

USING HIGH-RESOLUTION ORTHOIMAGE FOR UPDATING AND OVERLAYING AGRICULTURAL CANAL GEOSPATIAL DATA

UTILISATION D'ORTHOIMAGES À HAUTE RÉOLUTION POUR METTRE À JOUR ET SUPERPOSER LES DONNÉES GÉOSPATIALES DES CANAUX AGRICOLES

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ABSTRACT

Since the 1990s, the Irrigation Agency in Taiwan has developed GIS maps for agricultural canals. However, early GPS interference and low-resolution aerial imagery caused significant positioning errors between GIS cadastral maps and actual facility locations. To address this, modern Unmanned Aerial Vehicles (UAVs) are utilized to generate high-resolution orthoimages, enabling the correction of route alignments and canal hierarchy relationships in GIS maps.

A crucial application of these updates is supporting the policy of "compensation for the continued use of agricultural facilities land use". UAV high-resolution orthoimages allow the conversion of old data from a polyline format to a polygon format, accurately reflecting the actual width and flow direction of the canals. Once established, this foundational data is overlaid and cross-referenced with cadastral maps and land ownership registries. This generates an accurate inventory of occupied land areas, lot numbers, and ownership details, serving as the basis for official boundary surveys and formal compensation.

Producing 1,000-hectare orthoimages with a Ground Sampling Distance (GSD) of approximately 5 cm takes only about 4 days, demonstrating the rapid acquisition of current-state data. This comprehensive inventory allows management to prioritize compensation based on land use zoning, ownership, and announced land values. Consequently, funds can be raised and compensation plans formulated in advance, thereby accelerating and effectively implementing the continued use policy.

Keywords: Agricultural canals; Unmanned Aerial Vehicles (UAVs); Inventaire précis; High-resolution orthoimages; Land values.

RÉSUMÉ

Depuis les années 1990, l'Agence de l'irrigation de Taïwan élabore des cartes SIG des canaux agricoles. Toutefois, les perturbations affectant les premiers systèmes GPS et la faible résolution des images aériennes ont entraîné d'importantes erreurs de positionnement entre les plans cadastraux du SIG et l'emplacement réel des ouvrages. Pour remédier à ce problème, des véhicules aériens sans pilote (UAV) modernes sont utilisés afin de produire des orthoimages à haute résolution, permettant de corriger l'alignement des tracés et les relations hiérarchiques entre les canaux dans les cartes SIG.

L'une des principales applications de ces mises à jour consiste à soutenir la politique d'« indemnisation pour la poursuite de l'utilisation des terrains occupés par les ouvrages agricoles ». Les orthoimages à haute résolution acquises par UAV permettent de convertir les anciennes données d'un format polyligne en un format polygonal, afin de représenter avec précision la largeur réelle et le sens d'écoulement des canaux. Une fois constituées, ces données de référence sont superposées et recoupées avec les plans cadastraux et les registres de propriété foncière. Elles permettent de dresser un inventaire précis des superficies occupées, des numéros de parcelles et des informations relatives aux propriétaires, qui sert de base aux levés officiels des limites et aux procédures formelles d'indemnisation.

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La production d'orthoimages couvrant 1 000 hectares, avec une distance d'échantillonnage au sol (GSD) d'environ 5 cm, ne prend qu'environ 4 jours, ce qui démontre la rapidité d'acquisition des données sur l'état actuel. Cet inventaire complet permet aux gestionnaires de hiérarchiser les indemnisations en fonction du zonage de l'utilisation des sols, du régime de propriété et des valeurs foncières publiées. Les fonds peuvent ainsi être mobilisés et les plans d'indemnisation préparés à l'avance, ce qui accélère et facilite la mise en œuvre effective de la politique de poursuite de l'utilisation.

Mots clés : Canaux agricoles; Véhicules aériens sans pilote (UAV); Inventaire précis; Orthoimages à haute résolution; Valeurs foncières.

INTRODUCTION

Agricultural canals are the lifeline ensuring smooth irrigation and drainage for farmlands. To improve irrigation management efficiency, Taiwan has actively integrated spatial data of agricultural irrigation and drainage canals, as well as hydraulic structures, into Geographic Information Systems (GIS) since the 1990s. However, early digitization efforts heavily relied on handheld PDAs paired with early GPS for on-site track tracing. Constrained by the U.S. military's "Selective Availability (SA)" signal interference at the time, positioning errors often reached several meters or even over ten meters. Coupled with the long update cycles and insufficient resolution of publicly available aerial photos back then, frequent discrepancies and offsets have occurred between historical GIS maps and the actual canal locations and shapes.

With the rapid development of Unmanned Aerial Vehicles (UAVs) and the subsequent high-precision optical sensing technologies and aerial triangulation measurement software, acquiring high-precision, large-area, and timely spatial information has become feasible. In terms of land administration and agricultural resource integration, numerous domestic and international studies have utilized UAV advantages for practical applications. In international research, UAV-generated orthoimages have proven effective in agricultural land consolidation and management. By comparing image results with modern Global Navigation Satellite System (GNSS RTK) measurements, their high geometric accuracy not only reduces the time and cost of traditional field surveys but also provides an objective and transparent spatial data foundation for land valuation and boundary demarcation (ResearchGate / MDPI, 2024).

In terms of local technical verification and legal promotion in Taiwan, pilot studies have focused on using modern high-resolution UAV orthoimages to optimize large-scale canal and attribute data from the historical GIS maps of the Hsinchu Management Office. Using the Zhudong and Ruanqiao irrigation districts as empirical cases, the research successfully corrected numerous line offsets caused by historical positioning errors and reorganized the hierarchical relationships of the canals, laying a solid practical and technical foundation for the application of UAV technology in updating the spatial information of grassroots farmland hydraulic facilities (Lin et al., 2023). Subsequently, addressing the "compensation for the continued use of agricultural facilities land use" policy continuously promoted by the Irrigation Agency, scholars used the Guandu Plain as a practical case. They verified that low-altitude UAVs could produce high-resolution orthoimages with a Ground Sampling Distance (GSD) of 5 cm in a short time. By digitizing canals into high-precision polygon format maps and overlaying them with cadastral data, they efficiently produced occupation inventories, serving as a critical administrative planning basis for prioritizing compensation and raising funds (Hung, 2024).

The purpose of this study is to integrate UAV high-resolution orthoimage production technology with the practical management policies of grassroots farmland hydraulic facilities. Through spatial data updating and overlay analysis, this study resolves the long-standing issues of inaccurate canal positions and mismatched widths. Furthermore, it applies these solutions to the "compensation for the continued use of agricultural facilities land use" policy, establishing a standard operating procedure from image acquisition to legal compensation inventory.

METHODOLOGY

To overcome the geometric offsets in historical spatial maps of irrigation canals and precisely implement the administrative requirements for continued use land compensation, this study established a spatial legal analysis framework that deeply integrates high-precision UAV mapping with cadastral spatial overlay (as shown in Figure 1). The core objective of this methodology is to gradually transform purely spatial geometric data into a statutory inventory valuable for administrative decision-making and budget planning.

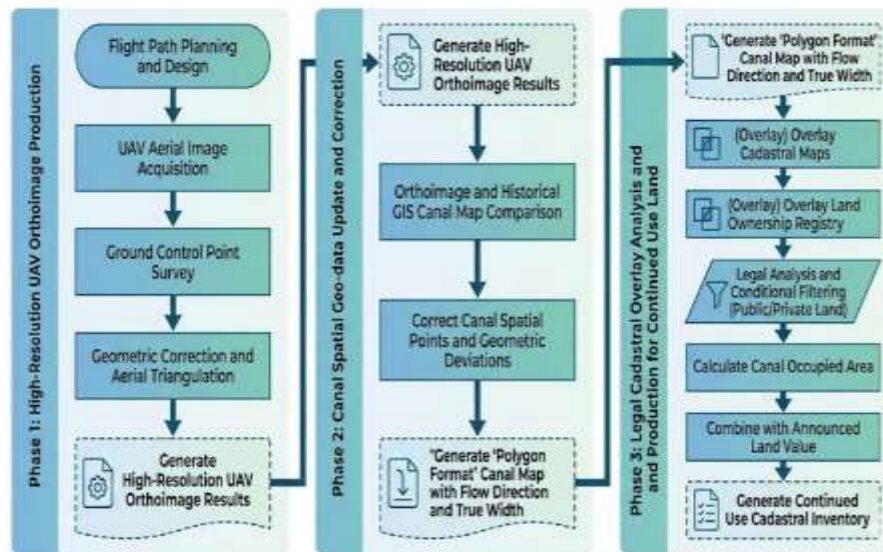


Figure 1. Research architectural flowchart

The overall technical and practical workflow is primarily divided into three core stages. First, large-area aerial photography is conducted using UAVs equipped with high-resolution optical sensors, and new-generation photogrammetry software is utilized for aerial triangulation and geometric correction to produce highly timely, high-resolution orthoimages. Second, using orthoimages as precise base maps, the topological structures and route alignments of traditional GIS canals are corrected, and the canal maps, which previously could not reflect true widths in polyline format, are fully digitized and upgraded to polygon format. The third stage involves performing spatial overlay analysis between these canal polygons and the latest legal cadastral maps and land ownership registries. This crosses technical and regulatory boundaries to automatically inventory the lists, lot numbers, and ownership relationships of private lands occupied by canals, and combines announced land values to rate the priority of phased compensation.

Study Area and UAV Image Acquisition

This study conducted UAV aerial photography over a large-scale agricultural irrigation area (based on a 5,000-hectare scale). A highly mobile multi-rotor UAV, capable of avoiding cloud interference and equipped with a high-resolution sensor (as shown in Figure 2), was selected. To ensure the accuracy of subsequent canal digitization and cadastral overlay, ground control point measurements were planned and co-measured with national control points. The distribution of control points is shown in Figure 3, and the actual measurement of control points is shown in Figure 4. Newly established control points mostly used existing on-site features like road markings and parking spaces, evenly distributed across the survey area, as shown in Figure 5. The expected mapping Ground Sampling Distance (GSD) was set to approximately 5 cm. The entire aerial photography and data processing operation could be rapidly completed in about 4 days.



Figure 2. Multi-rotor UAV equipped with a high-resolution sensor



Figure 3. Distribution of national control points



Figure 4. National control point surveying



Figure 5. Newly established control points surveying

Orthoimage Production and Canal Correction Methods

Utilizing the new-generation professional optical measurement and photogrammetry stitching software, Pix4Dmatic (Pix4D SA, 2023), high-speed aerial triangulation calculations and geometric corrections were performed on thousands of highly overlapping aerial photographs. This software boasts excellent processing efficiency for large-scale UAV mapping and precise cartography, stably producing large-area, high-resolution orthoimages and Digital Surface Models (DSM).

Using the high-resolution orthoimages as base maps, they were compared with existing GIS canal maps. The line offsets caused by early GNSS errors were corrected, and the hierarchical relationships of the canals (such as main canals, branch canals, lateral canals, and farm ditches) were reviewed and adjusted.

Canal Polygon Digitization and Cadastral Overlay Analysis

In the past, canal maps were mostly presented in polyline format, representing only the centerlines or general directions of the canals, which could not reflect the true widths and occupied areas of the canals.

Based on the 5 cm resolution orthoimages, the true boundaries of the retaining walls on both sides of the canals were manually digitized. The canal maps were comprehensively upgraded to polygon format, and details such as actual canal width, flow direction, and facility type were meticulously recorded in the attribute tables.

The digitized canal polygon layers were subjected to Spatial Overlay analysis with the latest legal cadastral maps and land ownership registries (including landowners, land categories, and announced land values) provided by land administration authorities.

RESULTS AND DISCUSSION

Large-Area High-Efficiency Map Updating

The research results indicate that producing high-resolution orthoimages using UAVs exhibits extremely high temporal and spatial efficiency. The latest current-state data for 5,000 hectares of farmland can be obtained in just 4 days, eliminating the traditional manual field surveys that previously took months. More importantly, the 5 cm GSD imagery can clearly identify field farm ditches only tens of centimeters wide. The detailed results are shown in Figure 6. Correcting canal maps based on the current conditions captured in the orthoimages has significantly enhanced the internal management unit's capability to rectify discrepancies between the canal maps and actual conditions as shown in Figure 7. Finally, all corrected canal maps with their GIS attributes are precisely positioning on the orthoimage as shown in Figure 8.



Figure 6. Detailed results of UAV-generated orthoimages



Figure 7. Canal map correction (error digitation on farm)



Figure 8. Orthoimage overlaid with canal map

Effectiveness of Continued Use Occupied Land Inventory

The core practical contribution of this study is the application of the corrected canal polygon layers to the compensation policy for the "continued use" of agricultural facilities land. Through GIS spatial overlay, the system can automatically cross-reference and produce a highly accurate land occupation inventory. This inventory clearly records: (1) Occupied area, which is the precise geometric area of public and private land actually crossed and occupied by the canal; (2) Lot numbers and ownership, clearly indicating the affected land lot numbers, distinguishing between public or private lands, and identifying different land owners; (3) Compensation priority rating, combining land use zoning and announced land values from cadastral data, enabling the management office to scientifically evaluate compensation priorities under limited budgets.

In the practical workflow, the system uses the canal polygon layers—which possess high geometric accuracy and width information—alongside cadastral maps rich with ownership and demarcation details, to perform multi-factor calculations using Geographic Information System (GIS) Spatial Intersect Overlay technology. This method automatically extracts the physical land areas crossed and used by specific canals, thereby generating the continued use inventory list.

To verify the spatial accuracy and administrative practicality of this technical framework, this study conducted an empirical analysis using the Zhoumei Canal irrigation district in the Beitou District of Taipei City as a typical case. In the overall spatial analysis procedure, an accurate base of on-site features must first be established. This study adopted the high-resolution orthoimages produced by UAVs as the foundation for spatial geometry. On this image base, researchers conducted detailed digitization based on the clearly distinguishable canal retaining wall features in the images, thereby constructing canal polygon layers with actual physical widths (as shown in Figure 9). This completely replaces the traditional polyline maps that lacked width information and could not reflect the true occupied areas.



Figure 9. Polygon digitization results according to the actual width of the canal

Once the geometric boundaries of the canals are clear, the spatial data must be aligned with non-spatial legal property rights relationships. This study concurrently linked the legal cadastral maps and land ownership data provided by land administration authorities within the system via Relational Database Linkage, fully activating the attribute data of the cadastral maps. Subsequently, a spatial intersection overlay was performed between the polygonized canal layers and the activated property cadastral maps as shown in Figure 10. Utilizing the GIS geometric engine's intersection calculation, the precise intersection areas of private lands occupied by the canals were automatically segmented and extracted. The key to this step is that the segmented geometric figures can automatically inherit core administrative attributes such as the corresponding parcel lot numbers, owners, and land use zoning.



Figure 10. Spatial overlay analysis of the occupied extent

Finally, the system's geometric engine automatically calculates the physical area occupied by the canal within each land lot, thereby quantifying a precise continued use area. Through this automated procedure, management units can generate a spatial decision-making inventory with a single click, containing key fields such as lot numbers, occupied areas, landowner lists, and announced current values. This empirical analysis result breaks the traditional dilemma where grassroots management units had to blindly apply for on-site boundary surveys from land administration authorities, which was time-consuming and involved high administrative costs. With the occupation inventory automatically generated by this spatial model, management offices can accurately grasp the geometric areas of land occupation and the ratio of public to private ownership early in the policy implementation stage, thereby scientifically evaluating compensation priorities combined with announced values.

This result breaks the past predicament of having to blindly apply for time-consuming and expensive land boundary surveys from land administration authorities. Management offices can now conduct an inventory first and survey later, significantly shortening the administrative process.

Application in Policy Promotion and Budget Raising

Through the generated occupation inventory, various farmland hydraulic management offices can accurately estimate the total compensation quota required for the area during the initial stages of policy promotion. This allows the management office to "raise funds in advance" and "formulate phased compensation plans early," avoiding the awkward situation of policy stagnation due to insufficient budgets, and significantly accelerating the overall administrative efficiency of land legalization and expropriation compensation.

CONCLUSION

This study successfully demonstrates a complete paradigm of deeply integrating technological innovation (UAV high-resolution orthoimages) with practical government policies (land compensation for continued use). Through the high efficiency and high spatial resolution of UAVs, not only were the geometric and hierarchical errors of historical GIS canal maps resolved, but purely spatial geographic data was transformed into an administrative decision-making basis with legal and economic value via the conversion from polyline format to polygon format and cadastral spatial overlay analysis technology. This workflow, starting from image production, proceeding through canal correction and cadastral overlay analysis, and connecting to administrative measures like inventory generation and budget planning, has proven effective in implementing the land compensation policy for farmland hydraulic facilities, providing an excellent reference model for future smart farmland hydraulic management and land administration.

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