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BUILDING THEMATIC MAP USING UAV TECHNOLOGY FOR WATER SUPPLY AND DRAINAGE PLANNING IN THE CASE STUDY OF HAI PHONG CITY

Hanh Hong Tran[*], Anh Van Tran
Geomatics in Earth Sciences Research Group
Hanoi University of Mining and Geology, Vietnam

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Abstract

Thematic maps are crucial representations that depict specific natural and socioeconomic phenomena. Unmanned Aerial Vehicles (UAVs) offer several advantages, including high resolution, accuracy, rapid image processing, easy 3D data creation, and cost-effectiveness. UAV technology is highly suitable for mapping small or inaccessible survey areas using direct measurement methods. This article aims to establish a thematic map using UAV technology for urban water supply and drainage planning, focusing on the case study of Le Chan district in Hai Phong city. The steps involve image capture, control point surveys, image block processing, thematic map establishment, and accuracy assessment. This resultant map for water supply and drainage planning will significantly contribute to effective and sustainable planning and exploitation of the case study in the near future.

Keywords: Thematic map; UAV; Water supply and drainage; Hai Phong.

[*]**Corresponding author. Email:** hanhtranvub@gmail.com

1. Introduction

Thematic maps illustrate specific, distinct natural and socioeconomic phenomena, focusing on one or several elements. Compared to general geographical maps, thematic maps exhibit a more diverse range of topics and methodologies. While general geographical maps evenly display various content elements, thematic maps present a clear division between primary and secondary content. The primary content requires clarification, while the secondary content aims to support and enhance this primary focus. Thematic maps delve deeply into the internal content of the subject, predominantly utilizing non-proportional symbols [1].

Thematic maps at regional, national, continental, or even global scales significantly and effectively contribute to the planning, development, construction, utilization, and preservation of natural, human, and socioeconomic resources within each country and worldwide.

Unmanned Aerial Vehicles (UAVs), initially developed for military use, have now transitioned into commercial applications across various industries.

When it comes to capturing terrain images, the utilization of UAVs offers numerous distinct advantages over the traditional approach using manned aircraft. Its key benefits include cost-effectiveness, high resolution, rapid image processing, remarkable accuracy, and simplified 3D data creation. Notably, UAVs are particularly well-suited for mapping small or inaccessible survey areas using direct measurement methods [2, 3].

Utilizing UAV images in mapping is incredibly beneficial worldwide [4, 5, 6, 7, 8]. One study [4] explored the capacity of UAVs to create digital maps and assessed the accuracy of UAV-based mapping. It successfully digitally designed and implemented three diverse drainage networks, facilitating the analysis of potential erosion mitigation costs and benefits [5]. In instances requiring detailed spatial information for small, unplanned areas, low-cost UAVs offer a practical solution [6]. Azmi et al., [7] conducted an assessment of accuracy and compared topographic mapping using UAV images integrated with aerial and satellite images. The results of this study [8] could serve as a benchmark for geospatial data collection and be instrumental in mapping various scales.

In Vietnam, the applications of UAV technology in mapping, terrain surveying, 3D model construction, and related fields are notably diverse [9, 10, 11, 12]. A 3D model of the dam area at Suoi Hai lake in Ba Vi district was generated using UAV image data from the Drone Inspire 1 device [9]. The research [10] focused on identifying suitable UAV flight modes for topographic surveys of linear structures. Furthermore, a topographic map at a 1:1000 scale was produced utilizing drone-taken photos in Thanh Tri district, Hanoi city [11]. Nguyen Quoc Long's work [12] involved constructing a model and assessing the accuracy of the digital surface model (DSM) at the Deo Nai open pit mine. This evaluation included two cases: one using photos obtained from UAV/PPK, and the other utilizing photos from UAV/PPK combined with ground control points (GCPs).

UAV technology has found broad success and extensive application across various fields, including surveying and mapping, transportation, construction planning, agricultural production, geology, mining, and environmental research. Both open-source and commercial software now integrate SfM (Structure from Motion) algorithms, enabling nearly complete automation of image processing and the creation of diverse map products such as Digital Surface Models (DSM), Digital Elevation Models (DEM), ortho maps, 3D maps, and videos [13].

Hence, creating a thematic map for water supply and drainage is crucial for enhancing the efficiency and sustainable management of the experimental area. This map will serve as essential content for policymakers and planners, addressing the current needs and enabling the development of necessary policies and plans.

2. UAV technology and case study

2.1. UAV technology

The UAV structure consists of three primary components: the aircraft system, the ground control station, and the image processing station required for generating DSM [2]. The aircraft system comprises a fuselage, GPS receiver, wind speed sensor, altitude sensor, pressure sensor, balance sensor, and signal transceiver. Additionally, the aircraft is equipped with a battery to power all the onboard equipment. UAVs are categorized into two main types based on their structure: fixed-wing aircraft and multi-rotor aircraft.

The structure of the ground control station involves a tablet or smartphone integrated with flight programming and flight control software. Meanwhile, the image processing station utilizes workstation computers with robust configurations and software specialized in processing aircraft images to generate DSM. Various sources of error impact UAV results, encompassing image errors, lens distortion errors, atmospheric refraction errors, terrain elevation errors, errors in photogrammetry (equipment, data), method errors, and image resolution.

The equipment utilized in the research is the DJI brand's UAV Phantom 4 RTK (Figure 1). This device is capable of autonomous flight according to pre-set programs, facilitating easy takeoff and landing. Additionally, it possesses a feature to measure image rotation angles and determine image center coordinates using the RTK method. Noteworthy parameters [14] include flight speed: 30 - 40 km/h; dimensions: 40 × 40 × 35 cm; weight: 1,391 g; operational duration: up to 30 minutes; maximum shooting altitude: 70 - 250 m; camera resolution: 20 Mpx; focal length: 8.8 - 24 mm.

The software utilized for processing is Agisoft Metashape (Figure 1). This Russian-made software specializes in image control enhancement and model construction for surveying purposes, ensuring high accuracy.

Figure 1 displays the UAV (Unmanned Aerial Vehicle) utilized in the study, along with the accompanying software employed for data analysis.

Figure 1: UAV and software used in the study

2.2. Case study

The case study is the An Bien ward, located in the Le Chan district of Hai Phong city (Figure 2). The An Bien ward is positioned at coordinates 20°51′18″ N and 106°40′38″ E, accommodating a population of 9,216 people and boasting a population density of 31,779 people per square kilometer.

This area, situated in the city center, hosts a relatively dense population. Predominantly, it consists of residential buildings with two to five floors and is crisscrossed by several streets, including

Nguyen Duc Canh, Me Linh, Hai Ba Trung, Cat Cut, Le Chan, and various key landmarks such as the Ngo Quyen High School, Ngo Quyen Secondary School, Hai Phong Distance Education Center, Nghe Temple, and An Bien Communal House.

The city of Hai Phong currently relies on three primary freshwater river systems: the Gia River, the Re River, and the Da Do river. These rivers play a crucial role in supplying water for daily life, agricultural production, and industrial needs throughout the city. Unfortunately, these vital water sources are significantly polluted due to the discharge of waste from approximately 350 different sources.

Indeed, the planning and construction of the water supply and drainage network in Hai Phong city, especially in the Le Chan district, lacks reasonable design. There's a notable absence of coordinated management between the public transport sector and other related sectors, leading to numerous challenges and complexities in the management of drainage systems within the city.

The urban sewer network situated in the heart of Hai Phong city handles rainwater, wastewater, and various discharges, channeling them directly into canals, lakes, and rivers without prior treatment. Unfortunately, the density of sewer construction remains relatively low, primarily concentrated within older urban zones like the Hong Bang, Le Chan, Ngo Quyen, and Hai An districts. In more recently urbanized regions, the sewer networks are severely lacking, resulting in significantly degraded quality and often failing to meet essential drainage requirements.

Figure 2: The case study belongs to Le Chan district, Hai Phong city

2.3. Technological process

The specific steps in the technological process are outlined as follows:

2.3.1. Flying and creating an ortho-image using a UAV

To digitally map the land use boundaries on the ortho-image, the established ortho-map needs to meet several key prerequisites:

Firstly, it must be transformed to align with the Hai Phong coordinate system, setting the meridian axis at 105°45' and adopting projection zone 30.

Secondly, the ground image resolution, or the image pixel size on the ground, should not exceed 10 cm.

Finally, the accuracy of pixel positions concerning control points should fall within the range of mp ≤ ± 30 cm.

a. Establishing a ground control network

Considering terrain characteristics, measurement area, and the existing state control points network, a ground control network is established to aid in tasks involving image control measurements and the inclusion of unidentified objects within the image. These points are set up to match a Class IV GPS network standard. The density of both newly established points and the state points is maintained at a minimum of one point per 15 km^2.

b. Creating ground control points

Ground control points serve as the foundation for image processing, ensuring that the image block aligns with the correct coordinates and scale. These points' coordinates are determined using the GPS-RTK method, employing a satellite orbit calendar correction file. The base points for this process are GPS Class IV points, and the maximum distance from the measurement point to the base station does not exceed 5 km.

c. Flight height

The flight height ranges between 80 to 200 meters to guarantee ground image resolution is maintained below 10 cm. The distance between photos must meet specific criteria: a vertical coverage of 80 % or more and a horizontal coverage of 60 % or more.

d. Image block processing

During processing, the entire measurement area can be processed as a single block, or subdivided into smaller blocks for more convenient processing.

e. Exporting ortho-image

The ortho-image, generated from photos and DEM obtained during image block processing, is exported to facilitate the digitization of land use boundaries and map objects. It is exported as map fragments, extending 20 meters beyond the frame. The image is based on the Hai Phong coordinate system, aligned with a meridian axis of 105°45' and projection zone 30. The image is formatted in TIFF with a pixel size of less than 10 cm.

2.3.2. Map digitization

The ortho-image captured using UAV technology has been converted to the designated scale required for the map creation. By interpreting the features and colors visible on the ortho-image, objects are predicted, interpreted, and digitized. This content encompasses several primary class groups: The hydro system layer; the Traffic layer; the Land plot boundary layer; Layer containing notes, explanations, and administrative boundaries at all levels.

2.3.3. Fieldwork

The fieldwork is conducted based on the digitization outcomes derived from the color ortho-image in map units. Subsequently, this information is transferred onto paper for field verification and editing purposes. This fieldwork aims to validate the boundary segments digitized during office work, ensuring their alignment with the current land use status of each area. It involves verifying existing boundaries, identifying new ones, updating changes in boundaries, and removing obsolete boundaries as observed in the field.

2.3.4. Map editing

After the fieldwork outcomes and the digitization carried out in the office, along with supplementary field surveys, the digitized office work file is updated and adjusted. This process is standardized according to each class group as per the updated regulations for the map edition.

2.3.5. Quality inspection

The map acceptance process can occur in stages or as a complete procedure, contingent upon the actual situation. The acceptance process is divided into two steps: Step 1: Fieldwork verification involves assessing the data from the fieldwork on the printed paper map of land use boundaries for acceptance inspection. Step 2: Office work inspection includes the examination of accompanying documents.

3. Results and discussions

In this study, the RTK measurement method involves using GNSS RTK equipment to measure points in the field. The RTK device can use a CORS station to collect coordinates. On the other hand, the photogrammetric method involves collecting measurement points in the software after obtaining the ortho-image and DSM from processing UAV data.

During the image capture process, the base point is the reference point for the UAV flight. Each take-off point for the aircraft has a corresponding base point. This point is measured using RTK and inputted into the aircraft before the flight. Meanwhile, the M points are used as ground control points. They are employed to calibrate the altitude and coordinates, or can also serve for verification purposes.

Before the flight, two coordinate and altitude points were measured using the static GPS method to serve as reference points during the flight. Additional measurements of terrain altitude and checkpoint data were also collected. These two points, referred to as AB-01 and AB-02, can be assessed with an accuracy equivalent to that of analytical point 2 (Figure 3). The calculated coordinates and elevations are outlined in Table 1. Further details regarding the flight design and control, conducted using the specialized Phantom4-RTK software, are presented in Figure 4.

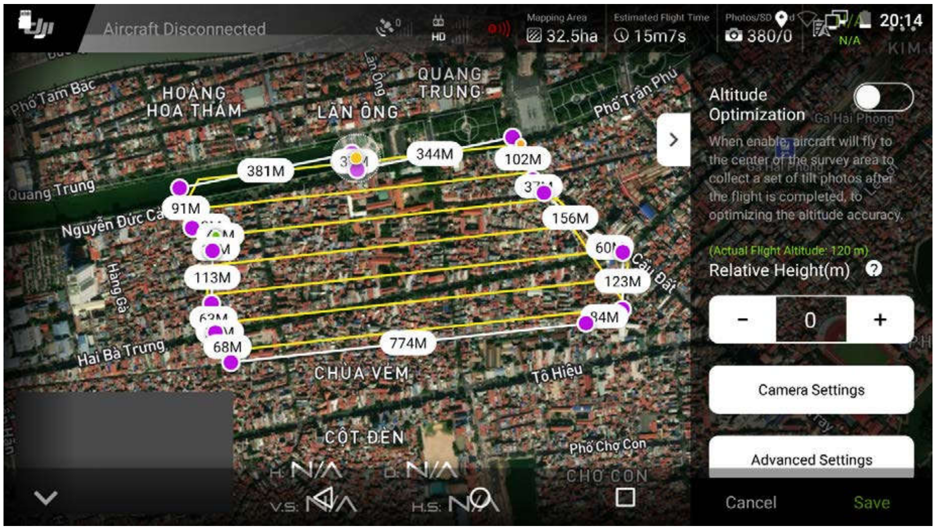
Figure 3: Diagram of base points

Table 1. Coordinates of base points

No	X	Y	H
AB-01	2307151.968	596035.274	2.015
AB-02	2307251.020	596385.438	2.232

The coordinates of the center point were derived using data from the GPS files on both the UAV and the base, along with the satellite coordinate file in the RTKpost tool. Subsequently, the images were processed using Agisoft Metashape software, with control points M02 and M07 employed in the process.

The ortho-map, captured using UAV technology, has been rectified to comply with the prescribed map scale. Based on images and colors on the ortho-image, and the land use boundary objects, the land occupation objects that do not form land plots, such as roads, irrigation works, dykes, rivers, streams, canals, and other land occupation elements along the route, are predicted and digitized. Furthermore, a distinction exists within each class group. This ensures that the map content remains consistent across object layers, preserving their spatial positions. Moreover, it mandates absolute overlap for objects that intersect in geometry.



Altitude Optimization

When enable, aircraft will fly to the center of the survey area to collect a set of tilt photos after the flight is completed, to optimizing the altitude accuracy.

(Actual Flight Altitude: 120 m)

Relative Height(m): 0

Camera Settings

Advanced Settings

Cancel

Save

Figure 4: Flight project design

The digitalized content comprises several major groups: (1) the Hydrosystem layer: which includes rivers, natural canals, man-made canals, lakes, ponds, etc.; (2) the Transport layer: which comprises roads, railways, and associated objects; (3) Land plot boundary layer: contains land plot boundaries, land plot numbers, and land plot areas; (4) Legend layer: provides information on administrative boundaries at all levels.

The field survey relied on digitized results obtained from ortho-rectified color images, which were subsequently printed on paper for fieldwork assessment and modification. Fieldwork was essential in identifying, and supplementing new boundaries, updating changed boundaries, and removing obsolete boundaries. This process ensures alignment with the current ground reality.

The fieldwork results were directly integrated into the ortho-map in compliance with regulations, highlighting missing, redundant, and inappropriate boundaries observed in the field. Subsequently, office work necessitated adjustments to align with the current land-use status for individual households and land-use organizations. Given the area's high construction density, the ortho-image lacked clarity in depicting alleys, and accuracy was compromised in areas with high-rise structures due to limitations in DSM data. Therefore, conducting a supplementary survey for altitude points using the GPS-RTK method, with a base station situated at point AB-02, becomes necessary.

Within the image block captured at an altitude of 120 m, 12 field points were identified using the GPS-RTK method. Among these, two points (M02 and M07) were employed for absolute positioning calculations. The remaining points were utilized to cross-reference measurements between the field and ground positions, comparing these with the ortho-image and altitude data from the DSM (Figure 5).

The specific checking points were displayed on the map with their respective flat coordinates, while their altitudes were determined through interpolation using the DSM on ArcScene software. These coordinates were derived from the ortho-image, based on their field locations. The comparison outcomes are documented in Table 2, while the error analysis for the 12 field points is detailed in Table 3.

Figure 5: Location of validation points on Ortho-image

Table 2. Comparison of coordinates and altitude at validation points

No	GPS-RTK measured coordinates and altitude			Image measured coordinates and altitude		
	X	Y	H	X	Y	H
M01	2306876.084	596126.482	1.835	2306876.011	596126.405	1.831
M03	2306957.166	596468.958	1.863	2306957.152	596468.885	1.946
M04	2306870.547	596624.012	2.310	2306870.467	596623.902	2.394
M05	2307018.434	596812.844	1.727	2307018.386	596812.757	1.771
M06	2307052.641	596968.281	1.809	2307052.600	596968.226	1.801
M08	2307283.008	596700.972	2.571	2307283.042	596700.884	2.599
M09	2307264.319	596578.879	2.290	2307264.349	596578.835	2.243
M10	2307215.153	596382.947	2.231	2307215.077	596382.861	2.157
M11	2307170.505	596173.400	2.278	2307170.555	596173.350	2.189
M12	2307041.322	596211.975	2.040	2307041.310	596211.887	2.034

Table 3. Errors of 12 field points

No	Error			
	m_x	m_y	m_p	m_h
M01	0,026	0,073	0,0775	0,004
M03	-0,072	0,014	0,0733	-0,083
M04	-0,076	0,08	0,1103	-0,084
M05	0,073	0,048	0,0874	-0,044
M06	-0,036	0,041	0,0546	0,008
M08	-0,081	-0,034	0,0878	-0,028
M09	-0,032	-0,03	0,0439	0,047
M10	-0,041	0,076	0,0864	0,074
M11	-0.006	-0,05	0,0504	0,089
M12	-0,087	0,012	0,0878	0,006

The errors depicted in the result tables are notably small, predominantly less than 10 cm, even meeting the necessary precision for establishing a topographic map at a scale of 1:2000. An influential factor enhancing the accuracy of this method in urban settings is the presence of consistently stable road surfaces. Consequently, altitude interpolation in generating the DSM tends to be more accurate for roads than for varied terrains or cover areas. However, the creation of maps using image-based methods encounters challenges, particularly in alleys obstructed by closely situated high-rise buildings. In such cases, additional altitude measurements become imperative for accurate mapping.

The results from office digitization, combined with supplementary fieldwork, demonstrate that updating and revising digitized files to comply with mapping regulations for each class group is more streamlined. The thematic map adheres to the VN-2000 national coordinate system, displaying a longitude axis of 105º45’, in projection zone 3 degrees. It is structured and presented according to the prescribed format of a cadastral map (Figure 6).

Figure 6: Thematic map for water supply and drainage planning in An Bien ward, Le Chan district, Hai Phong city

4. Conclusions and perspectives

UAV technology is an advanced one that significantly supports the establishment of thematic maps in water supply and drainage planning, offering numerous advantages over traditional methods. These include the ease of organizing fieldwork, swift processing of office-based tasks, and diverse product outputs from UAV data, such as 2D maps, DEM, DTM, DSM, and ortho-images.

In the case study in Le Chan district, Hai Phong city, the utilization of the UAV technology enables the creation of a highly accurate thematic map. This method allows for the measurement of otherwise inaccessible areas, significantly reduces time and effort, incurs lower costs, and enhances labor safety. Moreover, the timely provision of documents for water supply and drainage planning, effective management, and sustainable development are additional benefits derived from this approach.

This study will be crucial for policymakers and planners, as it addresses present requirements and facilitates the creation of vital policies and strategies. It's suggested to utilize UAV technology for extensive mapping in various experimental zones for diverse objectives, while also considering the use of different types of UAVs.

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