GEO-CONSTRAINTS FOR UAV-BASED LARGE-SCALE GIS DATA COLLECTION

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ABSTRACT:

This article explains vertical/takeoff-landing UAV applications on geographic modeling of geo-database for realistically virtual 3D training scenarios. Automatic mission plan was adopted to acquire 3-5 cm spatial resolution images. A photogrammetric software package was used to obtain image coordinates from a GPS-embedded camera and image orientation parameters from a UAV-installed sensor to start the process for 5 cm image resolution. Such fine resolution enabled precise area measurements, tree and building heights, and terrain elevations. The achieved image maps were an ideal source of visual interpretation for large-scale GIS data layers. Additionally, the digital elevation models were further used for the calculation of tree building heights and terrain variations that were an essential content in training scenario creation. Although the studied areas were mountainous, hilly and densely populated on the valleys or mountain ridges, highly humid with surge of atmospheric turbulence and windy, such geo-constraints were studied in advance of the mission, carefully considered as key success factors and single-handedly treated in the field to achieve the 3D terrain modeling goal of the project.

Keywords: UAV, digital terrain modeling, large-scale image map, UAV image acquisition, geo-constraints

INTRODUCTION

GIS has been adopted as a situation awareness and decision making tool in military applications. A number of academic papers and technical reports are seen GIS playing a central and vital role in defense domain (Kumsap and Meegla (2013), Kumsap et al (2013), Chalainanont et al (2014), Kumsap et al (2014), Tanvilaipong et al (2014) and Chalainanont et al (2015)). Nagy (2004) stated that the unexploited mine of information is remote sensing, which is going to have a very important role in the future. These new systems are the guarantee for conformity with GIS of the 21th century and for the information system of the modern army. This development is the power of future, which offers unlimited possibilities for today's military experts. Therefore, it is not entirely because of GIS that the military embraced to the surveillance, intelligence and reconnaissance cycle. The advancement of remote sensing deserves mentioning since it facilitates incredibly fine resolution, frequently acquired data, minutely classified spectrum, and variously installed platforms. Unmanned Aerial Vehicle (UAV) is part of the advancement and becomes widely available due to the suitability, feasibility, affordability and flexibility of the UAV. Tiwari and Dixit (2015) reported the study for the understandings of how UAV technology started to revolutionize remote sensing by its cheaper and smaller sensors, better integration and ease-of-use options. They concluded that UAVs have great potential to conduct essential ground operations in a more efficient way, seen to directly effecting the defense domain. Anders et al (2013) found that UAVs provided a promising and flexible platform for the acquisition of multi-temporal digital surface models (DSMs) and orthorectified airphotos by demonstrating the quality of derived DSMs and terrain properties in civilian applications. The military was also expected to gain a great deal from such advanced products.

Image acquisition from UAV is a currently eminent subset of airborne remote sensing. It takes the similar manner of aerial photography where aircraft are traditionally flown for aerial surveillance and reconnaissance. It is widely accepted that a round of flying an aircraft to acquire photos of one particular study area is time-consuming, painstaking and, most importantly, expensive. The aerial mapping situation in Thailand is far removed from any possibilities since only authorized agencies are lawfully allowed to execute the aerial surveillance and reconnaissance missions. From an update point of view, an aerial photo is less reliable with attempt to keep fast growing areas in the developing world up-to-date. UAVs are an alternative to keep the mapping and aerial photos current and adopted for many mapping applications. In military aspect, precise and rapid mission execution requires UAVs that are easy to operate, portable to carry away, ready for takeoff and landing (see Figure 1). Military operations other than war such as live report during parade, camp surveillance and monitoring, and logistics survey are among others that demand the UAV utilization. Although UAVs are an ideal tool for rapid terrain modeling and mapping, there are considerations and key success factors that need thorough scrutiny. This academic paper reports the application of UAV in defense geo-database creation under various geo-constraints and weather limitations. The final output of the geo-database was to facilitate realistic 3D terrain modeling for incorporating current and realistic scenarios into military simulators.

Figure 1. Multi-rotor UAV needs a small, flat terrain for takeoff and landing

UAV REQUIREMENTS

In creation of defense geo-database for monitoring and surveying drug trafficking, Robert et al (2015) used Quick Bird images to undergo Rational Function Model, Rational Polynomial Coefficient and Relief displacement for spatial correction. In the validation of forest inventory data after applying random point generation means, the accuracy was achieved at around 72%. That incorporated tremendous ground survey and ground truth. Orthorectified images were not readily achievable but had to undergo several steps. The fact that the study areas were along the mountainous borderline made the ground survey and ground truth almost impracticable. Therefore, they recommended different seasonal scenarios for drug smuggling, which inevitably involves large-scale GIS data layer generation. Satellite imagery can hardly be dependent upon considering, among other reasons, its coarser spatial resolution, lengthy temporal resolution.

Figure 2. Control station displaying real-time functionality.

The suitable UAV for this application required that it be; 1) vertically taken off and landed, 2) functional with automatic mission plan and photogrammetry, 3) remotely communicated at all time with a control station, 4) able to display real-time functionality (see Figure 2), 5) small, light and portable, 6) operable amid gusty wind and turbulence, 7) returned home after mission completed, 8) GPS-capable for flight position identification, 9) equipped with stabilizer to control a camera and airborne orientation logger, and 9) directly and automatically controlling the camera for image acquisition. To qualify for the afore-mentioned requirements, Phantom 3 Advance UAV was used to fly over the study areas to acquire 3-5 cm spatial resolution images, far better than the results achieved from using satellite images. The temporal reason is shown on Figure 3 that rapid image acquisition could be flexibly manipulated before heavy rains came, and after they stopped.

Figure 3. UAV data collection minutes before heavy rains.

UAV DATA COLLECTION

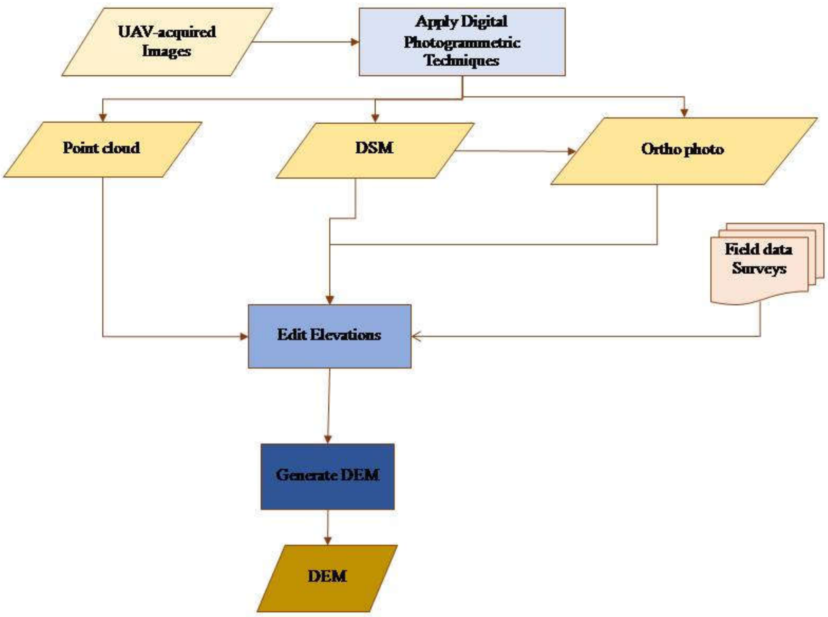

Figure 4. DEM and orthoimage generation.

Map Pilot for DJI (Map Made Easy, 2015) was used to create and fly flight paths to create large-scale maps using the map processing service. The UAV was flown at an average altitude of 100 m above ground level, which resulted in 4.3 cm ground sampling distance. Each flight path was calculated to have an overlapping area of 80% for both images along the same flight path and those of adjacent flight paths. The total flight paths were approximately 8 km and took a solo flight of 13 min to cover one single study area. To complete the mission, four rounds of image acquisition were needed to obtain 1,129 images of the entire study areas. Pix4D Mapper Pro was the photogrammetric software package used for processing 12 ground control points collected from an RTK GPS survey. Digital elevation models and orthoimages from which large-scale GIS data layers were extracted were produced from the automatic processing package as illustrated in Figure 4.

GEO-CONSTRANTS

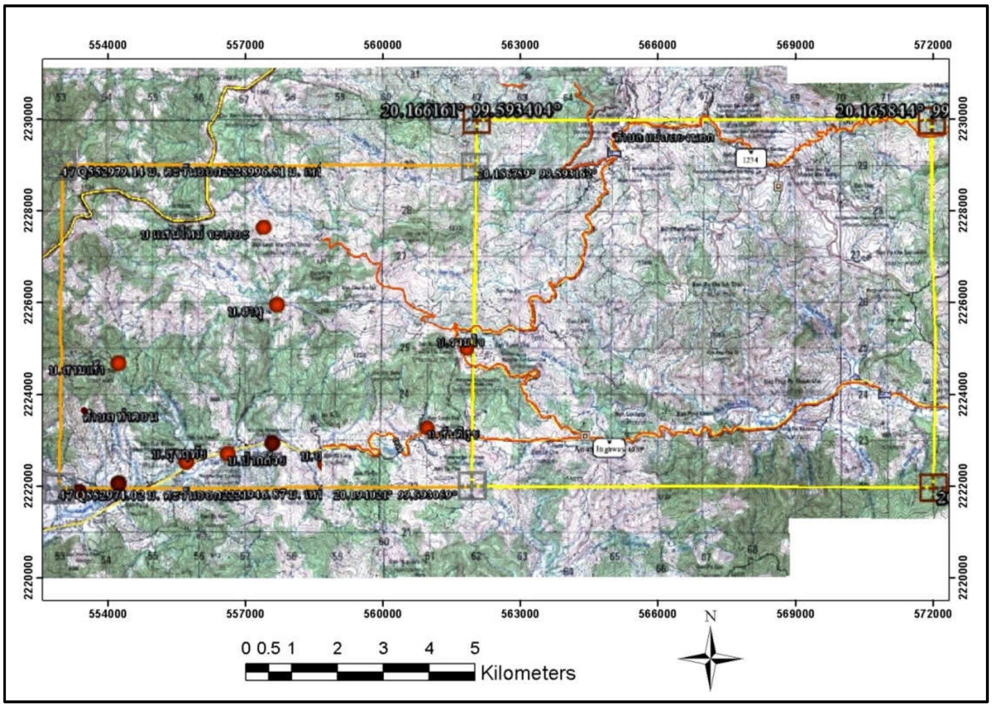

Figure 5. Study areas of dense forest and occupied villages on mountain ridges.

The geographic and topographic features of the study areas as shown in Figure 5 brought challenges to the UAV aerial photography. One of the most challenging factors was that such ground truth and survey could not be performed as frequently as needed. This project was conducted with military officers and soldiers stationed within the areas as co-researchers, cornering the task to the limited time slot. Such approach as discussed by Chalainanont et al (2013) that the Android-based mobile devices were applied to interface mobile network with field survey and ground truth missions was relevant to the time-saver aspect of the project because it involved research partners who stayed close to the sites to perform field survey and ground truth missions and reported back to the project office. However, the need for UAV-based fine resolution images for large scale GIS layers necessitated the field mission to take place.

Figure 6. Geographic nature of the study areas.

Mountainous and Hilly Terrain

The first geo-constraint for the UAV image acquisition of for the project was the geographic locations that lie along country's highlands of the northern borderline (see Figure 5 above). Given topographic maps and stored aerial photos for flight plan, takeoff and landing sites were still indecisive for the survey team. Witnessed mountainous and hilly terrain as seen on Figure 6 far left required a GPS receiver and an actual visit to the sites prior to planning. The terrain heights were found to be 1,000 - 1,400 m above mean sea level. Travel from site to site was made possible by dedicated vehicles.

Densely Populated on Valleys

Villagers reside densely on mountain range and mountain ridge. The residence was found to sporadically scatter in the evergreen forest and compactly cling in one another with a few narrow roads for commuting from village to village. Houses were set close to one another on both sides of the road see the second left inset of Figure 6. Limited access to the roads was evident since they were constructed on the mountain ridge that was shared further by residential purpose.

Mountain Ridges

The residential areas on mountain ridge were considerably varied in elevation. Houses built on sudden deep foothills were seen across the areas, making it difficult to locate the takeoff and landing sites. Where open spaces were located, their elevations were excessively different than acceptable amount to suit the takeoff and landing site of one mission. The GPS receiver and dedicated vehicle were ideal for this trial-and-error site survey.

High Humidity

High humidity seemed not to have direct effect on communications between the control computer and the UAV. However, when it reached 98% during the UAV liftoff, data upload and download faced loss of communication. A significant drop of the humidity see the inset of Figure 6 brought the communication back to normal toward noon time of the day.

Surge of Atmospheric Turbulence

Atmospheric turbulences were witnessed due to the topography and also key indication of the UAV mission. Surge of weather included thick fog (see the far right inset of Figure 6) early in the morning, heavy rains for a short period of time or several consecutive days, clear sky prior to or after heavy rains, changes of wind direction at all time and irregular wind speed that brought in clouds over the areas.

PROBLEM TACKLING AND KEY SUCCESS FACTORS

Advices from local military officers suggested that the survey team arrive at the sites before the survey day for a detailed mission plan. That was to ensure that takeoff and landing locations for the UAV were identified to avoid on-site difficulties. The final flight plan was determined after the actual visits of the locations. Below are considerations for the optimum mission plan, leading to problem tackling of the geo-constraints.

1. Terrain height variations were taken into account when GPS and topographic maps were source of locating UAV takeoff and landing. The takeoff and landing positions were kept no more than 10 m different from the average height of the study area, conforming and keeping the pixel size at 5 cm.
2. Takeoff and landing areas could be located in the urban since the UAV needed only 5 x 5 m to start and end the mission. The survey team took less populated spots to fly the UAV such as the flight mission in Figures 1 and 3. A consultation with the hotel owner also helped secure takeoff and landing place from the hotel rooftop.
3. Each site for takeoff and landing was unable to repeat more than once. Line of sight was mostly a key indicator to move from site to site often. Notice tall objects such as pines and buildings because they could block communications between the UAV and the control computer.
4. Although weather conditions made access to the site problematic, such surge of weather could clear out for a short period of time, which was enough to proceed with the mission. The humidity prevailed early in the morning on highland and maybe got worse after rains, most of this resolved near noon. If the fog covered the area, adjustment of exposure time was set at ISO 200 for cloud-covered and foggy conditions and ISO 800 - 1600 for clear and sunny sky.

Thus, the key success factors for tackling the geo-constraints for large-scale GIS data collection from UAV imagery would include:

1. To arrive at the study area at least a day or two prior to the UAV image acquisition;
2. To locate *in situ* takeoff and landing places;
3. To evaluate current weather conditions;
4. To prepare for unexpected field problems;
5. To run through UAV Checklists;
6. To perform after flight check; and
7. To assess, copy and store image data flight by flight.

LARGE-SCALE GIS DATA LAYERS

The spatial feature extraction was performed by heads-up digitization where the geographic features from ortho-rectified images were transformed to vector-based GIS layers (see upper insets of Figure 7). Landuse was classified into agricultural, residential and other class by a combination of vectorization and object-oriented image classification from UAV images except for forest that the forest inventory technique was carried out (see lower left inset of Figure 7). Urban survey was the most tedious task of ground truth when a handheld GPS and personal access were combined house by house to validate residential attribute (see lower right inset of Figure 7).

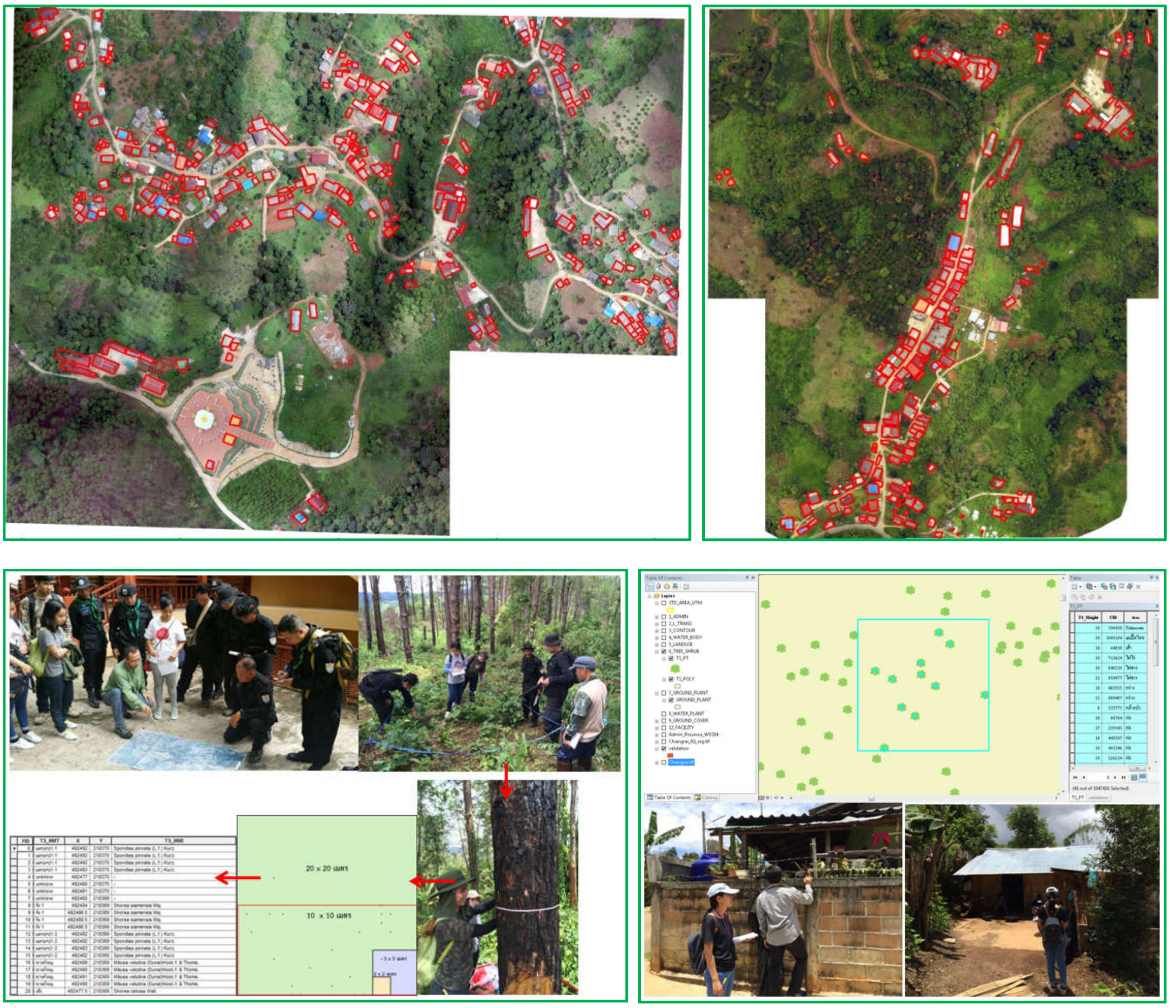

Figure 7. UAV-based large-scale GIS layer collection.

RESULTS AND DISCUSSION

It was found that the goal of UAV image acquisition was reached amid a number of limiting factors. The use of multi-rotor UAVs for the image acquisition was successful due mostly to the site survey in advance. Thus, the detailed and flexible plan for image acquisition was the paramount task to finish with the uncontrollable nature of weather as a reminder. The role of humidity in up- and down-load communications during UAV image acquisition that the survey team encountered needed further studies to understand the complete effect on image quality. The decision and judgment after some familiarization with the environment in the field would help the mission proceed to the goal. The 5 cm orthoimages (top left of Figure 8) from the UAV-acquired images were successfully produced from applying automatic photogrammetric technique. They were further processed with pointcloud, DSM (middle left of Figure 8) and RTK GPS field survey to obtain 10 cm DEMs. The large-scale orthoimages were further used as the base map for extracting 13 GIS data layers (lower left of Figure 8). Remote access to the result geo-database is shown on the right inset of Figure 8.

One point that is clear and deserves to mention is the human-in-the-loop process. The researchers who are expert with the tool being adopted still need advices from local people who are familiar with local weather conditions and geographic features. Technology dependency should be limited to mission where consistent weather conditions are expected. The introduction of new comers to a strange place should come with local support and guidelines. This discussion was evident that the survey team managed to shorten the survey time and avoid heavy and frequent rains in the field. Furthermore, local ingenuity was also another valuable source being populated to the attribute of GIS layers. Manmade layers such as RESIDENTIAL, CONSTRUCTIONLANDMARK, FACILITY and L_TRANS were filled with data from local soldiers. UAV technology demonstration to local authority was another point to discuss. Local requirements for the technology was expressed and discussed during the takeoff and landing. Last but not least, ties between military officers and civilians from academic and public sectors were seen to grow, owing to the geo-constraints that were like a test for the team to tackle.

CONCLUSION

The application of UAV for collecting large-scale GIS data layer reported in this article was aimed at creating realistic 3D virtual scenarios for a military simulator. The remote sensing technique was the main and reliable source of the base map for the digitization. The UAV-based data collection helped the project team to obtain up-to-date GIS layers of the targeted study areas. Although there were geo-constraints such as terrain variations, turbulent weather, high humidity, limited takeoff and landing areas and unpredicted wind speed and direction, the carefully planned flight mission with readily adjustable solutions from indigenous assistance and UAV preflight checklist was the paramount key to the mission success. The data assessment and data storage were additional necessity to avoid flight repetition in the course of extreme weather variance. Thus, military operations that involve image intelligence including surveillance, intelligence and reconnaissance can largely depend upon the UAV image acquisition following the geo-constraint tackling of this report. The 5 cm orthoimage and 10 cm DEM are an ideal source of the military intelligence cycle plus the capability to update geo-database as often as desired taken into account the proposed key success factors for tackling the geo-constraints. Additionally, co-researchers who are familiar with local weather conditions and geographic features are advised to provide support and guidelines for new coming researchers or surveyors to a strange study area. Not only local ingenuity is a valuable source for populating the attribute of GIS layers but also ties between collaborative sectors that a research project creates can lead to institutional teamwork as research by-products.

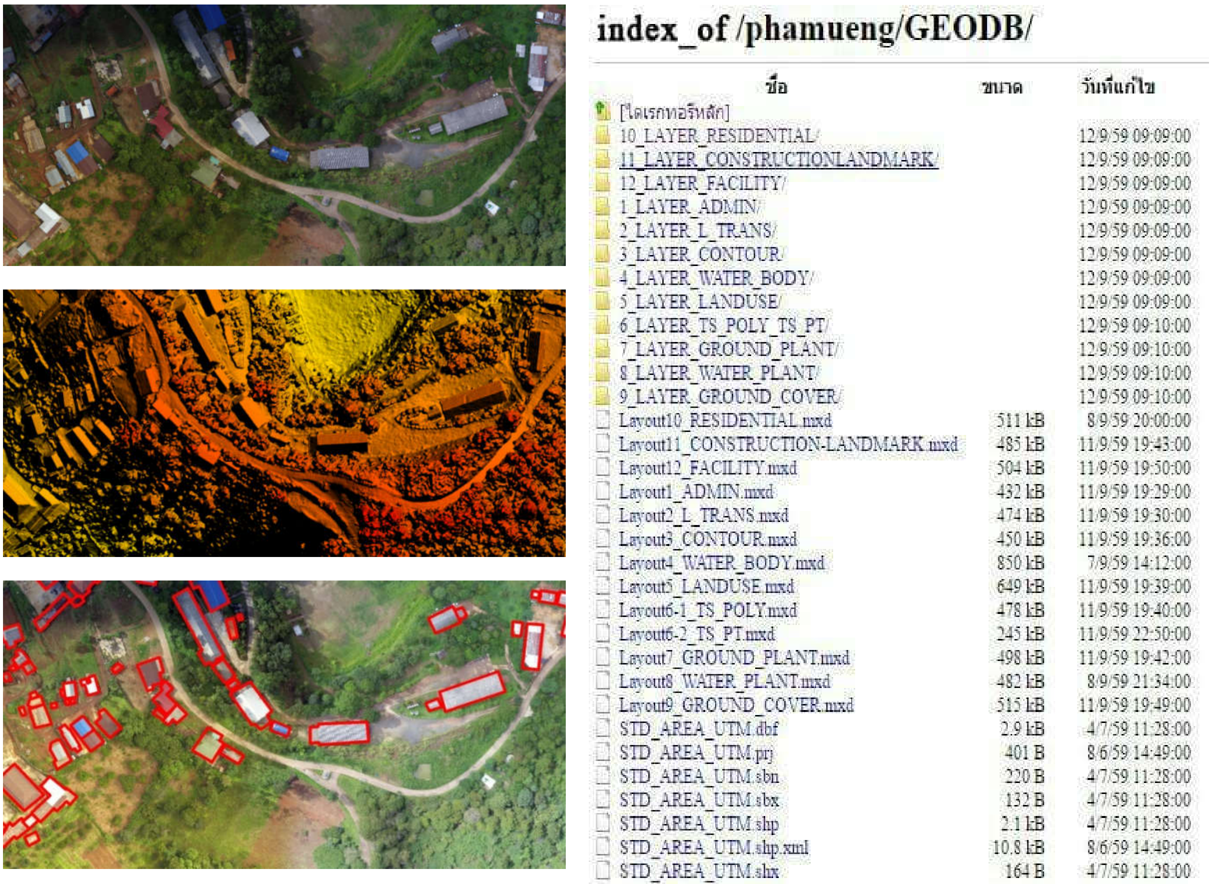

Figure 8. Geo-database from UAV-based GIS data collection.

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