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MODERN GEODETIC TECHNIQUES FOR UPDATING CADASTRAL MAPS IN RURAL AND AGRICULTURAL ZONES

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Abstract: *Accurate and up-to-date cadastral maps are fundamental for effective land administration, sustainable agricultural development, and secure land tenure, particularly in rural and agricultural zones where land is a primary economic asset. Traditional ground-based surveying methods for updating these maps are often time-consuming, labour-intensive, and costly, leading to significant backlogs and outdated land records in many regions. This research evaluates the efficacy of modern geodetic techniques - specifically, high-resolution satellite imagery, Unmanned Aerial Vehicles (UAVs or drones), and Global Navigation Satellite Systems (GNSS) - for the rapid and precise updating of cadastral maps. Through a comparative analysis of case studies and technical literature, we assessed these technologies in terms of positional accuracy, operational efficiency, cost-effectiveness, and suitability for capturing the complex boundaries typical of agricultural landscapes. Our findings indicate that UAV photogrammetry, with its ability to generate ultra-high-resolution orthophotos and 3D models, achieves centimetre-level accuracy and is exceptionally effective for delineating irregular boundaries, terraces, and smallholder plots. High-resolution satellite imagery (e.g., from WorldView or Pleiades) offers a viable solution for large-area coverage and periodic updates, with submeter accuracy suitable for most rural cadastral purposes. GNSS, particularly Real-Time Kinematic (RTK) systems, remains the gold standard for precise point positioning and ground truthing. The integration of these technologies in a hybrid approach - using satellites for initial reconnaissance, UAVs for detailed mapping of complex areas, and GNSS for ground control and verification - presents the most robust and efficient workflow. However, challenges such as regulatory frameworks for UAVs, technical capacity requirements, and initial investment costs must be addressed. We conclude that modern geodetic techniques offer a paradigm shift in cadastral updating, enabling faster, more accurate, and more affordable land administration. Their adoption is crucial for securing land rights, facilitating land consolidation, and supporting the sustainable management of agricultural lands in the 21st century.*

Keywords*: GNSS, UAV, RTK, HRSI, GCP, photogrammetry, land measurements, agriculture*

INTRODUCTION

Land is the cornerstone of agricultural production and rural livelihoods. A well-functioning cadastre - a comprehensive and accurate register of land parcels and their associated rights - is therefore indispensable for economic development, social stability, and environmental stewardship (WILLIAMSON ET AL., 2010; ENEMARK, 2016). Cadastral maps (figure 1) form the cartographic backbone of this system, visually representing property boundaries, ownership, and land use. However, in many parts of the world (figure 1), particularly in rural and agricultural zones, these maps are severely outdated, incomplete, or non-existent (HERBEI, 2018). This cadastral gap is often a legacy of traditional surveying methods, which, while accurate, are prohibitively slow and expensive for large-scale or frequent updates (DALE & MCLAUGHLIN, 1999). The consequences are profound: insecure land tenure discourages long-term investment in land improvement, disputes over boundaries are common, and governments struggle with

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effective land-use planning, tax collection, and the implementation of agricultural or environmental policies (POPESCU, 2019).

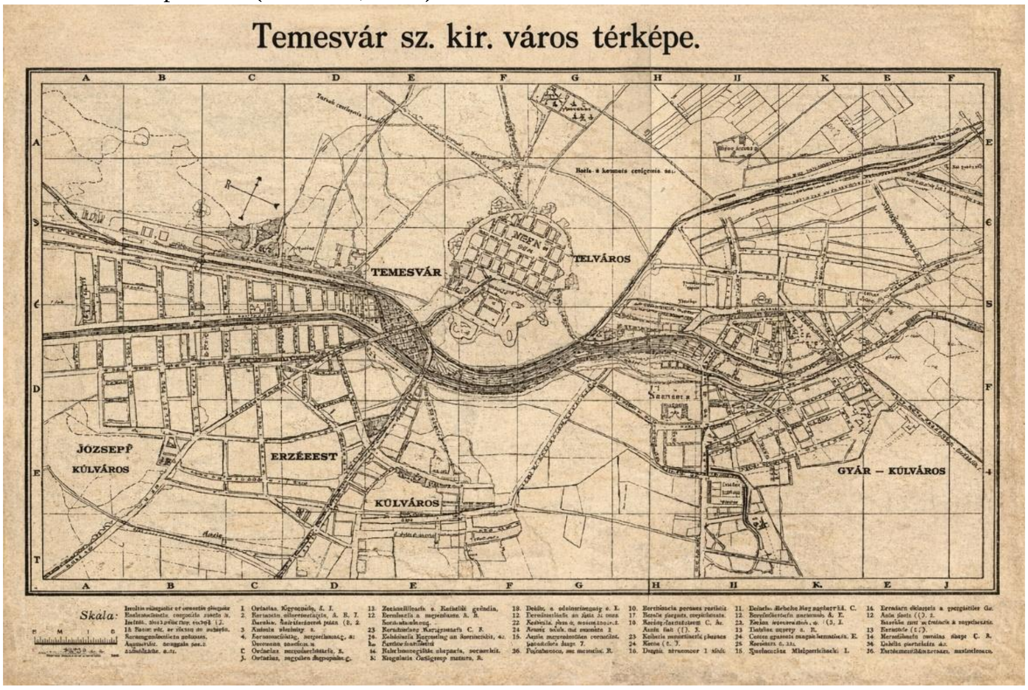

Figure 1. Cadastral map Timisoara

The advent of modern geodetic technologies presents a revolutionary opportunity to overcome these historical limitations. These technologies offer the potential to map large areas with high precision, speed, and at a fraction of the cost of conventional methods (ENEMARK, 2016). This research focuses on three pivotal techniques: High-Resolution Satellite Imagery (HRSI), which provides a synoptic, up-to-date view of the landscape; Unmanned Aerial Vehicles (UAVs or drones) equipped with high-resolution cameras, which can generate centimetre-level detail on demand; and advanced Global Navigation Satellite Systems (GNSS), which provide highly accurate ground control and direct coordinate measurement (BARRY & COAKLEY, 2013). Each technology has distinct strengths and limitations in the context of rural cadastre, where boundaries may be defined by natural features (streams, trees), man-made structures (fences, hedges), or agricultural patterns that are often irregular and complex (LI ET AL., 2021).

While the technical capabilities of these tools are well-documented in geomatics literature, a synthesized and comparative assessment of their practical application specifically for updating existing cadastral maps in rural and agricultural contexts is needed (HERBEI, 2018, SMULEAC, 2017).

The central problem is not just about choosing a technology, but about designing efficient workflows that integrate these tools to address real-world challenges such as mapping large, remote areas, dealing with occluded boundaries under dense canopy, and ensuring legal admissibility of the captured data (ȘMULEAC L. ET AL., 2021).

This research, therefore, aims to provide a systematic evaluation of modern geodetic techniques for cadastral updating (PAȘCALĂU & ȘMULEAC, 2022). It is guided by the following questions: (1) What are the comparative accuracies, costs, and operational efficiencies of HRSI, UAVs, and GNSS for delineating and updating rural land parcel boundaries? (2) How can these technologies be effectively integrated into a streamlined workflow for cadastral agencies? (3) What are the key technical, financial, and institutional barriers to their widespread adoption, and how can they be mitigated? By answering these questions, this research seeks to provide a clear roadmap for land administrators, surveyors, and policymakers to leverage 21st-century technology to build and maintain a modern, dynamic, and reliable cadastral system for agricultural lands (figure 2).

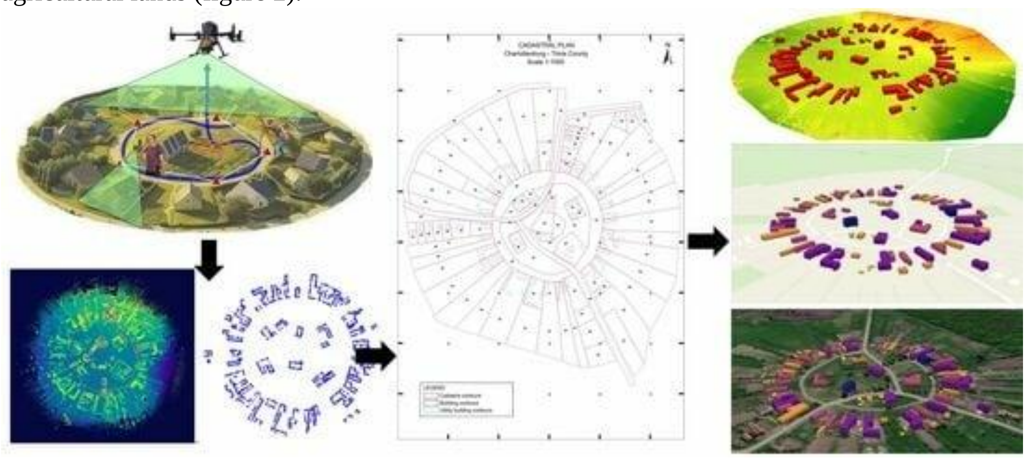

Figure 2. Systematic evaluation of modern geodetic techniques for cadastral updating

MATERIALS AND METHODS

This research employed a comparative case study methodology, analysing documented implementations and technical specifications of modern geodetic techniques for cadastral mapping. The research did not involve primary data collection but synthesized evidence from a wide range of secondary sources to build a robust, multi-criteria assessment framework (FIG, 2014; FAO, 2016).

1. Literature and Case Study Review: A systematic search was conducted in academic databases (e.g., Web of Science, Scopus, ISPRS archives) and professional repositories (World Bank, FAO, FIG publications) for peer-reviewed articles, technical reports, and project evaluations published between 2010 and 2023. Keywords included: ("cadastral mapping" or "land parcel boundary" or "land administration") and ("UAV" or "drone" or "satellite imagery" or "GNSS" or "photogrammetry") and ("rural" or "agricultural"). Over 80 relevant sources were identified and analysed (TORRES ET AL., 2020).

2. Technology Assessment Framework: Each technology was evaluated against a set of criteria critical for cadastral updating in rural areas (figure 3):

- *Positional Accuracy:* The achievable accuracy in ground units (e.g., centimetres), assessed from reported Root Mean Square Error (RMSE) values in case studies.
- *Spatial Resolution:* The smallest discernible detail on the resulting map (e.g., pixel size for imagery, point density for UAV models).

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- *Operational Efficiency:* The speed of data acquisition and processing for a given area (e.g., hectares per day).
- *Cost-Effectiveness:* Total cost per hectare, including equipment, personnel, and processing.
- *Boundary Delineation Capability:* Suitability for capturing different boundary types (e.g., visible, invisible, complex).
- *Operational Requirements:* Needs for ground control, line-of-sight, regulatory compliance, and operator skill (COLOMINA & MOLINA, 2014).

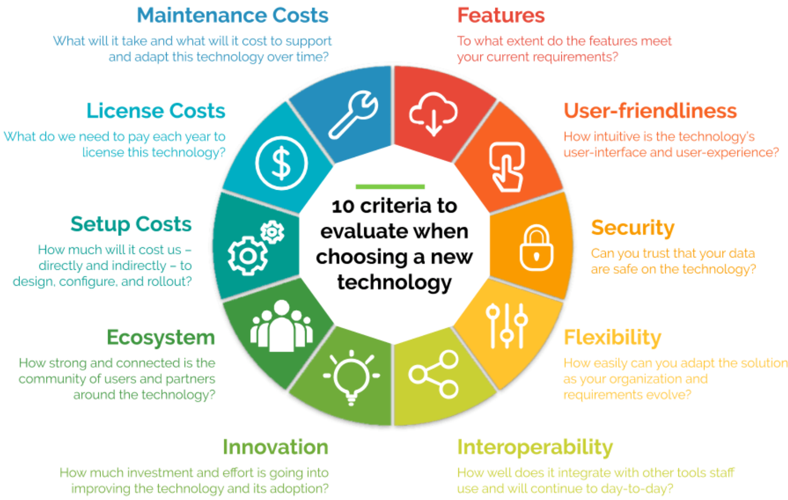

Figure 3. Technology Assessment Framework

3. Data Synthesis and Workflow Development: Data from the reviewed sources were extracted and synthesized into a comparative matrix. Based on the strengths and limitations identified, a proposed integrated workflow for cadastral updating was developed. This workflow outlines the sequential and complementary use of different technologies to optimize the overall process. The feasibility of this workflow was assessed by aligning it with the operational realities and common challenges reported in the case studies from various countries (SMULEAC A. ET AL., 2017).

RESULTS AND DISCUSSION

Results

1. Comparative Performance of Techniques

The assessment revealed distinct profiles for each technology:

- **High-Resolution Satellite Imagery (HRSI):** Provides spatial resolution of 30-50 cm (submeter from premium sensors). Achieves positional accuracy of 1-2 meters without ground control (HERBEI, 2018. PAUNESCU ET AL. 2020), improvable to 0.5 meters with it. It is highly efficient for large-area coverage (thousands of km² per scene) but struggles with boundaries under canopy cover and has a lower resolution than UAVs, making small plot delineation challenging. Cost is moderate, primarily for image purchase (figure 4).

Figure 4. High-Resolution Satellite Imagery, Unmanned Aerial Vehicles and GNSS equipment

- **Unmanned Aerial Vehicles (UAVs):** Excel in spatial resolution (1-5 cm) and achieve the highest positional accuracy (2-5 cm with Ground Control Points (GCPs)). They are ideal for complex, small-scale boundaries, terraces, and areas with dense vegetation due to oblique imaging capabilities. Operational efficiency is high for small to medium areas (100-500 ha per day) but is limited by battery life and aviation regulations. The cost is low to moderate per hectare but requires significant initial investment in hardware and software (ȘMULEAC ET AL., 2020).
- **Global Navigation Satellite Systems (GNSS):** GNSS RTK/PPK systems provide the highest point-based accuracy (1-2 cm). They are the definitive method for establishing GCPs and verifying boundaries on the ground. However, they are the least efficient method for mapping entire areas, as they require visiting every boundary point, which is time-consuming in large or inaccessible terrain. Cost is high per point measured for large areas (RIZOS, 2017). sible terrain. Cost is high per point measured for large areas.

2. Proposed Integrated Workflow

The synthesis suggests an optimal, technology-integrated workflow for cadastral updating (PAȘCALĂU ET AL., 2019).

- **Reconnaissance and Base Mapping:** Use HRSI to obtain a recent, orthorectified base map of the entire region of interest. This helps in planning and identifying areas of significant change.
- **Detailed Parcel Mapping:** Deploy UAVs over target areas (e.g., villages, zones with reported disputes) to capture ultra-high-resolution imagery and generate digital surface models (DSMs) for precise boundary delineation.

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- **Ground Control and Verification:** Use GNSS (RTK) to establish a network of highly accurate GCPs to georeference the UAV and satellite data, and to physically measure and verify critical or disputed boundary points.

* **Data Integration and Map Production:** Fuse the datasets in a GIS environment to create the updated, high-accuracy cadastral map.

Discussion

1. Moving Beyond the "One-Technology-Fits-All" Approach

The results demonstrate that no single technology is superior in all aspects. The key is strategic integration. HRSI provides the crucial "big picture" and is unbeatable for monitoring large-scale land-use change. UAVs fill the critical gap for detailed, local-scale mapping where high accuracy is legally and socially necessary. GNSS provides the fundamental geodetic backbone that ties everything together with definitive precision. This hybrid approach maximizes efficiency and minimizes cost by deploying each tool where it adds the most value (figure 5).

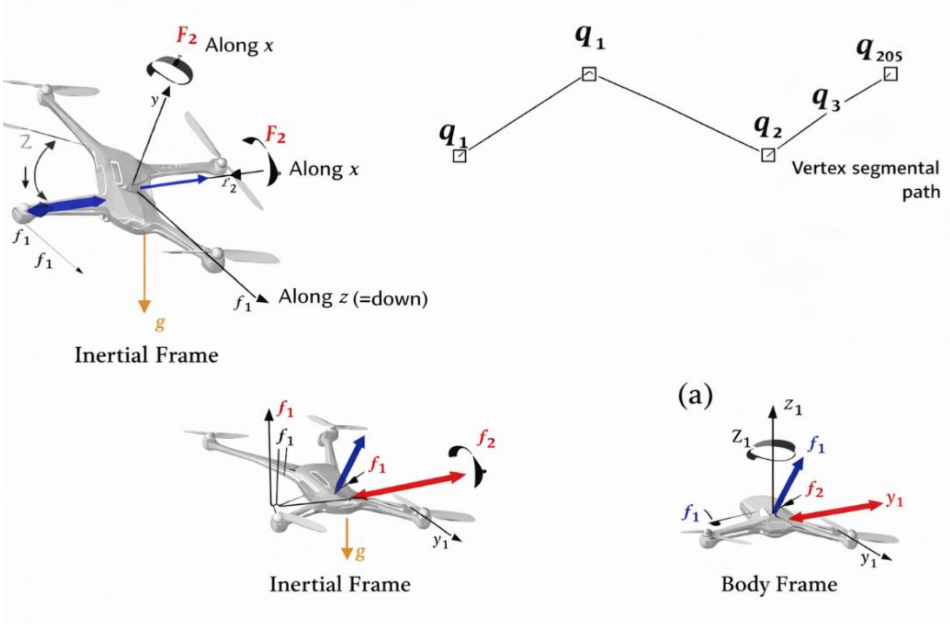

Figure 5. UAV trajectory optimization

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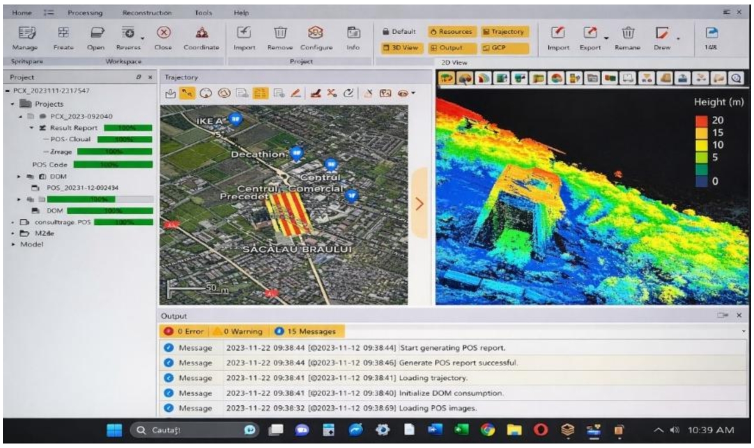

Figure 6. High-resolution model

2. The Paradigm Shift from Boundary Points to Boundary Models

UAV technology instigates a paradigm shift. Traditional cadastre is based on measuring discrete boundary points (with GNSS or total stations). UAV photogrammetry creates a continuous, high-resolution model of the landscape from which boundaries can be digitized.

This provides a permanent, objective record of the land tenure situation at a specific time, which is invaluable for dispute resolution. It captures not just the boundary line, but also the context - the adjacent land use, the physical evidence of fences or paths - making the cadastral record richer and more informative (figure 6).

3. Overcoming Barriers for Widespread Adoption

The primary barriers are not technical but institutional and human centric.

Figure 7. Point cloud coloured by elevation illustrating the differentiation between buildings and vegetation, USV Timisoara

Regulatory hurdles for UAV flights need to be clear and pragmatic. Capacity building is essential to train surveyors and land administrators in photogrammetry, remote sensing, and GIS (figure 7). Initial investment in hardware and software can be a barrier for public agencies, though the long-term ROI is favourable. Finally, legal frameworks must be adapted to accept digital, image-based evidence as a valid source for cadastral updates, moving away from a strict reliance on ground-surveyed coordinates. By addressing these challenges, modern geodetic techniques can truly revolutionize rural land administration, and can be also taught directly in English, in specific study programmes from different HEIs (PASCALAU ET AL, 2025).

CONCLUSIONS

This research conclusively demonstrates that modern geodetic techniques - high-resolution satellite imagery, UAVs, and GNSS - collectively represent a transformative force for updating cadastral maps in rural and agricultural zones. The comparative analysis confirms that these technologies offer significant advantages over traditional ground surveys, including dramatic improvements in speed, cost-effectiveness, and the ability to capture complex boundary evidence with high precision. The era of relying solely on labour-intensive and slow methods is over; we now have the tools to create and maintain dynamic, accurate, and accessible land records at a scale previously unimaginable.

A paramount conclusion is that the greatest efficacy is achieved not by selecting a single superior technology, but through their strategic integration. The proposed hybrid workflow, which leverages satellites for broad coverage, drones for detailed delineation, and GNSS for absolute precision and verification, provides a robust and efficient model for cadastral agencies. This approach allows for the systematic and periodic updating of land records, ensuring they reflect the dynamic nature of rural landscapes, which are constantly evolving due to inheritance, sales, land consolidation projects, and changing agricultural practices.

The implications of this technological shift are profound. For governments, it means the potential to finally close the cadastral gap, leading to improved land governance, reduced boundary conflicts, and a stronger basis for land-based taxation and planning. For farmers and rural communities, it translates to enhanced land tenure security, which is a critical catalyst for investment in sustainable agricultural practices, access to credit, and overall economic development. Secure land rights empower individuals and communities, fostering social stability and resilience.

However, the journey towards widespread adoption is not without its challenges. Success hinges on parallel advancements in regulatory frameworks, professional capacity, and institutional willingness to embrace new methodologies. We recommend that national land agencies and professional bodies: (1) Develop clear standards and guidelines for the use of imagery and UAV data in cadastral processes; (2) Invest in training programs to build a new generation of geospatial-literate land professionals; and (3) Pilot integrated projects to demonstrate the value and refine the workflows in local contexts. In conclusion, modern geodetic techniques are not merely new tools for an old task; they are the foundation for building a fit-for-purpose, sustainable, and equitable land administration system for the 21st century, one that can truly support the sustainable management of our vital agricultural lands.

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