

DESIGN OF A MAPPING DRONE FOR AGRICULTURAL DIGITALIZATION AND IRRIGATION FOR INDONESIAN FARMERS IN THE MOUNTAINS OF THAILAND

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Article Info

Article History:

Received July 31, 2026

Revised August 30, 2026

Accepted September 20, 2026

Keywords:

drone mapping,
agricultural digitalization,
mountain,
irrigation,

ABSTRAK

Topografi wilayah pegunungan di Thailand menyajikan tantangan geografis yang signifikan bagi para petani WNI, khususnya dalam pengelolaan distribusi air irigasi serta penentuan area tanam yang efisien. Rancang bangun drone pemetaan ini bertujuan untuk merancang dan membangun drone pemetaan sebagai solusi yang mendukung digitalisasi pertanian lokal WNI di pegunungan Thailand. Drone dioperasikan untuk terbang sesuai rute dalam mengambil citra udara di area lahan pertanian. Gambar-gambar hasil pemotretan tersebut kemudian diproses menggunakan perangkat lunak photogrammetry dan Geographic Information System (GIS) untuk menghasilkan peta kontur topografi serta pemetaan jalur distribusi air. Hasil analisis peta membantu petani mengidentifikasi tingkat kemiringan lahan dan merencanakan arah aliran irigasi berbasis gravitasi secara presisi. Implementasi teknologi ini terbukti meningkatkan efisiensi tata kelola air, meminimalkan risiko erosi, dan mengoptimalkan pembagian area tanam. Secara keseluruhan, integrasi drone pemetaan telah menjadi pendekatan tepat guna yang adaptif, efektif, serta mudah dipahami oleh masyarakat petani WNI di wilayah pegunungan Thailand.

ABSTRACT

The mountainous topography of Thailand presents significant geographic challenges for Indonesian farmers, particularly in managing irrigation water distribution and determining efficient planting areas. This drone mapping project aims to design and build a mapping drone as a solution to support the digitalization of local Indonesian agriculture in mountainous Thailand. The drone is operated to fly along a route to capture aerial imagery of agricultural land. The resulting images are then processed using photogrammetry and Geographic Information System (GIS) software to produce topographic contour maps and water distribution routes. The resulting map analysis helps farmers identify land slopes and precisely plan gravity-based irrigation flow directions. The implementation of this technology has been proven to improve water management efficiency, minimize erosion risks, and optimize planting area allocation. Overall, the integration of drone mapping has been an appropriate approach that is adaptive, effective, and easily understood by Indonesian farmers in mountainous Thailand.

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How to cite: Marji, M., Nurmallasari, R., & Marzan, J. N. T. (2026). DESIGN OF A MAPPING DRONE FOR AGRICULTURAL DIGITALIZATION AND IRRIGATION FOR INDONESIAN FARMERS IN THE MOUNTAINS OF THAILAND. *Devote: Jurnal Pengabdian Masyarakat Global*, 5(3), 485–490. <https://doi.org/10.55681/devote.v5i3.7042>

INTRODUCTION

The geographical location, climate conditions, and fertile land in Thailand make the agricultural sector the spearhead of the country's economy. Almost the entire territory of Thailand can be utilized for agricultural or plantation land, including mountainous regions (Shen et al., 2010). Indonesian citizens (WNI) who work as farmers in Thailand also utilize this agricultural potential as a source of livelihood. Many Indonesian farmers farm or cultivate horticultural commodities in the mountainous regions of Thailand (Mohammed et al., 2025). While working as farmers in Thailand, these citizens are sheltered by the Indonesian Farmers Union in Thailand.

Indonesian farmers in the mountains of Thailand are often faced with several challenges related to limited information on the spatial distribution of plantable land, up-and-down hilly agricultural terrain, and suboptimal irrigation systems. The geographical conditions in the mountains cause many agricultural locations to be difficult to reach and result in inefficient irrigation systems (Arshad & Shakoor, 2017; Brouwer & Heibloem, 1986; Chandra et al., 2025; Evans, 2010). Most Indonesian farmers still use conventional methods based on instinct and experience for land management and watering processes. As a result, planning errors in planting patterns and irrigation imbalances often occur, which impact low agricultural productivity. If this situation continues, it can lead to high agricultural operational costs that are disproportionate to the yields produced (Kumnerdpet & Sinclair, 2011; Mane, 2024).



Figure 1. The condition of Indonesian farmers' agricultural land in the Mountains of Thailand

The mountainous region has complex and dynamic hydro-topographic characteristics, marked by steep slope gradients, extreme elevation variations, and soil structures vulnerable to erosion (Feres et al., 2003; Wilcox, 1955). This geophysical condition causes surface water flow behavior to move very rapidly from high elevations to valley areas. Without planned management, rainwater or irrigation water supplies will flow away, leaving behind nutrient-rich topsoil, or even triggering rill erosion and landslides (Mongkolsmai, 1983). Therefore, a deep understanding of spatial topography is an absolute prerequisite in managing water resources in hilly areas so they can be utilized optimally without damaging the land ecosystem.

Traditional irrigation management in mountainous areas often faces challenges of water distribution inequality between land locations (Albiac & Dinar, 2012; Ray & Majumder, 2024). Agricultural land located at higher elevations often experiences water crises due to the difficulty of channeling water to high points, while land at the bottom is actually at risk of experiencing excess water and plant root rot. This imbalance is generally triggered by the absence of accurate contour and elevation map data, so the determination of water channel paths relies only on farmers' intuitive estimates (García et al., 2020). In this context, digital map-based topographic spatial analysis becomes crucial to identify natural water flow behavior and plan even irrigation distribution.

Irrigation mapping integrated with slope data provides a direct contribution to sustainable agricultural land zoning and management (Bouhachlaf et al., 2023; Pérez-Blanco et al., 2020). On slopes with high steepness, for example above 25°, mapping data helps determine the need for terracing structures such as bench terraces or contour bunds as well as the location of safe drainage channels. This

arrangement aims to cut the length of the slope so that the kinetic energy of water runoff is reduced, erosion can be suppressed, and irrigation water can be temporarily stored at each terrace level to meet vegetation needs (Jägermeyr et al., 2015; Wang et al., 2017). At slopes of less than 15°, the area is suitable for horticulture and open irrigation channels. At slopes of 15°–25°, it is suitable for terracing and gentle contour irrigation paths. At slopes greater than 25°, it is suitable for tight terracing, drainage channels, and protective plants.

The existence of digital irrigation and land maps is an important instrument in increasing the productivity and food security of farming communities in mountainous areas (Adeyemi et al., 2017; Binayao et al., 2024). For farmers managing marginal hilly land, limited water access is often the main factor for crop failure during the dry season (Eris et al., 2022; Mohammed et al., 2025; Prabhakar et al., 2025; Roychowdhury et al., 2005). The digitalization of irrigation maps provides practical guidance in determining the points of irrigation center construction, water distribution efficiency among farmers, and the selection of crop commodities suitable for local hydro-topographic conditions (Shrestha et al., 2017; Yaqoob et al., 2026). Thus, irrigation mapping is not merely a geospatial modeling activity, but a strategic investment to realize sustainable precision agriculture based on environmental carrying capacity (Fazliev et al., 2019; Nurmallasari et al., 2023).

Based on these conditions, a solution is needed so that Indonesian farmers in Thailand have data related to agricultural land mapping that can be used to support farming processes and more accurate irrigation mapping. To realize this, the development of appropriate technology is needed that can map agricultural land layouts in mountainous regions completely and precisely (Eris et al., 2022; Siebert et al., 2013). One technology that can be developed is a mapping drone for agricultural digitalization and irrigation land layout optimization. This mapping drone is capable of producing land contour data, analyzing vegetation, and mapping irrigation water distribution. This technology works by using a camera to capture images according to the land to be mapped. The captured images are then processed by photogrammetry and GIS software to produce land layout visualization that is precise and easily understood by Indonesian farmers. During image capture, the drone is flown according to a planned route, to then capture land image data which is then processed into contour maps and irrigation zones. These results can be used by Indonesian farmers to determine planting areas, irrigation flow directions, and other agricultural needs based on topography.

METHODS

The applied method used a Research and Development (R&D) approach based on a prototyping model that was designed gradually to produce a precise mapping drone that was adaptive to the characteristics of the Thai mountains. The initial stage began with a field needs analysis which included a topographic study of the hilly region, an analysis of local weather dynamics, and a mapping of the technical needs of Indonesian farmers regarding land slopes and irrigation accessibility. Based on these data, the system design phase was carried out, covering hardware and software aspects. After the design was finalized, it was followed by the system integration and assembly stage, which was succeeded by a series of calibrations. The flight trial phase was conducted in the hilly area to evaluate battery endurance, maneuver stability, and the reliability of navigation features. The aerial image data captured by the camera with a minimum overlap of 75–80% were then processed in the photogrammetry processing stage using photogrammetry software. This processing produced outputs in the form of orthomosaic maps, Digital Elevation Models (DEM), and slope maps. In the final stage, the topographic and elevation data were analyzed using a Geographic Information System (GIS) to simulate the accumulation and flow direction of water. The results of this spatial analysis were utilized as the basis for land layout recommendations, determining the position of gravity-based irrigation channels, terracing creation, and the placement of efficient water storage points for the agricultural activities of the Indonesian farming community in the mountains of Thailand.

RESULTS And DISCUSSION

The technology was developed to map agricultural land layouts in mountainous regions completely and precisely. One of the objectives is for agricultural digitalization and irrigation land layout optimization. This mapping drone is capable of producing land contour data, analyzing vegetation, and mapping irrigation water distribution. This technology works by using a camera to capture images according to the land to be

mapped. The captured images are then processed by photogrammetry and GIS software to produce land layout visualization that is precise and easily understood by Indonesian farmers. During image capture, the drone is flown according to a planned route, to then capture land image data which is then processed into contour maps and irrigation zones. These results can be used by Indonesian farmers to determine planting areas, irrigation flow directions, and other agricultural needs based on topography.



Figure 2. How the drone works for mapping

The success of aerial image acquisition is strongly determined by the establishment of flight paths and high photo overlap percentages. In mountainous regions with uneven topography, an overlap of 80% longitudinally and 75% laterally proved effective in preventing the emergence of blind spots or unmapped areas due to obstruction by hilltops or steep slope shadows. Lighting consistency and determining flight time at midday (when the sun angle is perpendicular) also proved to minimize plant shadow distortion, so that image stitching can run smoothly without misalignment gaps.

The image reconstruction results provide a real picture of the irrigation constraints faced so far by Indonesian farmers in the mountains of Thailand. Before aerial mapping was carried out, water distribution was done intuitively, which often caused land areas at the top to experience drought because water flowed down quickly, while areas in the valley experienced excess water that triggered soil erosion and root rot. Precise contour data from this mapping proves that soil elevation differences can be utilized positively to flow water naturally using gravity without requiring expensive water pump machines (Mainuddin et al., 1997).

The generated irrigation and land layout recommendation maps provide practical and measurable solutions for the Indonesian farming community. By utilizing water flow path maps and slope maps, farmers can divide land zoning more effectively: steep slopes ($>25^\circ$) are allocated for terracing and erosion-protecting vegetation. Meanwhile, gentle slopes ($<15^\circ$) are focused on horticultural planting areas and open irrigation path arrangement.

The precise arrangement of irrigation paths based on soil height contours not only saves operational costs for water procurement, but also maintains soil structure stability from landslide hazards (Bouhachlaf et al., 2023; Fazliev et al., 2019; Pérez-Blanco et al., 2020). Overall, this aerial image capture and geospatial data processing successfully transformed conventional farming methods into an efficient, measurable digital agricultural system adaptive to mountainous landscapes.

CONCLUSION

The design of the mapping drone has been implemented as a reliable and stable appropriate technology to operate in the mountainous regions of Thailand. The combination of aerial image processing using software is capable of producing accurate contour maps and water distribution analysis maps, thereby

facilitating the planning of gravity-based irrigation channels and reducing the risk of land erosion. Overall, the application of this technology provides a real contribution to the digitalization of Indonesian farmers' agriculture, making it easier for farmers to determine optimal planting areas and realizing a more measurable, efficient, and sustainable land management.

ACKNOWLEDGMENTS

Thank you to Universitas Negeri Malang, LPPM UM through UM internal funding in 2026, and all parties who have supported the community service activities carried out in Thailand.

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