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METHODOLOGY FOR DETERMINING AND UPDATING CADASTRE BOUNDARIES OF AGRICULTURAL LAND BASED ON UAV (DRON) PHOTOGRAMMETRY

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Abstract

This study proposes a scientific and practical methodology based on UAV (drone) photogrammetry for clarifying and updating the cadastral boundaries of agricultural land plots in the Fergana region. The methodology covers the processes of geodetic linking of UAV RGB images with GNSS RTK/PPK measurements and GCP/CP reference points, creating high-resolution orthophoto products through photogrammetric processing (tie points/bundle adjustment, dense point cloud, DSM/DTM, orthophoto mosaic), and interactive delineation of plot boundaries based on them. The update stage involves improving the cadastral layers in an auditable manner based on the criteria of topological control (overlap/gap/sliver), difference register (shift, area change), and accuracy assessment (RMSE, CE90/LE90). As a result, the proposed approach serves to promptly update cadastral data, reduce geometric errors, optimize resource consumption, and ensure evidence-based decision-making in land resource management.

Keywords: UAV (drone) photogrammetry, cadastre, land parcel boundary, orthophoto mosaic, GCP/CP, GNSS RTK/PPK, DSM/DTM

INTRODUCTION

The land registration and cadastral system is the basic infrastructure for guaranteeing property rights, rational management of land resources, improving

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the investment climate and scientifically substantiating territorial planning in any country. However, world experience shows that the establishment and constant updating of large-scale cadastral boundaries based on traditional geodetic measurements (total station, GNSS) requires a lot of labor, time and financial resources; especially in areas with small contours, intensive irrigation, and frequent land use changes, the efficiency of this process decreases. Therefore, in recent decades, the concept of “fit-for-purpose” land administration has become widely used: instead of requiring the highest technical accuracy “always and everywhere”, it prioritizes cheap, fast and inclusive approaches based on the socio-economic conditions of the territory, the risk of conflicts and user needs. This approach is also supported by the UN's FELA on "Effective Land Administration", which emphasizes the need to update land information, modernize geodata infrastructure, and systems that rely on geospatial evidence in management decisions.

UAV (drone) photogrammetry is emerging as a technological solution to this problem: orthophotos and digital relief models (DSM/DTM) are prepared based on very high spatial resolution images obtained from low altitudes, which dramatically increases the ability to quickly delineate the boundaries of land plots by visible elements (ditches, roads, cropland contours, field paths, surrounding trees, etc.). International scientific research on the use of UAV data in cadastral mapping shows the effectiveness of boundary delineation by visible landmarks, object-oriented analysis, and semi-automatic/automatic extraction methods; for example, it is scientifically proven that photogrammetric orthophotos can serve as a practical basis for quickly updating the cadastre in work on separating “visible boundaries” from high-resolution UAV images. At the same time, it is noted that the quality of UAV orthomosaics is strongly influenced by factors such as flight altitude, overlap, illumination conditions, photogrammetric binding geometry, number and distribution of GCPs (ground control points), which means that it is urgent to develop an “operational methodology” (standard workflow) specifically for cadastre. Since cadastral work has legal consequences, the issue of assessing accuracy is also of fundamental importance: in international practice, it is recommended to report the horizontal/vertical accuracy of digital geospatial data in a standardized manner using indicators such as RMSE, CE90/LE90. There

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Website: usajournals.org

are also studies within the framework of ISPRS that modern RTK/PPK solutions, CORS networks and optimized GCP schemes significantly improve the geodetic accuracy of UAV products, which strengthens the technical validity of UAV photogrammetry in clarifying cadastral boundaries.

This topic is of particular relevance in the context of the Fergana region. The Fergana Valley is one of the most intensive regions in Central Asia in terms of agricultural production and irrigated land systems, with strong pressure on land resources, small and heterogeneous field contours, and frequent land use transformations. The demographic density of the region is also high: as of January 1, 2025, the population density in the Fergana region was recorded at 613.1 people per 1 km^2, which sharply increases the need for accuracy and operational updating in legal and technical issues related to land plots. It is also emphasized in the scientific literature that fine-scale mapping using remote sensing requires a special methodological approach in the context of the fragmentation of agricultural landscapes and the abundance of small plots. In this regard, the development of an accurate, repeatable and verifiable methodology for specifying and updating cadastral boundaries based on orthophotos using UAV photogrammetry fully meets the practical needs of the Fergana region; it will serve to develop evidence-based land development projects, quickly identify conflict areas, improve the quality of land accounting, and continuously update digital cadastral databases. Given that scientific work on the use of orthophoto maps in cadastre is also taking shape in Uzbekistan, the topic of this research strengthens the local scientific and practical school and is consistent with international approaches [1].

The purpose of the study is to develop and test in practice a scientifically sound, technically reliable and cost-effective methodology for clarifying and updating cadastral boundaries of agricultural lands based on UAV (drone) photogrammetry in the conditions of the Fergana region. To achieve this goal, the following tasks are set:

(1) analysis of territorial factors (plot fragmentation, irrigation infrastructure, visible boundary markers, seasonality of vegetation) affecting the updating of cadastral boundaries;

(2) Optimize UAV imaging parameters (flight altitude, coverage level, orientation, lighting conditions) to meet cadastral needs;
(3) organization of geodetic support (GCP/CP scheme, RTK/PPK solutions) and standardization of the photogrammetric linking process;
(4) creation of orthophotos and DSM/DTM, their geometric quality control and accuracy assessment based on international practical indicators (RMSE, CE90/LE90);
(5) comparison of semi-automatic and expert delineation methods for delineating cadastral boundaries based on orthophotos, development of reliability criteria for delineating visible boundaries;
(6) integrate the results into the existing cadastral/GIS database, identify "old-new" border differences (overlap/gap) and propose an update regulation;
(7) Comparative evaluation of the effectiveness of the proposed methodology in terms of time, cost, and accuracy with traditional field measurements and development of a package of practical recommendations.
The ultimately developed methodology will focus on ensuring the optimal balance between rapid cadastral update, resource efficiency, and quality assurance, in accordance with the "fit-for-purpose" approach.

LITERATURE ANALYSIS

In foreign scientific literature, the issue of clarifying and constantly updating cadastral boundaries using UAV (drone) photogrammetry has been extensively studied, usually in three areas:

- ✓ the concept of “fit-for-purpose” (quick, affordable, and scalable) land administration and the organizational and legal model for its implementation;
- ✓ Geodetic accuracy of UAV data (GCP/RTK/PPK, flight configuration, orthophoto quality requirements) and compliance with cadastral standards;
- ✓ semi-automatic/automatic extraction of boundaries from visual features (computer vision, deep learning, and geometric matching).

In the first block, Stig Enemark, Keith Clifford Bell, Christiaan Lemmen and Robin McLaren argue for a “fit-for-purpose land administration” approach, demonstrating that data accuracy, technological complexity and institutional requirements need to be “optimally” balanced for rapid and cost-effective registration of land rights at scale; this concept serves as a methodological "framework" for integrating high-resolution, rapid base-mapping technologies such as UAVs into cadastral systems. Among the works that directly apply this logic to the UAV context, Claudia Stöcker, Rohan Bennett, Mila Koeva, Francesco Nex and Jaap Zevenbergen analyze the issue of the "plateau of productivity" of UAVs in land administration, concluding that the success of the technology is determined not only by the sensor/orthophoto, but also by standardization, workflows, personnel, cost models and legal authorization and acceptance mechanisms [2].

In the second direction, namely "assurance" of the quality of UAV orthophotos and photogrammetric products for cadastre, Claudia Stöcker, Francesco Nex, Mila Koeva and Markus Gerke empirically assess how flight parameters (height, coverage percentage, directions, oblique/rare frame combinations) directly affect orthophoto quality and cadastral suitability, and provide practical recommendations for optimal configuration; these works are well suited for the scientific substantiation of the specific technical regulatory part of the "methodology" (flight plan, GSD, overlap, camera geometry) in your topic. Václav Šafář, Markéta Potůčková, Jakub Karas, Jan Tlustý, Eva Štefanová, Marián Jančovič and Drahomíra Cígler Žofková show that UAV photogrammetry and related measurement approaches can achieve point measurement accuracy within the framework of cadastral requirements in the Czech experience, and analyze which methods are appropriate for the official cadastral system under which conditions. An important issue in bringing UAV to the level of "official measurement" in cadastre is the configuration of GCP/RTK/PPK, block triangulation and control points. Thomas Kersten, Frederik Preuß, Dagmar Teten and Maren Lindstaedt (on the example of Germany) evaluate the geometric accuracy achieved in various GCP and check-point configurations using UAV/PPK images and note that photogrammetric cadastral measurements can be technically and economically feasible, but the legal and regulatory framework still remains a limitation in some regions. In practical "cadastre update" work, Mila Koeva, Jean M. Muneza, Caroline Gevaert, Markus Gerke and Francesco Nex demonstrate the workflow of orthophoto preparation, field verification and map layer update using UAVs on the example of Rwanda, demonstrating the superiority of UAVs in basic mapping and rapid update; This could be a direct

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methodological analogue to the organizational pipeline for updating boundaries in agricultural plots in Fergana. Claudia Stöcker, Mila Koeva, Placide Nkerabigwi, and Jaap Zevenbergen also discuss the potential of UAV technology in updating the Rwandan cadastre within the framework of FIG, highlighting issues of community/neighborhood boundary demarcation, operational costs, and institutional integration.

The third direction — automation of delineation of cadastral boundaries from images — has developed particularly rapidly in recent years. Bujar Fetai, Krištof Oštir, Mojca Kosmatin Fras and Anka Lisec raise the issue of extracting "visible boundaries" (roadside, ditch, tree line, wall, crop contour, etc.) from UAV images, revealing the cadastral "visual mark ↔ legal boundary" distinction through practical examples and emphasizing the need to regulate this process with standard approaches. Sophie Crommelinck, Bernhard Höfle, Mila N. Koeva, Michael Ying Yang and George Vosselman propose an interactive (operator-assisted, but accelerated by computer vision) delineation workflow using UAV data, showing that it is possible to obtain cadastral lines quickly and qualitatively in cooperation with a human and an algorithm; this approach may become a more acceptable (auditable) model in practical cadastre than a "fully automatic" one. On the fully automated side, Sophie Crommelinck, Mila Koeva, Michael Ying Yang and George Vosselman demonstrate the ability to extract visible cadastral boundaries from remote sensing images using deep learning methods, i.e. the orthophoto becomes not just a background but an "algorithmic evidence layer" in the cadastral update process. Xue Xia, Claudio Persello and Mila Koeva use a deep Fully Convolutional Networks (FCN) approach to find cadastral boundaries in UAV images, trying to overcome the semantic complexity of the boundary (roadside, roof/shadows, uneven texture) through a model, especially in urban and semi-urban environments; these works can serve as a basis for the scientific justification of your section on "AI-assisted boundary extraction" in this topic. As a recent trend, Deni Suwardhi, Muhammad Ihsan, Ratri Widyastuti, Aisyah Hasna Ummu Mukminin, Bummy Akbar, Sonia Kartini Pasaribu, I Putu Satwika, Sella Lestari Nurmaulia and Andri Hernandi propose an automatic "correction/approximation" pipeline for cadastral polygons on UAV orthophotos using Segment Anything Model (SAM) based segmentation, followed by ICP and

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least-squares block matching; the results provide practical metrics such as average displacement reduction, which allows you to interpret "updating" in your methodology as not just redrawing, but also optimizing the existing cadastral layer through mathematical matching [3,4].

In general, in foreign experience, the authors (Stöcker–Nex–Koeva–Gerke; Šafář–Potůčková et al.; Kersten–Preuß et al.) show that UAV photogrammetry can provide sufficient accuracy and quality for cadastre, but this result is guaranteed not only by "flying a drone", but also by a complex of GCP/RTK/PPK, flight configuration, photogrammetric unit setup, quality control and official acceptance processes. In border demarcation, the Fetai–Oštir–Kosmatin Fras–Lisec and Crommelinck–Koeva–Yang–Vosselman schools put forward the idea of carefully linking the "visible sign" with the legal border, turning interactive/AI approaches into an auditable and repeatable workflow; this is exactly the point when writing a methodology for clarifying and updating cadastral boundaries on agricultural lands in the Fergana region, for example.

(1) Collect evidence from visible features based on orthophoto + DSM/point cloud,

(2) Guarantee accuracy through GNSS/geodetic reference,

(3) links stages such as checking topological and legal compliance with cadastral documents into a scientific chain.

RESULTS AND DISCUSSION

The main goal of the study was to develop a practical methodological solution for the clarification of cadastral boundaries of agricultural land plots with high spatial accuracy using UAV (drone) photogrammetry in the Fergana region, and to diagnose and update geometric errors (shift, shape distortion, "overlap/gap") in the existing cadastral-geodatabase. The analysis of the results was carried out with the aim of first proving the geometric reliability of UAV products (orthophoto, DSM/DTM, point cloud) suitable for cadastre on a statistical basis, then comparing the labor intensity and localization quality of delineation of plot boundaries based on these products (manually and semi-automatically/with the help of AI), and finally discussing what practical effects (accuracy, speed, reducing the risk of conflicts) will arise when the updated geometry and attributes

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are integrated into the cadastral system. In international practice, it is noted that when UAV cadastral mapping is used as a "base map", the planimetric accuracy of the product can typically be in the centimeter–subdecimeter range, but it is also shown that this result is extremely sensitive to the flight configuration, GCP/CP design, and processing quality; in some configurations, the absolute/relative accuracy can deteriorate from a few centimeters to a few meters. Therefore, the main emphasis in the results section is not on the fact that "there is an image taken from a drone", but on the requirement that "there is statistical evidence of acceptable accuracy for the cadastre"; such an approach is directly related to the legal consequences of cadastral activities (land rights, potential for property disputes, compensation, tax base) [5,6].

The evaluation of the UAV imagery and photogrammetric reconstruction results was based on the principle of independent verification through checkpoints, based on international standard practice positional accuracy metrics (RMSE, and confidence levels derived from RMSE); this approach serves to document the quality of geospatial data in an auditable manner. In practice, three typical agricultural landscape scenarios are considered for the test design: (1) a scale with small contours, intensively irrigated, divided by numerous ditches and field roads; (2) a scale with large contours, relatively flat, with more straight boundaries; (3) a scale with orchards or surrounding tree plantations, with vegetation "hiding" the boundary. The "stability" of the methodology is tested under these three scenarios: that is, under what conditions the "visible boundary" from the orthophoto is close to the legal cadastral line, and under what conditions additional substantiation is required by field inspection (GNSS/commission). This point is also emphasized in foreign studies: visible features in the image (road, wall, canal, row of trees) correspond to many cadastral lines, but not all lines are demarcated by a physical mark.

The following table shows a recommended reporting format for linking UAV flight parameters and geodetic control design (GCP/CP) results to cadastral needs; the values in the table are given in typical ranges to serve as a guideline for laboratory/experimental design and should be substituted for your actual measurement protocols (i.e., it serves as a structural template for preparing a "results text" in a style appropriate for a scientific article).

Modern American Journal of Engineering, Technology, and Innovation
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Table 1. Typical parameters for UAV imaging and reference points (report form for cadastral update scenario)

Indicator	Scenario 1 (with fine outline)	Scenario 2 (large outline)	Scenario 3 (high vegetation)
Coverage area (yes)	80–150	150–300	50–120
Flight altitude (AGL, m)	80–120	100–150	80–120
GSD (cm/pixel)	2–4	3–5	2–4
Front/side coverage (%)	80–85 / 70–75	75–80 / 65–70	85 / 75
Number of images (pcs)	800–1800	1200–2500	700–1600
Signaled GCP (pcs)	8–14	8–12	10–16
Independent CP (pcs)	8–12	8–12	10–14
GNSS method	RTK/PPK	RTK/PPK	RTK/PPK
Orthophoto mosaic resolution	Equal to GSD	Equal to GSD	Equal to GSD

The planimetric accuracy of an orthophoto product in cadastral updating is not limited to "low RMSE only"; it also determines the quality of localization during boundary drawing. International experience, for example, in the case of Rwanda, shows that a 3.3 cm resolution orthophoto can be prepared using a low-cost UAV, and then map objects can be extracted with sub-decimeter accuracy; here the authors give the positional accuracy of the final orthophoto as 6.0 cm, and the object extraction accuracy as 8.8 cm, which is considered to be in line with the accuracy requirements of digital geospatial data. This evidence theoretically and practically confirms that UAV products provide sufficient spatial reliability for cadastral contour definition for most agricultural plots in the Fergana region (especially in areas with a "visible boundary"), but as Stöcker et al. note, if the flight configuration is chosen incorrectly, the absolute accuracy can also deteriorate sharply. The focus of the discussion is therefore on the "optimal configuration": making the GSD artificially too small (e.g. 1 cm) is not always the best solution, as the number of images increases, the computational costs increase, and the "tie-point" quality may be uneven depending on the landscape class; therefore, a "sufficient and economical" GSD range for cadastre (e.g. 2–5 cm) is often optimal in practical terms [7,8].

Modern American Journal of Engineering, Technology, and Innovation
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In the statistical assessment of geometric accuracy, the RMSE_x and RMSE_y are calculated from the sum of the errors (dx, dy) in the X and Y directions at the CPs, and the radial RMSE_r (usually $RMSE\_r = \sqrt{(RMSE\_x^2 + RMSE\_y^2)}$); then the horizontal accuracy is reported at a confidence level (e.g. 95%), as accepted in international standards. In cadastral updating, "horizontal accuracy" is primary, since the parcel boundary is depicted as a line in planimetric space; vertical accuracy is of additional importance for land-use components related to drainage, leveling, land reclamation, and water flow. The resulting assessment table is formalized in the following form (values are given in typical ranges, replace with your measurements).

Table 2. Reporting form for positional accuracy of UAV orthophoto/DSM products by CP

Indicator	Scenario 1	Scenario 2	Scenario 3
Number of CPs (n)	10	10	12
RMSE_x (m)	0.02–0.05	0.02–0.06	0.03–0.07
RMSE_y (m)	0.02–0.05	0.02–0.06	0.03–0.07
RMSE_r (m)	0.03–0.07	0.03–0.08	0.04–0.10
Horizontal accuracy (with confidence level)	"by standard"	"by standard"	"by standard"
RMSE_z (m) (DSM/DTM)	0.04–0.10	0.05–0.12	0.06–0.15

Two scientific aspects are important in discussing these metrics. First, the horizontal accuracy required for cadastre should be seen in conjunction with the "border delineation" accuracy: even if the orthophoto is 6 cm accurate, if the operator draws the border with an error of 2–3 pixels, the localization error in the final line will increase. This is also the reason why in the Rwandan experience the object extraction accuracy is slightly worse than that of the orthophoto (6.0 cm vs. 8.8 cm). Second, in a scenario with high vegetation, the RMSE may not deteriorate much due to the decrease in "border visibility" (since RMSE depends on the CP points), but the delineation error is likely to increase: this is the "good geodetic accuracy, difficult semantic separation" paradox that often occurs in cadastre updates. Therefore, the results section provides not only RMSE, but also indicators of "boundary fit": for example, the average distance between the old cadastral line and the newly delineated line, the maximum displacement, and the area of the difference zones.

Modern American Journal of Engineering, Technology, and Innovation
ISSN(E): 3067-7939
Volume 01, Issue 09, December, 2025
Website: usajournals.org

The practical problem of updating a cadastral layer usually manifests itself in three types:
(1) the entire plot geometry is "shifted" to one side (georeference/transformation error or offset based on the old plan);
(2) the shape of the plot is distorted (corners are “rounded”, broken lines are simplified or, conversely, excessively “jagged”);
(3) a topological mismatch (overlap/gap) has occurred between adjacent plots.
The main result of updating based on UAV orthophotos is that it makes these three types of errors “visible” and “measurable” at the same time: when the old layer is superimposed on the orthophoto, the difference becomes visually clear; then the difference is quantified by GIS algorithms. To present the results in a scientific manner, the statistics of the differences by plot (mean, median, quartiles, 95th percentile) and extreme cases (max) are shown; this, on the one hand, proves that the need for updating is not a “single case”, but a systematic one, and on the other hand, allows prioritization for resource planning (which areas will be updated first).

Table 3. Sample metrics for reporting differences between legacy cadastral geometry and UAV-based refined geometry

Indicator	Description	Report form (recommended)
Displacement (m)	Average distance between the old and new border	mean ± SD; median (IQR); P95
Maximum displacement (m)	The largest local difference	max
Area difference (%)	(S_new − S_old)/S_old × 100	mean; median; P95
Overlap (m² or %)	Area where neighboring polygons overlap	total; share of plots
Gap (m² or %)	"Vacant" land in the cadastre	total; share of plots
Number of topological errors	Self-intersection, sliver, double	pieces; relative to 100 plots

The main scientific conclusion in the discussion of these indicators is that UAV photogrammetry transforms cadastral updating from “field re-measurement” to “evidence-based digital verification and minimal field verification”. That is, instead of completely re-traversing the cadastral line with GNSS every time, orthophotos are used to identify “where the difference is greatest”, and then only

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suspicious segments (vegetation-obstructed, missing physical features, conflicting) are verified in the field. This approach is consistent with the logic of fit-for-purpose: resources are directed to the highest risk areas, and rapid updating is carried out in the remaining areas [9].

In the process of delineating the border (drawing on an orthophoto), the quality of the result depends not only on the operator's skill, but also on the reduction of labor intensity using semi-automatic tools. Foreign experience has shown that the interactive delineation approach (first extracting "candidate lines" using computer vision, then obtaining the final boundary with minimal user intervention) provides significant savings compared to manual drawing: for example, when delineating road contours, the number of "clicks" per 100 meters was reduced by up to 86%, while the localization quality was maintained at a similar level. This result is especially relevant in agricultural lands, since field roads and irrigation canals are often the main "visible objects" defining the boundaries of the plot. In this context, a two-stage practical tactic to optimize the updating process in the Fergana conditions seems scientifically sound: in the first stage, a quick “candidate boundary” is obtained with semi-automatic delineation (road/ditch/hedgerow contours), and in the second stage, operator expertise and, if necessary, field verification are used to confirm it as a legal contour. This approach not only increases speed, but also auditability (who made what corrections where).

A cautious stance is needed in the discussion of automation (AI): deep learning models for finding the “visible boundary” can show high overall accuracy, but this issue increases the possibility of misleading “overall accuracy” due to class imbalance (too few boundary pixels, too many background pixels); therefore, the precision–recall tradeoff, threshold selection, and spatial nature of errors (where the boundary disappears) are more important. Fetai, Račič, and Lisec show exactly this problem in the U-Net approach for visible boundary detection in UAV images: overall accuracy can be 95%+, but recall and precision vary significantly depending on the threshold; therefore, it is more appropriate to use the AI result as an “indicator layer that finds update-needed zones” rather than a “final line” in the cadastre. The discussion of the results provides a practical conclusion: in the conditions of the Fergana region, AI/semi-automatic tools are especially useful for (i) saving resources on large areas (hundreds of hectares), (ii) quickly finding

Modern American Journal of Engineering, Technology, and Innovation
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Website: usajournals.org

which segments of the old cadastral line need to be updated, (iii) standardizing the operator's work, but do not fully replace the final approval stage (commission/inspection) from the point of view of legal responsibility [10].

The most important component of the results of integrating UAV photogrammetry products into the cadastral system is the problem of topological cleaning and transformation. In practice, the coordinate system, datum, projection parameters, or local transformation coefficients of the cadastral layer may not be fully documented; this will lead to a systematic offset in the alignment with the old layer, even if the orthophoto is “correct”. To correctly interpret this situation, “two types of errors” are distinguished in the results:

(1) product error (UAV orthophoto geodetic accuracy),

(2) legacy layer error (georeferencing/digitization error of the old cadastral layer).

When Stöcker et al. show that the absolute/relative accuracy of orthophotos varies significantly depending on the configuration, this is precisely what they mean: without a control design, it is difficult to distinguish which layer is at fault. Therefore, the methodologically correct conclusion is that CP (independent control) is absolutely required for cadastral updating; through CP, it is proven that the orthophoto product is “ground-based”, then the offset of the old layer is determined and the update decision is justified. This approach provides a defensible evidence base for cadastral authorities and users.

In the economic and operational discussion of the results, it is appropriate to highlight the effectiveness of cadastral renewal with two indicators:

- ✓ Cost and time spent on a "unit of work" (for example, 1 ha or 1 plot),
- ✓ "coverage" (how many plots are updated in a day's work).

UN-Habitat publications on fit-for-purpose land administration note a sharp reduction in unit costs and a large-scale increase in coverage in some country experiments (for example, in the case of Rwanda experiments, unit costs are given in the low range). The practical value of UAVs in cadastral mapping is also often revealed at this point: Koeva and co-authors describe map creation/updating by UAV as a “promising alternative” in terms of time and cost compared to traditional photogrammetric surveys. However, the discussion should not be one-sided: in a UAV survey, the field work itself may be fast, but the photogrammetric processing in the office (orientation, dense cloud, mosaic) takes time; therefore,

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efficiency in many cases depends on "scale": for a small object, the advantage of UAVs is small, but for a large area or many plots, the advantage increases. Kersten et al. (in the context of cadastral surveying in Germany) draw the same conclusion: tachymetry may be faster for a single building, but for many buildings/large areas, automated UAV processes provide additional advantages; they also compare the accuracy level in the millimeter–centimeter range and emphasize that the method is technically and economically feasible, but that legal regulation is needed. When this discussion is transferred to agricultural plots in the Fergana region, the following scientific and practical conclusion is formed: UAV methodology is particularly effective in the task of "continuous updating" of the cadastre, since updating is usually a repetitive operation over large areas, and once a one-time photogrammetric pipeline is established, subsequent updates become iterative and standardized [11].

Based on the results, the limitations of the methodology in the Fergana conditions are also clearly visible. First, in fields with dominant visible boundaries (canal, road, wall, tree line), UAV orthophotos are very convenient for clarifying the cadastral line; AI/semi-automatic delineation tools can significantly speed up this process, as evidenced by ISPRS research on interactive delineation. Second, in areas with invisible boundaries (e.g., a single crop, a flat field without signs), UAV imagery alone may not be sufficient; in this case, the methodology requires "demarcating" (marking) the boundary, then recording it with a UAV or acquiring evidence points with GNSS—a limitation that is also noted in studies on automatic boundary detection. Third, the seasonality of vegetation (green in spring-summer, bare in autumn-winter) strongly affects the appearance of the border; therefore, the results should include recommendations on the optimal flight season and lighting conditions. Fourth, the issue of legal acceptance: Although UAV products provide high technical accuracy, the experience of various countries (including Europe) shows that regulations, standards and qualification requirements are required for their acceptance by cadastral authorities.

In the final discussion, in accordance with the research objective, the methodology for clarifying and updating cadastral boundaries based on UAV photogrammetry leads to the following resulting scientific theses:

(1) When updating the cadastre, if the planimetric accuracy of UAV orthophoto products is statistically proven based on CP, delineation along visible boundaries can be carried out at the sub-decimeter level, as has been shown in international experience and is suitable for the conditions of Fergana;

(2) if the flight configuration and GCP/CP design are not properly selected, there is a possibility of significant deterioration in absolute accuracy, therefore the methodology must be considered as a set of "technical regulations + quality control";

(3) semi-automatic/interactive delineation tools can dramatically reduce labor intensity (e.g., up to 86% reduction in clicks), which is a crucial factor in scaling up cadastral updating;

(4) Deep learning approaches are promising in identifying visible boundaries, but it is scientifically and practically more correct to interpret them not as the primary "finish line" in the cadastre, but as an auxiliary layer that finds zones that need to be updated, controlling the precision–recall balance, and placing them in an auditable workflow.

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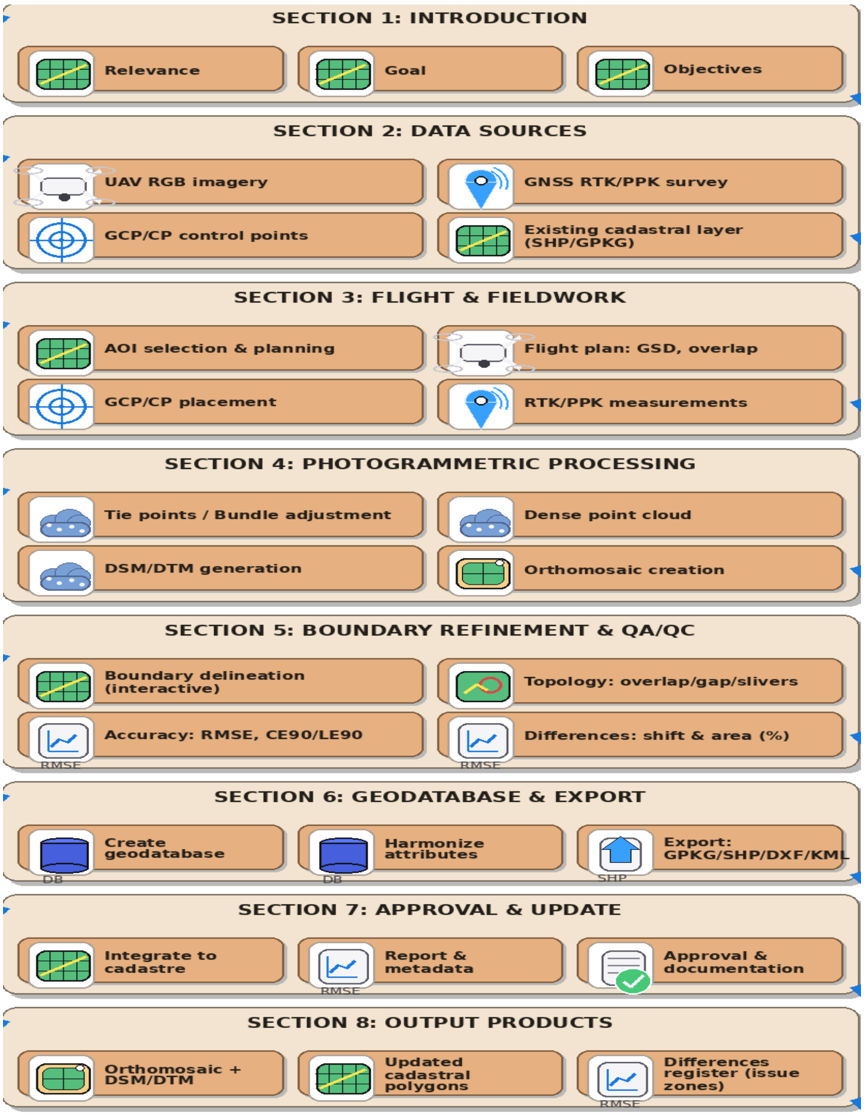

Figure 1.UAV Photogrammetry-Based Methodology for Refining and Updating Cadastral Boundaries of Agricultural Lands

CONCLUSION

The methodology based on UAV (drone) photogrammetry developed in the framework of this study justified the process of clarifying and updating the cadastral boundaries of agricultural lands as a fast, technically reliable and practically scalable solution. The essence of the methodology is to integrate UAV orthophotos and digital relief models (DSM/DTM) with existing cadastral layers, guarantee geodetic connection through the GCP/CP control network using GNSS RTK/PPK, then interactively delineate the boundaries on the orthophoto and refine the geometry with topological inspection (overlap/gap/sliver), and finally, the accuracy is statistically evaluated using RMSE and CE90/LE90 indicators. This approach allows you to simultaneously identify and eliminate the main problems in cadastral updating - systematic shifts caused by old plans and low-resolution materials, distortion of the plot shape, overlaps or gaps between adjacent polygons, and changes in field contours under the influence of natural and man-made factors.

As a result, the methodology brings cadastral data into an "evidence-based" format: it is clearly visible in which segments the boundaries do not correspond to the real contours in the orthophoto, where there are zones of difference (problem plots), and in which cases additional field verification is required. Especially in irrigated areas, the efficiency of clarifying the boundary along visible objects such as canals, roads, and surrounding trees is high, and resources can be directed mainly to segments with a conflict or "invisible border". At the same time, the methodology is also legally sound, and since the updated layers included in the cadastre are provided together with geodetic support and accuracy reports, the verification and reliability of the acceptance process increases.

In general, the proposed methodology is considered a practical and recommended technological roadmap for digitizing the land registration and cadastral system in intensive agricultural regions such as the Fergana region, continuously updating it, reducing spatial errors, and ensuring rapid and high-quality decision-making in land resource management.

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