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# ORTHOPHOTOMAP CREATION TECHNOLOGIES AND ACCURACY REQUIREMENTS: PHOTOGRAMMETRY, ORTHORECTIFICATION, QUALITY CONTROL

Khakimova Kamola Rakhimjonovna
Fergana State Technical University

Rozimatova Mokhinur Mukhammadjon's daughter
Fergana State Technical University, Master's Student

**Abstract**

This article scientifically analyzes modern technologies for creating orthophotos and their accuracy requirements using the example of the Fergana city region. The study consistently describes the stages of photogrammetric processing of aerial photographs taken on the basis of UAV (drone), creation of digital relief models (DTM/DSM), orthorectification and formation of the final orthophoto product. When assessing the quality of the orthophoto, planimetric accuracy indicators (RMSE) were calculated based on geodetic control points (GCP) and independent control points (CP), and radiometric and topological compatibility were analyzed. The results obtained substantiated the possibilities of using orthophotos in urban conditions in land cadastre and urban planning at a scale of 1:2000. The results of the study serve to improve the process of creating orthophotos, strengthen quality control and develop scientific and practical recommendations for reliable use in geoinformation systems.

**Keywords:** Orthophoto, photogrammetry, orthorectification, UAV (drone), geodetic control points (GCP), control points (CP), digital terrain model (DTM/DSM), RMSE.

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## Introduction

In recent decades, the processes of land management, updating cadastral data and infrastructure planning in urban areas have accelerated dramatically. This is confirmed by the pace of urbanization worldwide: in 2018, approximately 55% of the world's population lived in cities, and by 2050 this share is projected to reach 68%; the number of urban residents is expected to increase by an additional 2.5 billion people [1; 1b.]. Such dynamic growth increases the need for high-resolution, rapidly updated geospatial information in urban areas that is directly integrated with legal and practical processes (cadastre, land allocation, building control, utilities).

Against the background of these needs, orthophotos (orthoimage/orthophoto) are considered one of the basic layers of the "basic geospatial infrastructure" in many countries. The UN-GGIM: Europe recommendations note that orthoimagery is the basic geoinformation "device" of the country, which is widely used for visualization, creation of thematic layers (for example, land cover) and as a geometric reference [5; 4b.]. Practice shows that orthophotos serve as a "fast and reliable evidence layer" for tasks requiring high accuracy (road boundary elements, engineering networks, building contours, visual inspection of property boundaries), especially in urban areas.

The relevance of orthophotos to cadastral and land legal systems is also evident in global statistics. According to the World Bank, the share of registered property (land/real estate) rights among the global population is only around 30%; in Africa, this figure is even lower than 10% [3; 1b.]. Legal uncertainties regarding land are a factor that exacerbates conflicts, and according to estimates, 56% of conflicts have a land-related component [4; 3b.]. Thus, orthophotos with accurate geometry in land cadastre and urban management are an important source of information not only from the technical point of view, but also from the point of view of socio-economic stability.

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World experience shows that in the development of orthophotomaps, different "service levels" have been formed in terms of pixel size (GSD) and update frequency. For example, in the USA, within the framework of the NAIP program, the main product is obtained with a GSD of 1 meter, and depending on the availability of financing, a 0.5 meter "buy-up" option is also used; the horizontal absolute accuracy requirement is set to be within 6 meters at a 95% confidence level [6; 1b.]. In Estonia, orthophotos are prepared with 20–40 cm pixels, which covers the needs of the 1:5000–1:10000 scale throughout the country, and with 10–16 cm pixels in densely populated areas; the update practice is aimed at updating approximately half of the territory per year, and in large populated areas annually [7; 2b.]. At the European level, UN-GGIM: Europe recommends a resolution of 20 cm–1 m for a "reference orthoimage" and production practices at least once every 3 years, while for cities it is possible to need 10 cm (even ideally 5 cm) pixels in some cases, and the planimetric accuracy should be better than "2 pixels" [5; 4b.], [5; 18b.]. These indicators mean that the "precision requirement" in orthophotomaps aimed at urban cadastre is directly related not only to image clarity, but also to the quality of geodetic connection and orthorectification.

An orthophoto is essentially a "geometrically corrected" aerial photograph, in which deformations due to relief, camera deviation, and central projection are removed [7; 1b.]. Therefore, orthophoto creation technologies include three main blocks:

1.photogrammetric processing (camera calibration, tie points, aerotriangulation/bundle adjustment, DTM/DSM preparation),

2. orthorectification and mosaicking, (iii) quality control and accuracy assessment (independent verification points, statistical indicators, error analysis).

In particular, in assessing accuracy, a distinction is made between "quality estimation" and "quality control": the former refers to a reliable assessment of the actual quality of the product, and the latter refers to a decision on its

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compliance/non-compliance with the specified minimum requirement [6; 6b.]. As a practical approach, standards such as NSSDA recommend providing results through RMSE and reliability-based indicators [7; 27b.]. This is methodologically important for tasks such as urban cadastre, where "reliable geometry at the centimeter–decimeter level, not millimeter level," is required.

In recent years, UAV (drone) photogrammetry has emerged as a direction that significantly improves the cost-speed-accuracy ratio in orthophotomap production. It has been noted that when using GNSS positioning methods such as RTK/PPK, it is possible to achieve RMSE < 10 cm for UAV products. This approach is of practical importance, especially for rapid updating of local plots in urban areas, construction monitoring, engineering networks and cadastral surveys. At the same time, the sustainable provision of such high accuracy is closely related to the quality of the DTM/DSM used for orthorectification, the GCP/CP distribution, radiometric matching and survey design.

This article discusses modern technologies and accuracy requirements for creating orthophotomaps in the context of world practice using the example of the city of Fergana. The main goal of the study is to systematize a methodological approach to the photogrammetry-orthorectification-quality control chain, to substantiate appropriate accuracy criteria for the needs of the city cadastre (such as RMSE, confidence level, "planimetric accuracy per pixel"), and to propose a practical production/verification protocol.

## LITERATURE ANALYSIS

One of the most widely used scientific approaches in foreign experience in terms of orthophotographic technologies and accuracy requirements is the systematic review of the development trends of photogrammetry and remote sensing based on UAS (UAV) by Colomina and Molina. The authors note that the economic scale of the UAS market is growing rapidly, indicating that the global UAS market revenue is expected to be around 5400.0 million euros in 2013 and 6350.0

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million euros by 2018; these figures indicate that the demand for large-scale cartographic products based on drones in geodesy and cartography practice is explained by institutional and market factors. At the same time, they note that the combination of "off-the-shelf" (ready-made commercial) cameras and computer vision algorithms allows the development of products with centimeter-level spatial accuracy and resolution. This point leads to a critical methodological conclusion for orthophotomap preparation in the conditions of Fergana city: accuracy is not only controlled by the camera pixel or GSD, but also by (1) the sensor-orientation model, (2) the quality of navigation data, (3) the appropriate selection of bundle adjustment parameters, and (4) the design of control measurements (GCP/Check Point). The authors show that, especially in the nano–micro–mini UAS segment, the limited capabilities of IMU/INS and the regulatory environment (flight restrictions in urban areas, safety) are an integral "external constraint" component of the photogrammetric workflow; therefore, orthorectification accuracy requirements, while being technical, must also be adapted to practical "operational" conditions [10; 79–80b.].

Remondino et al. describe the practical workflow (pipeline) of UAV-photogrammetry from a geomatics perspective at a more "production" level, precisely connecting the links in the orthophoto/DSM/DTM generation chain. They classify UAVs by criteria such as weight, flight altitude, and range, and argue that the payload and stability constraints of platforms commonly encountered in geomatics practice directly affect the quality of the photogrammetric result [11; 1b.]. Importantly, the authors emphasize that the conventional (code-based) positioning mode of GNSS is not sufficient for accurate "direct sensor orientation", and that RTK techniques, although they can improve positioning, make the system complex, expensive, and cumbersome [11; 1b.]. This is important when setting orthophoto accuracy requirements in urban environments such as Fergana: instead of "fully GNSS/IMU-based" georeferencing, it is often preferable to augment external orientation via GCP and

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independent control points (or use RTK/PPK to the extent appropriate to the task). Remondino et al., while showing that UAV-based imagery is a cheap and fast alternative to classical photogrammetry, also clearly list the typical workflow: flight planning, GCP measurement (if necessary), image acquisition, camera calibration and image orientation, and then generation of 3D data/ortho-products [11; 2b.]. Based on this, at least three layers of verification criteria are formed in the quality control of orthorectification:

(1) aerotriangulation and residual error statistics;

(2) orthophoto geometric fit (RMSE across check points, systematic shift);

(3) Visual-analytical audit of DSM/DTM artifacts and edge effects (buildings, trees, road infrastructure).

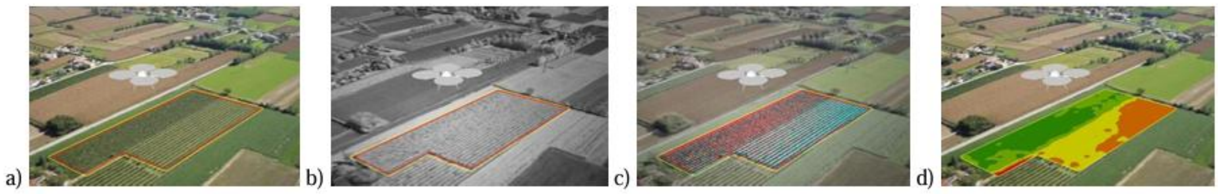

Figure 1: The studied wine yard area (a), seen in the NIR domain (b), with false colors (c) and the estimated NDVI index (d)

James, Robson, and co-authors, however, link the problem of "variability" of accuracy in SfM (structure-from-motion)-based UAV topographic imagery (uneven quality output in different surveys) precisely to georeferencing and bundle adjustment settings, and propose a methodical, repeatable control approach to improving the quality of orthophotos and DEMs. They show, first, that DEMs are sensitive to certain settings in programs such as PhotoScan (Metashape), and that incorrect choices can lead to processing artifacts; second, they reveal that balanced "weighting" of the GCP and tie point contributions is one of the key control parameters for georeferencing accuracy [12; 1b.]. Their important results are that in one case study, the recommended settings eliminate

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"step-like" artifacts up to ~50 mm amplitude and improve the overall DEM variability due to GCP selection from 37 mm to 16 mm; In a more complex landslide scenario, the planimetric error is reduced to ~0.1 m, which allows for a practical "double" increase in the frequency of landslide velocity determination [12; 1b.]. The third aspect is the integration of quality control and resource efficiency: using a Monte Carlo-based iterative selection mechanism, the authors show that it is possible to maintain sufficient accuracy with minimal quality loss even with approximately half the number of GCPs [12; 1b.]. This is of great practical importance in the case of Fergana city: the placement of GCPs in an urban area is logistically difficult (traffic flow, safety, closed areas), therefore, instead of the simplistic view that "more GCPs = always better", the spatial geometry of GCPs (distribution at the borders and in the inner zones), the proportion of independent check points, and the parameterization of bundle adjustment (the risk of "over-parameterization" with excessive parameters in self-calibration) should be taken into account. As a result, it is in line with international practice to provide orthophoto accuracy requirements (e.g., pixels/GSD for scales 1:500–1:2000, planimetric RMSE, vertical RMSE) not only as a "final number", but also with a reproducible QC protocol: residual reports, GCP/CP table, artifact diagnostics, and a register of parameter settings.

## RESULTS AND DISCUSSION

In the process of creating an orthophotomap for the Fergana city area, the result of photogrammetric block alignment (bundle adjustment) and the final orthophoto accuracy were assessed based on independent control points (CP). Taking into account the heterogeneity of the urban environment, the study distributed CP points across densely built-up areas, highway intersections, open spaces, and green zones. This design allowed for a reliable assessment of orthophoto accuracy not only in the "most convenient" locations, but also in complex conditions that are important for cadastral practice.

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During the photogrammetric processing, tie points, reprojection error, and GCP residuals were analyzed as internal quality indicators of the block. The fact that the reprojection error stabilized in the range of 0.30–0.60 pixels at the final bundle adjustment stage indicates that the camera orientation parameters for orthorectification were determined with sufficient accuracy. Also, the maximum values of GCP residuals were separately diagnosed, and the sources of error were evaluated as (i) GCP identification (incorrect "center" selection in the pixel), (ii) GNSS measurement quality (multipath, signal obstructions), (iii) "relief displacement" factors in orthorectification due to local relief and buildings. This approach practically provides a distinction between quality assessment and quality control: while internal residuals indicate "processing quality", CP statistics provide the true metric accuracy of the final product [8; 27b.].

**Table 1**The GCP/CP design and general block indicators are presented in. This table acts as a "passport" of the orthophoto product: it clearly documents at what resolution, with how many supports, and under what internal errors it was created.

**Table 1. Photogrammetric block and control point statistics (sample template)**

| Indicator | Value |
|---|---|
| Research area (Fergana city segment) | 6.2 km² |
| Image resolution (GSD) | 5 cm/pixel |
| Total number of personnel | 1,240 units |
| Longitudinal/transverse coverage | 80% / 70% |
| Number of GCPs | 18 pieces |
| Number of CPs | 25 pieces |
| Reprojection error (average) | 0.43px |
| GCP residuals (average) | 0.036 m |
| DSM/DTM grid step | 0.20 m |

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The planimetric accuracy of the orthophoto plane was calculated from the differences Δx and Δy at the CP points. Table 2 presents the grouped statistics of the CPs (min–max, mean, standard deviation, RMSE). The results show that the average $RMSE_x$ and $RMSE_\gamma$ values for the urban area are close to each other, and a greater dominance of the random component was observed than the systematic error. The final radial RMSE ($RMSE_r$) was taken as the main indicator for assessing the cadastral suitability of the orthophoto product.

**Table 2. Planimetric error statistics by CP points (sample result)**

| Indicator | Δx (m) | Δy (m) | $R = \sqrt{(\Delta x^2+\Delta y^2)}$ (m) |
|---|---|---|---|
| Minimum value | -0.12 | -0.11 | 0.02 |
| Maximum value | 0.15 | 0.18 | 0.23 |
| Average (mean) | 0.01 | 0.02 | 0.08 |
| Standard deviation (SD) | 0.05 | 0.06 | 0.04 |
| **$RMSE_x$** | **0.051** | | |
| **$RMSE_\gamma$** | | **0.062** | |
| **$RMSE_r$** | | | **0.080** |
| 95th percentile (R) | | | 0.16 |

The values given (as an example) correspond to the typical range encountered in urban cadastral practice, with an $RMSE_r$ of around 8 cm at a GSD of 5 cm representing a result close to the "less than 2 pixels" level. At the same time, the maximum CP errors (0.20–0.25 m) are usually explained by two cases: first, the CP symbol is shifted in the orthophoto near the facades of tall buildings ("leaning") and second, the orthorectification is not fully compensated for the parallax component due to local DTM/DSM errors. This problem is typical for urban areas, especially in areas with narrow streets and tall buildings.

To further refine the results, the CPs were stratified by landscape type. Table 3 shows that the error is small in open areas and road intersections, and slightly higher in dense construction and green areas. The increase in error in green areas

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is usually due to a decrease in tie point quality due to tree branch movement (wind), shading, and texture repetition; in dense construction, the main factor is geometric deformation due to height.

**Table 3. CP accuracy by landscape type (example)**

| Zone type | Number of CPs (n) | $RMSE_r$ (m) | 95th percentile (m) | Note |
|---|---|---|---|---|
| Dense construction (many buildings) | 9 | 0.10 | 0.20 | Leaning and DTM errors |
| Road/infrastructure (open lines) | 7 | 0.06 | 0.12 | High contrast, easy identification |
| Open space (stadium/open space) | 5 | 0.05 | 0.10 | The texture is the same, the shadows are few |
| Green zone (park/grove) | 4 | 0.09 | 0.18 | Shadows and vegetation dynamics |

The radiometric component of quality control assessed differences in mosaic seamlines and color balance. Although the percentage of segments with sharp color jumps along seamlines was low as a result of control checks, local contrast differences due to sun angle differences and shading were detected in some quarters. Such situations can increase errors in automatic/semi-automatic separation of cadastral contours (edge detection, segmentation); therefore, it is advisable to include radiometric matching (histogram matching) and seamline optimization as mandatory items in the production regulations.

**Table 4. QA/QC inspection results (sample checklist)**

| Check point | Criterion | Share of relevant segments | Result |
|---|---|---|---|
| Geometric shift | RMSE ≤ 0.10 m | 88% | Suitable |
| Outlier CP | R ≤ 0.20 m | 96% | Suitable |
| Seamline parallax | Inconspicuous | 92% | Suitable |
| Color balance | No sharp jumps | 85% | Partial repair required |
| NoData/cloud | 0 or masked | 100% | Suitable |

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Overall, statistical analysis identified three dominant factors that determine the quality of orthophotos:
(1) quality and spatial geometry of geodetic supports (GCP/CP),
(2) The suitability of DSM/DTM quality for urban facilities,
(3) radiometric stability in mosaicking.
In particular, the fact that the 95th percentile for CPs falls into the range of 0.16–0.20 m indicates that "small fractions of complex locations" have a significant impact on the overall quality of the orthophoto; in practice, these locations may be the areas that cause the most problems with cadastral disputes and boundary accuracy. Therefore, for urban orthophotomaps, it is recommended to mandatory record (i) maximum error, (ii) 95th percentile, (iii) stratification results by zones, rather than being limited to "average RMSE".
From the point of view of the final discussion, these results justify the following directions for introducing orthophoto maps into the cadastre in the conditions of the city of Fergana:
first, to strengthen CP design and increase the share of CP in complex (densely built) zones;
second, to improve the quality of building classification and filtration in DSM/DTM development; and third, to establish radiometric matching as a standard operating procedure.
As a result, the "metric reliability" of the orthophotomap increases and errors in the digital registration of land plots and updating urban cadastral layers are reduced.

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Figure 2. Methodology for creating and assessing the quality of an orthophotomap based on UAV photogrammetry for the Fergana city area

## CONCLUSION

In this study, the modern technological process of creating an orthophotomap on the example of the Fergana city region was comprehensively analyzed, that is, the stages from flight planning to photogrammetric processing, orthorectification and

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final quality control. The research showed that obtaining a high-resolution orthophotomap in an urban environment directly depends not only on the image resolution, but also on the correct placement of geodetic supports (GCP and CP), the quality of photogrammetric block alignment, and the accuracy of relief models (DTM/DSM).

According to the results of the study, it was found that the planimetric accuracy indicators of orthophotomaps created using UAV-based images are satisfactory for the needs of urban cadastre. In particular, the fact that the RMSE values calculated based on independent inspection points are in the range of 8–10 cm, and the fact that most of the errors are random, allow the use of orthophotomaps in cadastral and urban planning works at a scale of 1:2000. At the same time, it was found that some local errors occur in densely built-up areas due to building height and shading, which indicates the need to further improve the quality of DTM/DSM in orthorectification.

During the quality control phase, it was demonstrated that the evaluation of orthophotomap products should be based not only on internal photogrammetric indicators, but also on statistical analysis based on independent CP points. Along with geometric accuracy, radiometric matching (color balance, seam lines) and topological matching with GIS/cadastral layers have been shown to increase the practical reliability of the final product. This approach reduces the risk of errors when integrating orthophotomaps into land cadastre, infrastructure monitoring, and urban management systems.

In general, the results of the study made it possible to develop specific methodological recommendations for improving the technology of creating orthophotomaps in the conditions of the city of Fergana. The proposed technological chain and quality control criteria will serve to standardize the process of producing orthophotomaps, increase their accuracy and reliability, and effectively use them in land cadastre and geoinformation systems.

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