjust its track using RTK GPS unit and its attitude using its accelerometer. The post-processing software PostFlight Terra 3D generated a point cloud at a density of 115 points/m^3. 31 million individual observations in total. Accuracy comparison between eBee observations and ground control against 6 GCPs resulted in the following: mean error (X) equals 1.6 cm, mean error (Y) equals 2.8 cm, mean error (Z) equals 0.3 cm, $RSME_X$ = 4.7 cm, $RSME_Y$ = 3.7 cm, $RSME_Z$ = 5.5 cm. It means that using the eBee platform can successfully compete in accuracy with a conventional ground topographic survey completed using RTK GNSS receivers, comprising a base and rover. The time required to complete a ground survey in the field is

4 days while the aerial survey took only one hour. Post-processing time is similar in both cases, although there are more options available using the PostFlight Terra 3D software than there are using CAD software. The amount of data acquired is tremendous. The paradigm that surveying is done in the field and processing is done in the office will change to one where data acquisition is done in the field and surveying is done in the office. It allows us to have the parcel and surveyed objects in virtual form and makes it available for us at any moment of time without living our desks [2].

However, the real value of the UAV technology is time-efficiency. The UAVs are bringing a big revolution to cartography making it truly real-time. It is twice important for search and rescue operations when every second counts and delay can result in human deaths. While planes and helicopters require some time to be ready for deployment, a microdrone UAS can be put into action immediately. Drones equipped with sensors and GNSS/RTK receivers can fly over the area of interest, perform sensory operations to collect evidence of the victim presence, and report their information about the location of victims to a remote ground station right away. UAVs give real-time map of the site and help rescue teams to find a very accurate position of victims, plan the optimal path, evaluate the potential risks for the victims and people coming to their rescue, choose the optimal equipment and at the same time the evaluation of damage can be done using up-to-date maps provided by UAVs. UAVs can carry different payloads including GPS trackers for victims.

UAV technology significantly advances GIS and cartography.It found many extraordinary applications.

Drones provide critical support after big disasters. After the Haiti earthquake struck, un-updated maps made it difficult for aid agencies to deliver food, water and medicine to those in desperate need. A team of engineers sent three UAVs over Haiti for 10 days, correlating with Google Maps to create up-to-date, 3-D maps that covered 45 square kilometers. This allowed for humanitarian agencies to distribute supplies quickly [7].

In Japan, drones guide robot trucks at construction sites. Komatsu recently paired with American drone maker Skycatch with a plan to have drones survey and map construction sites, and then have unmanned bulldozers and other vehicles go to work. First, drones fly over a construction site, taking pictures of the ground below. Software then stitches these pictures into 3D maps, and site planners add in the information about what earth they want moved, which areas they want left intact, and what the next stage of construction should look like [8].

UAVs can be used to track crime. Since late 2006, the FBI has conducted surveillance using UAVs in eight criminal cases and two national security cases [9]. UAVs equipped with GNSS/RTK, sensors and infrared cameras can monitor areas where the crime rates are high. They will be able to track criminals and provide high-accuracy real-time maps with the current position of suspects. Regular flights over the most dangerous parts of cities would make a significant dent in the number of burglaries, robberies and murders. It will provide the police with a continuous stream of images covering the most dangerous parts. In a very ideal scenario of data collection, here’s how it would work: data from sensors (cameras, drones, gunshot detectors and license-plate readers) would be collected from thousands of spots in the city. Data analysts would then scan data in real-time to locate felons or provide reports to first responders [6].

UAVs are a great help when there is a need to inspect the areas where the presence of people is not possible or not safe. Industry is one of the examples. There might be the cases when a person cannot enter some parts of the factory or when it is necessary to stop the industrial process for a surveyor to do the job, which can result in huge money losses.

The inspection of complex infrastructure will benefit from regular aerial monitoring. The ability to sense in three dimensions, take thermal readings, and to detect metal strain will greatly improve infrastructure inspection. Small and unmanned platforms that can hover and get close and surround infrastructure, such as a bridge or plant, will provide a new level of detail to improve performance [4].

In my opinion, to make UAVs capable of constantly providing real-time maps, a few improvements have to be considered. The energy limitations should be decreased. The average flight time of civilian UAVs is 30-40 minutes. If a drone never had to land, it could act as an auxiliary GPS and be a geostationary satellite without the expense of going to space. The solar power can extend the durability of drone battery. Such companies as titan Aerospace, Airbus with its Zephyr are already using solar energy to extend durability. The solar panels can be paper-thin so they do not add weight.

The UAV technology will change the way we see GIS, geodesy and cartography. That is why it is necessary to make changes in the education. Nowadays, professionals can get tremendous volume of information and it takes little time and effort. That is why they have to be able to filter the information and to ‘calculate’ the minimum volume of data that is needed to solve problems and to maintain required accuracy, because the more information we get, the more time we spend processing it. Professionals should know the correlation between the weather conditions, height of the flight, image overlap and other parameters and accuracy. The schools should teach students how to use software for flight planning and introduce them to photogrammetric software. Students should study the flight route design, flight planning (autonomous and manual) for image quality.

Conclusion. In this article, the accuracy of surveys completed with modern UAVs was assessed and it was proved that UAV topographic surveying can successfully compete with ground topographic surveys. The volumes of information collected is much bigger, even though the time spent in the field is significantly decreased. Modern post-processing software gives more options when working with acquired data. Nowadays surveying is done not in the field but in the office. Collecting data has never been easier and faster. This allows us to get real-time maps. Because UAV technology significantly advances GIS and cartography, it found many extraordinary applications. But new technology requires professionals to acquire new skills.

Do drones have a future? UAV technology has already become an essential in various fields. Professionals around the world are realizing its effectiveness and convenience. Thanks to this new technology, we can get tremendous volumes of data in real time. The up-to-date and spatially accurate maps can be produced in fast and cheap ways. UAVs do have a big future. And this is not only my personal opinion, but also an opinion of Embry-Riddle Aeronautical University, Oklahoma State University, Indiana State University which have drone degrees now. New professions and trade that use just UAVs might arise. In the future, unmanned aircraft will need to be more autonomous and more cooperative, allowing one person to control a swarm of vehicles.

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ВИКОРИСТАННЯ БЕЗПІЛОТНИХ ЛІТАЛЬНИХ АПАРАТІВ ДЛЯ ЗБОРУ ГЕОПРОСТОРОВИХ ДАНИХ

У статті висвітлено використання безпілотних літальних апаратів (БПЛА) для збору геопросторових даних. У наш час використання недорогих БПЛА, оснащених камерами, лазерними сканерами та GNSS/RTK-приймачами, дають змогу складати мапи високої точності з мінімальними витратами часу та мінімальним втручанням з боку людини. Дрони уможливлюють картографію у реальному часі. Стаття містить опис процесу виконання зйомки з БПЛА та характеристику факторів, що впливають на точність. Проаналізовано точність БПЛА за різних погодних умов. У статті наведено СКП для хмари точок, цифрової моделі рельєфу та ортофотоплану. Виконано порівняльний аналіз наземної топографічної зйомки та топографічної зйомки з БПЛА, визначені переваги використання дронів.

Досліджено використання БПЛА в Україні, наведено опис послуг стосовно зйомок з БПЛА, які надаються однією з українських компаній. Стаття містить також приклад та аналіз нових сфер використання БПЛА, таких як будівництво, моніторинг споруд, пошуково-рятувальні операції, моніторинг злочинності. Запропоновано деякі удосконалення цивільних дронів. Уміщено висновки щодо нових навичок, якими повинні володіти сучасні фахівці у сфері ГІС, картографії та геодезії, а також доведено перспективність використання БПЛА.

***Ключові слова**: БПЛА, дрон, точність, ГІС, картографія, геодезія*

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ИСПОЛЬЗОВАНИЕ БЕСПИЛОТНЫХ ЛЕТАТЕЛЬНЫХ АППАРАТОВ ДЛЯ СБОРА ГЕОПРОСТРАНСТВЕННЫХ ДАННЫХ

В наше время использования недорогих БПЛА, оснащенных камерами, лазерными сканерами и GNSS / RTK-приемниками, дает возможность составлять карты высокой точности с минимальными затратами времени и минимальным вмешательством со стороны человека. Дроны делают возможной картографию в реальном времени. Статья содержит описание процесса выполнения съемки с БПЛА и характеристику факторов, влияющих на точность. Проанализированы точности БПЛА при различных погодных условиях. В статье приведены СКО для облака точек, цифровой модели рельефа и ортофотоплана. Выполнен сравнительный анализ наземной топографической съемки и топографической съемки с БПЛА, определенны преимущества использования дронов. Исследовано использование БПЛА в Украине, описаны услуги по съемкам с БПЛА, которые предоставляются одной из украинских компаний. Статья также содержит пример и анализ новых сфер использования БПЛА, таких как строительство, мониторинг сооружений, поисково-спасательные операции, мониторинг преступности. Предложены некоторые усовершенствования для гражданских дронов. Сделаны выводы относительно новых навыков, которыми должны обладать современные специалисты в сфере ГИС, картографии и геодезии, а также доказана перспективность использования БПЛА.

***Ключевые слова:** БПЛА, дрон, точность, ГИС, картография, геодезия.*

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ДО ПИТАННЯ РОЗРАХУНКУ ТОЧНОСТІ ВИЗНАЧЕННЯ КООРДИНАТ ТОЧОК ПІД ЧАС АЕРОФОТОЗНІМАННЯ З БЕЗПІЛОТНИХ ЛІТАЛЬНИХ АППАРАТІВ

У роботі розглянуто питання виконання попереднього розрахунку точності визначення координат точок за матеріалами аерофотознімання з використанням безпілотних літальних апаратів (БПЛА). Наведено математичну модель визначення координат за парою аерофотознімків. Математична модель враховує використання даних GNSS для визначення координат центрів фотографування та корегування інерціальної навігаційної системи (INS). Кутові елементи зовнішнього орієнтування у наведеній математичній моделі визначають за допомогою INS. Використовуючи алгоритм перетворення кореляційних матриць отримано строгий вираз для виконання попереднього розрахунку точності. Методом варіювання отримано вираз для розрахунку впливу систематичних похибок. За отриманими виразами виконано дослідження апріорної точності визначення координат для різних умов аерофотознімання. Експериментально розраховано точність аерофотознімання для БПЛА з типовими характеристиками, для створення топографічних карт і планів.

***Ключові слова**: безпілотний літальний апарат, розрахунок точності, інерціальна навігаційна система, кореляційна матриця, аерофотознімання.*

Постановка проблеми. Технологія аерофотознімання із використанням БПЛА нині набула значного поширення. БПЛА використовують для вирішення завдань з топографічного картографування, моніторингу, інвентаризації та спеціалізованих військових завдань [10; 15; 17; 19]. Значної популярності ця технологія набула серед геодезистів і фотограмметристів для створення топографічних планів і карт за матеріалами аерофотознімання об’єктів невеликої площі. Завдяки своїм особливостям знімання з БПЛА впевнено займає нішу між традиційним аерофотозніманням та наземним топографічним зніманням. Основна особливість та відмінність аерофотознімання з БПЛА, порівнянно з традиційним аерофотозніманням, полягає у якості даних. Обмежені габарити та низькі тактико-технічні характеристики БПЛА [2; 13] не дають змоги встановлювати на них високоякісну навігаційну та знімальну апаратуру, тому якість даних з БПЛА є