USE OF UAV AND GIS FOR INFRASTRUCTURE MANAGEMENT IN CAMBODIA

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ABSTRACT: Most of the Developing Countries (DCs) in Asia Pacific region, including Cambodia, are having high demand of investment in infrastructure development, including transportation. With the limited available resources, DCs are seeking outside financial support from bilateral and multilateral financing agencies, such as Japan International Cooperation Agency (JICA) and Asian Development Bank (ADB). In the absence of proper infrastructure management system, such as Right-of-Way (ROW), illegal encroachment and obstacles of public land around infrastructure, hinder their further development and upgrading. It requires a lot of efforts and significant amount of time and cost to clear the land for kick start the investment project. Considering the time and cost, there should be an appropriate and easy to implement technology, to encourage DCs to develop such system. This paper has presented the use of Unmanned Aerial Vehicle (UAV) and open source Geographic Information System (GIS) for this purpose. Low cost solution utilizing UAV, basic hardware and peripherals and open-source GIS technology meet the required accuracy and budgetary constrain. It avoided the costly and time-consuming conventional method of aerial photography and cadaster and land registration.

A project supported by the JICA for "Capacity Enhancement of Environment and Social Considerations in Implementing Agency in Road Sector", the Ministry of Public Works and Transportation (MPWT) of the Kingdom of Cambodia developed ROW management system through a pilot project along the part of National Highway No. 5 (NH5). A rotary type UAV mounted with multispectral optical sensor used for aerial photography along the NH5 corridor of 366km in length with 2.73cm Ground Sample Distance (GSD). To ensure the full coverage of 60m ROW, the width of photograph was 100m; 50m both right and left side from highway central line. For the flight plan and all other data processing, mostly free and open source GIS desktop software, QGIS, and WebGIS solutions were used. The UAV aerial photograph data processing Pix4D Mapper software, along with required number of Ground Control Points (GCPs) for each block used to generate geo-rectified imagery.

From the geo-rectified imagery, all the built-up features digitized inside the ROW polygon, complied along with other collected GIS data from secondary source, and uploaded in a well-defined geodatabase to create a WebGIS system. This is feeding into the development of ROW management system to identify current ground situation of illegal encroachment, obstacles, etc. along with devising necessary preventive measures. It is hoped that the ROW management system will be utilized to prevent future illegal encroachment.

1. INTRODUCTION

Most of the developing countries, including Cambodia, are having high demand of investment in infrastructure development, including transportation. Accordingly, both bilateral and multilateral development investment for infrastructure plays a significant role in developing countries. With the limited available resources, developing countries are seeking outside financing from bilateral Official Development Assistance (ODA), such as JICA, and multilateral agencies, such as ADB, in grant and loan by introducing different modalities, such as Public-Private Partnerships (PPPs), to meet the huge demand. According to one estimate, developing countries in Asia need $18.7 trillion in infrastructure investment from 2019 to 2030 (Nishizawa, 2018; ADB, 2019), where transportation alone will require $8.4 trillion in financing by 2030 (ADB, 2018). In order to tap scarce financial resource, there should be strong institutional setup and efficient mechanism of project implementation along with required data to quick start the project and complete on time, which is not the case in many developing countries.

As a part of strengthening the institutional capacity and preparation for project implementation, the MPWT, supported by the JICA, developed Right-of-Way (ROW), management system for future widening of national road project can be implemented efficiently (Chea et al, 2019). Depending upon the context and place, there are different meaning of ROW. In this Cambodia case, ROW is defined as the state land along the road with fixed distances from the centerline of existing roads for future development. In order to develop the system, up to date land use map, along the road corridor and other geospatial data are crucial, which can be readily accessible for necessary filed survey work. This paper is presenting widely used cost and time efficient UAV survey and mapping of land use and well-defined geodatabase on the WebGIS portal technology to feed into the ROW management system and fieldwork.

There are different types of UAV available for the professionals in the surveying and mapping industries. Currently, mainly two categories of UAVs, namely Multi-Rotor and Fixed-Wing, are available along with the wide range of sensors, such as optical, LiDAR, thermal, etc. Furthermore, UAVs and sensors are coming in different sizes and capacity, so that user can choose for quick small area mapping to the wider and land area mapping (Chapman, A., 2016). In addition, recently other two types of UAV, namely Single-Rotor and Fixed-Wing Hybrid, are also coming into the market, which will increase the prospective of UAV utilization for aerial surveying and mapping become a primary choice. UAV is very handy and cost effective for the linear infrastructure, such as Road, Power line, Pipeline, Irrigation canal, etc. The corridor along the infrastructure mapped with high resolution, which is usually difficult and costly for traditionally used fixed wing aircraft, helicopter and satellite mapping. The rotary UAV was used for acquiring required multispectral aerial photographs to create geo-rectified imagery followed by land use mapping and features extraction and other required Geospatial data collected from the concern line ministries, departments and institutions.

For WebGIS portal creation, there are mainly two options, both in terms hardware and software. For example, all the necessary hardware (computer/servers, peripherals) can be either installed locally or rented from the cloud service provider, such as Amazon Web Services, Google Cloud, etc., and for software either from Off-the-shelf or Open-Source products, for example ESRI or OSGeo respectively. In this project, OSGeo products used for WebGIS portal development, mainly by considering the cost and scope of the work. For hardware a medium capacity server, along with basic peripherals, such as note PC, Tablets, and internet connection, etc. were installed at the MPWT premises for hosting geodatabase and WebGIS system.

2. PILOT PROJECT AREA

The targeted pilot project area is a part of National Highway No. 5 (NH5) taken from the town of Oudong in Kampong Chhang province to the international border of Cambodia/Thailand in Banteay Meanchey province, which is approximately 366km in length and passing through Pursat and Battambang provinces (Figure 1). NH 5 is a part of Asian Highway network and Southern Economic Corridor and gateway to the Thailand. In addition, development along the highway, for both residential and commercial purpose, attracts the people from the surrounding areas. It, sometimes, leads to illegal encroachment of the public lands or inside the ROW along the entire length of pilot area, which is more prevalent in urban area compare to rural area.

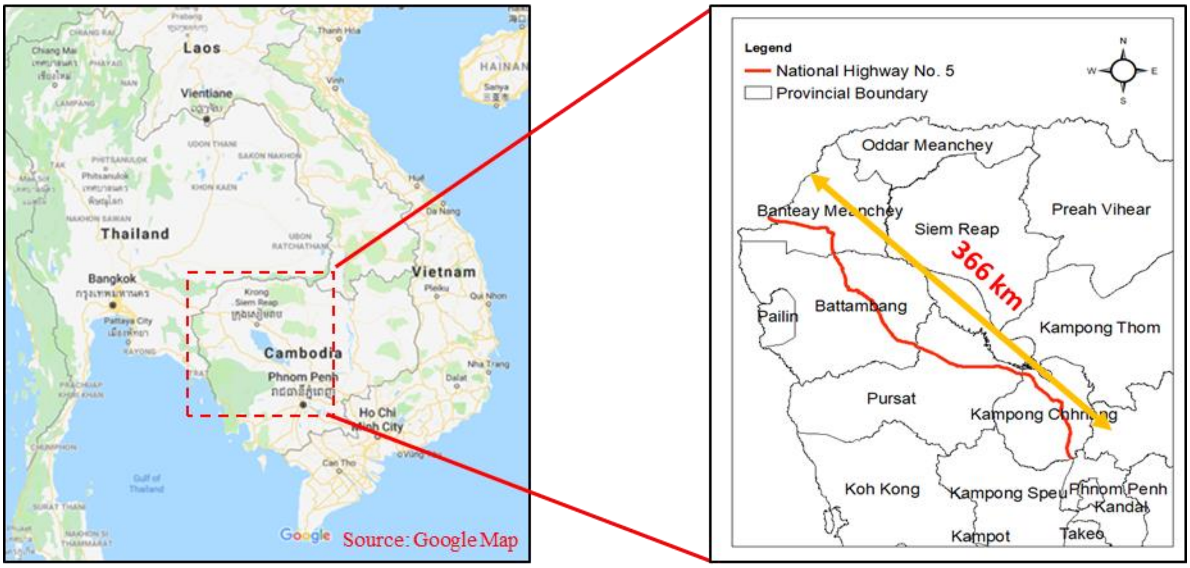
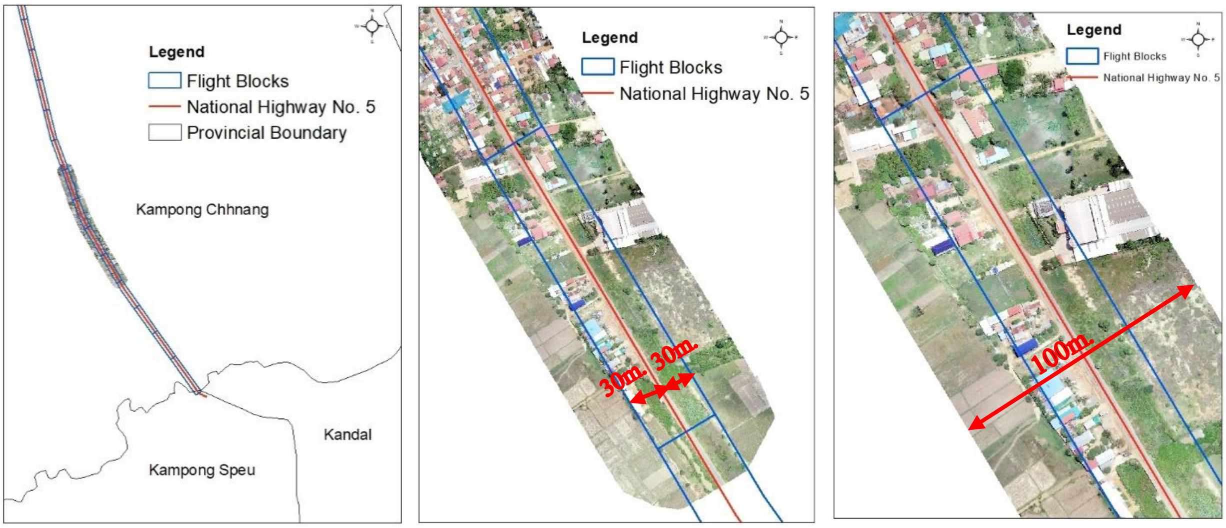


Figure 1: Pilot Project Area Location Map

Figure 2 illustrates the high-resolution fresh aerial photography scheme using UAV. According to the Government Ministerial Orders No. 06, 1999 and Sub-Decree No. 197, 2009, the ROW for National Highway No. 1, 4 and 5 is 30 m. length from the centerline on both right and left side. Thus, minimum mapping width of aerial photograph should be 60 m. plus some buffer area. In this project, the mapping width of aerial photograph is 100m., which ensure 100% coverage of the ROW with the highest confidence level.



(a) (b) (c)

Figure 2: Illustration of Pilot Project Area UAV Flight Blocks for Photograph Acquisition ((a) UAV Blocks (b) ROW-30m. Right & Left of NH5 central line (c) Width of Photograph 100m.)

3. UAV PHOTOGRAPHY DATA PROCESSING AND PRODUCTION

3.1 Selection of Technology and Work Flow

In the surveying and mapping industry, there are several methods to acquire aerial photographs as presented and compared in Table 1. The workflow of data acquisition and processing shown in Figure 3.

Table 1: Methods/Platforms for Aerial Photograph Acquisition

	EO Satellite	Aircraft	UAV (Fix wing)	UAV (rotary)
GSD	30 ~ 70cm	10 ~ 20cm	3 ~15cm	3 ~15cm
Initial Cost	High	High	Mid	Low
Running Cost	N/A	High	Mid	Low
Coverage	High	High	Mid	Low
Plan~ Acquisition	1 to 2 Months	Several months	1 Week	1 Week
Conditions	Minimum purchase 100sqkm (short side 5km)	Calibration and mounting to aircraft	Takeoff/landing space	Short flight duration

As basic condition, the project focused mainly on two points, (i) linear photograph/image acquisition along the national highway and (ii) the photograph/image resolution/GSD must be below 15cm to visualize central line of the road and building edge. High-resolution Earth Observation (EO) Satellite imagery can be effective for wide target area though due to purchase conditions and image resolution, it does not match these requirements. Aerial photography, using aircraft, is fast and accurate though the cost is not matching in this project. The project has short listed the fixed and rotary type UAV and selected the rotary, because identifying takeoff/landing space for the project length (366km) is insufficient. The rotary UAV is the most constant in cost and performance that meets all requirements of this project.

The Figure 3 illustrates the basic workflow of data acquisition, processing and production. As illustrated, after acquisition of aerial photograph, data processing conducted in the office, as deskwork, by utilizing standard software for UAV data processing to generate necessary data for field survey and data finalization. The details of each steps described subsequently in subsections.

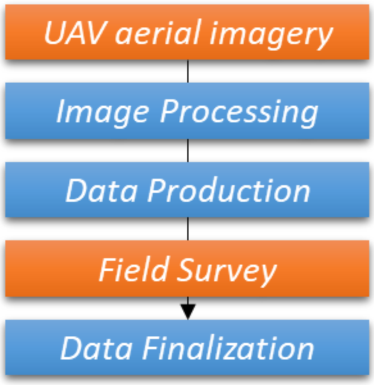


Figure 3: Basic Workflow (a) Orange - Outside/Field Work and (b) Blue – Office Work

3.2 UAV Aerial Photographs

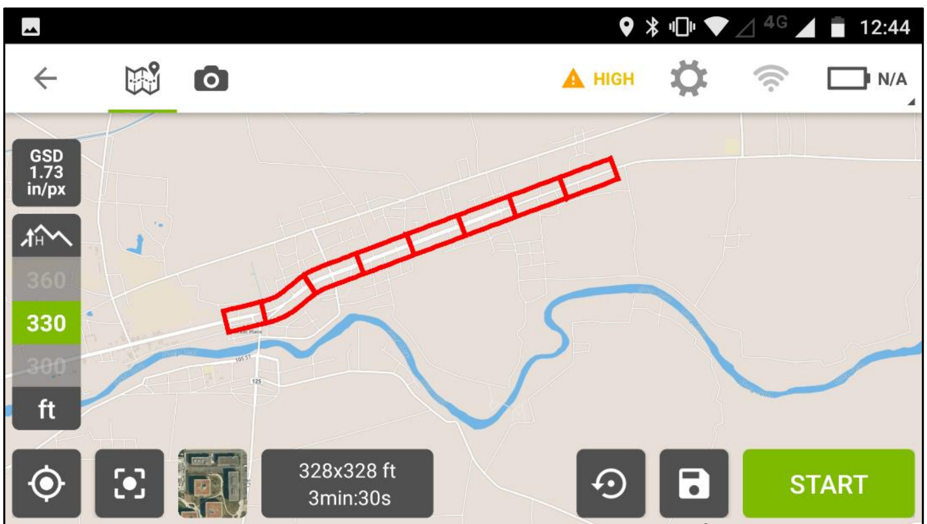
For the acquisition of aerial photographs, the used flight parameters are as given in Table 2.

Table 2: Flight Parameters

ITEMS	VALUE
Rotary UAV model	DJI Phantom 4 Pro
Over/Side Lap	80%
Ground Height	100m = 2.7cm GSD
Note: Although required GSD is below 15 cm, for clear appearance of Road Central line, the best possible GSD was used.	

In order to implement an efficient and accurate work, and give access to all members of data acquisition and production team without any software licensing restriction, we have used QGIS to create flight plan and divided into 500 m. blocks, with following steps:

(i) creating split points at 500 m interval along the NH5 road line,
(ii) splitting the road line utilizing these points,
(iii) buffering the lines using 100 m. width to fully cover the ROW with highest confidence level, and finally,
(iv) importing the blocks polygon into the operation tablet for data acquisition operators, using Pix4D Capture software, which includes background map, as illustrated in Figure 4.



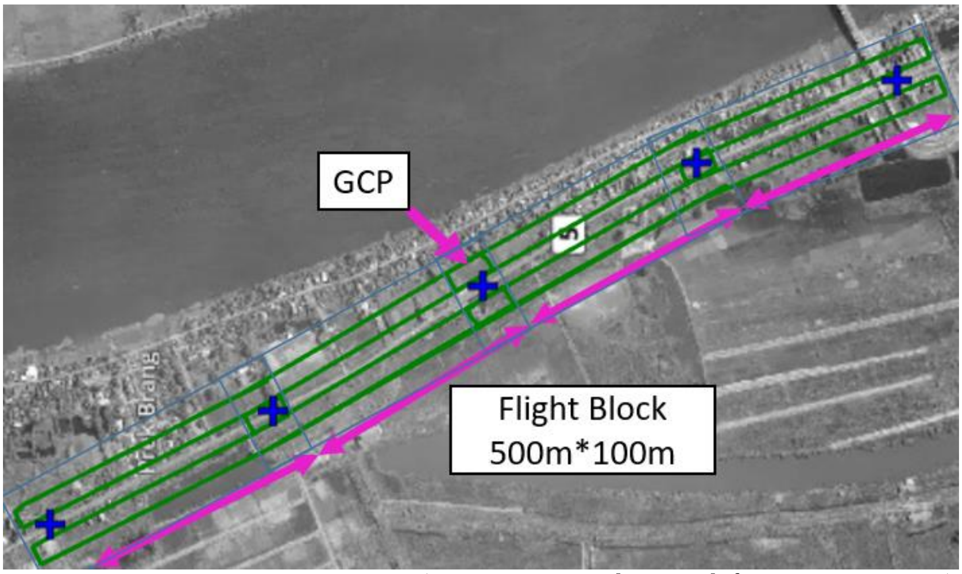
(Source: Existing Map from Pix4D Capture)

Figure 4: Sample Blocks into Operation Tablet used for Data Acquisition

Usually for linear photograph acquisition with a large number of connecting blocks, the photograph connection between neighboring photographs is the biggest problem. The project was not aiming for absolute accuracy as a map, rather to grasp the current conditions, specifically for illegal encroachment inside the ROW area. Therefor the project has used a handy Global Positioning System (GPS) receiver and created a temporary Ground Control Points (GCP) at the end of each flight blocks to create seamless imagery of entire pilot project area. The process resulted into an acceptable result as explained in the next subsection.

3.3 Image Processing

Pix4D Mapper, a Photogrammetry Software for UAV Mapping, was used as the post processing software. For each processing unit, four flight blocks and five GCPs were imported into Pix4D Mapper. A sample of such unit displayed on existing photograph as background is illustrated in Figure 5.



(Source: Exiting Photograph from Pix4D Mapper)

Figure 5: A Sample of Processing Unit (Four Flight Blocks and Five GCPs) on Existing Photographs

The limit of four flights photographs for a processing unit was due to the hardware and software limitations, as use of more than four flights, the workstation (specification given in Table 3) crashes multiple times.

Table 3: The Workstation Specifications

OS	Win 10 Pro 64 bit
CPU	Intel ® Core i5-8400 @2.8GHz
RAM	32GB
GPU	NVIDIA G Force GTX 1050Ti

Due to the mass work volume and the scope (which is not accurate mapping), the project has not verified the accuracy by comparing the geo-rectified image products and the ground coordinate value. However, referring to one processing project's quality report, exported from the Pix4D mapper software, states Route Mean Squire Error (RMSE) as X: 1.163, Y: 2.363, Z: 0.951 (m.), which is within the acceptable range under the scope of this project. In addition, using QGIS to show the geo-rectified imagery and by visually verifying the connections, no critical miss alignment found.

3.4 Data Production

The digitizing work conducted by utilizing processed geo-rectified imagery and QGIS software. To avoid confusion, the data was divided into three geometry types, which are Point, Line and Polygon as shown in Figure 6. Point data divided by more than 30 codes to subtypes such as building types, road facilities, and illegal land fillings. Line data has three codes, which categorizes the road classes. Polygon data includes subtypes such as building outline, concrete land fillings and land use. For all the data processing work, the World Geodetic System 1984 / UTM Zone 48N (egm96), projection system used, which is the standard projection system in Cambodia. The quality of data attained by utilizing the relevant data production manuals for required accuracy, metadata, data structure and topology and coding system. By considering the main purpose of physical features extraction, which is Current Status Identification (CSI), the features code for Point, Line and Polygon/Area assigned as “CSI_P”, “CSI_L” and “CSI_A” respectively.

Figure 6: Digitization of Defined Features using QGIS Software for their Current Status Identification (CSI)

3.5 Field Survey and Data Finalization

After completion of digitization of required features from processed imagery and the initial required data collection from available client source, field surveyors downloaded the data on their tablets (prepared for field survey work) and visited the project site to add attribute information as ground truth. Furthermore, the surveyor also took ground photos to record the date and actual ground condition as evidence. After the completion of the scheduled fieldwork, the surveyor returned to the office for further data processing.

The field surveyed and collected data further processed, cleaned and uploaded into the server in the office. Necessary steps were taken to maintain the pre-defined quality control protocols at the same time. In quality control, the operators check Perfection (any miss collected data), Logical (attribute and ground photo), geo location (point, line and polygon are in correct place and shape), besides others.

The section 3 and subsequent subsections explained the aerial photographs acquisition by using rotary UAV, image processing, required features extractions within the ROW, field survey, data finalization and uploading in server by utilizing workflow. In the next section 4 presents the utilization of simple and basic WebGIS system, which shows how all these activities achieved in the efficient manner by utilizing open source software.

4. DATABSE CREATION FOR WEBGIS SYSTEM

This section summarizes the database structure and applications. Figure 7 illustrates the database architecture mainly utilizing open source software such as OSGeo products (QGIS, PostGIS, Geoserver, etc.), PostgreSQL and MySQL. Currently the system is designed not to be open to the public through internet. Thus, the data transaction is only possible within the intranet for authorized user inside MPWT premises. It is in accordance with the disclosure policy of the MPWT, Cambodia, and content of the database.

4.1 QGIS

The GIS operator, with administrative privilege, directly connects to the database through QGIS and database connection function to modify the original data to draw road centerlines, plot illegal encroachment buildings and other structures by utilizing geo-rectified imagery, and create ROW boundary and buffers, flight blocks, compose cartographic maps, etc. In addition, GIS operator review the existing and collected GIS data and make necessary editing and integrate into the database.

4.2 Tablet Application

The Tablet Application, especially designed for the project, used for field survey work. After the fundamental data produced, in production stage using QGIS, the data is ready to download in a tablet local storage using an Application. The Application is a map viewer and contains functions for downloading and uploading data from and to the server, view the data as a map, modify points, add detail attributes, and capture and add ground photos. After completion of the targeted fieldwork, the surveyor returns to the office to upload the updated data into the server. All the uploaded data await verification and authorization by the administrator. Once the work is authorized, the server search and apply the modifications.

4.3 WebGIS

Management level officers can use this tool mainly to view the map, check progress, count points according to category, and output a report. The report will be a base information for decision making in order to take necessary measures and steps on illegal encroachment prevention. Figure 7 illustrates simple design of WebGIS system, where host server at MPWT installed with Relational Data Base Management System (RDBMS), using required open source software for data management, fieldwork and sharing among authorized user according to defined their access privileges.

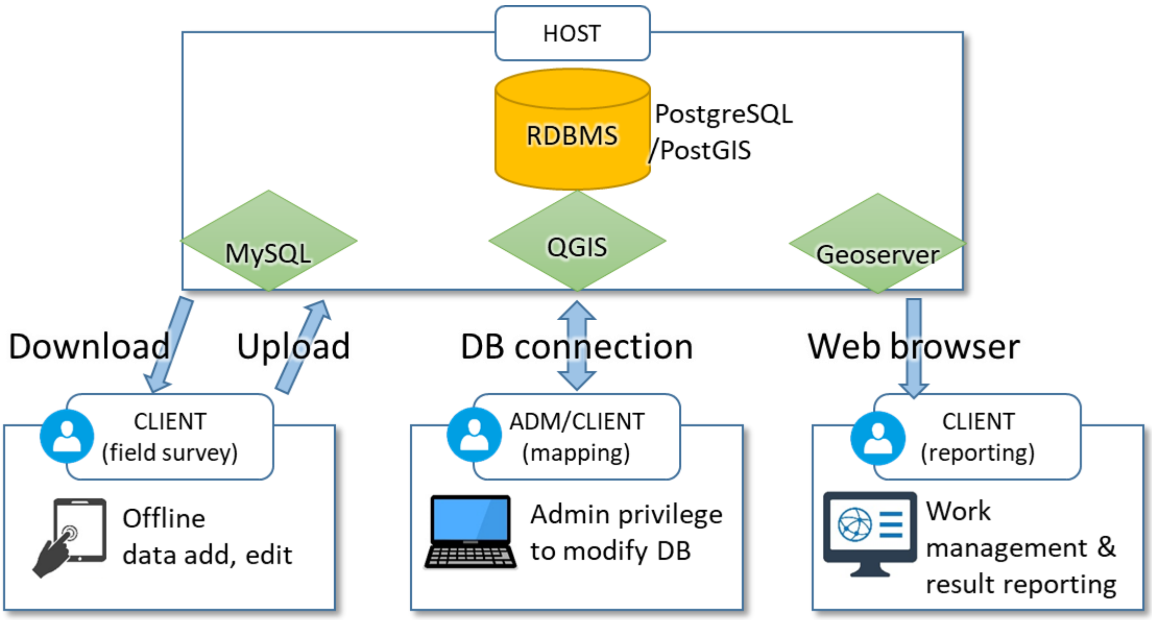


Figure 7: Design of WebGIS Portal for Data Management, Sharing and Fieldwork

5. CONCLUSION

Low cost solution has been devised by utilizing UAV, basic hardware and peripherals, and mostly open-source software while considering the required accuracy and available budget for the part of National Highway No. 5 as the pilot project area in Cambodia. The development of all required geospatial and information data, which feed into the ROW system, achieved successfully with the following five (5) steps:

- (i) acquiring very high resolution aerial photograph using UAV,
- (ii) geo-rectification of the aerial photograph, which meet the required accuracy,
- (iii) further processing and interpretation of geo-rectified imagery to extract required geo-spatial features, point, line and polygon data in Shape format,
- (iv) creating basic geo-database and WebGIS system for data management, sharing and necessary field survey work to acquire defined ground spatial and information attribute data, and
- (v) populating the geo-database of WebGIS system with all required data and information, which feeds into the ROW system development for the MPWT.

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REFERENCES

ADB, 2019, Asian Development Outlook, Strengthening Disaster Resilience, April, 2019, Asian Development Bank, Manila, Philippines

ADB, 2018, Experts Discuss Bridging Funding Gap for Asia's $8.4 Trillion Transport Needs, September 12, 2018, retrieved June 27, 2019 from https://www.adb.org/news/releases

Chapman, A., 2016, Types of Drones: Multi-Rotor vs Fixed-Wing vs Single Rotor vs Hybrid VTOL, Retrieved June 27, 2019, from https://www.auav.com.au/articles/

Chea, S., Nou, V., Tsuchida, T., Yamashita, A., Ochi, M., Kumagai T., and J. K. Watson., 2019, RIGHT OF WAY MANAGEMENT SYSTEM IN CAMBODIA, presenting at 39th Annual Conference of the International Association for Impact Assessment, 29 April - 2 May 2019, Brisbane Convention & Exhibition Centre | Brisbane, Australia

Nishizawa, T., 2018, Infrastructure Investment and Finance in Asia, Policy Research Institute, Ministry of Finance, Japan, Public Policy Review, Vol.14, No.5, pp. 925 – 953, September 2018