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The potential of UAV-based remote sensing for supporting precision agriculture in Indonesia

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Abstract

This paper shows some practical experiences of using Unmanned Aerial Vehicle-(UAV) based platform for remote sensing in supporting precision agriculture mapping. Some of the information for land preparation, cadaster boundary, vegetation monitoring, plant healthy, and stock valuation are required periodically. So, the UAV-Based remote sensing system should have characteristics such as cost-effective, fast in producing, easy in operation by local staff, and good geometry accuracy (sub-meter). The system consists of aerial platforms from R/C plane, point and shoots digital cameras, data processing with digital photogrammetric: structure from motion algorithms, and free open source-GIS for visualizing. This system has the ability to produce imagery with spatial resolution <10cm, measuring parcel area, assess the individual trees or plants stock, and topography. The basic products of the system are Orthophoto Image and Digital Elevation Model (DEM). The Average geometric accuracy can be obtained up to 3 pixels or equivalent to sub-meter accuracy, while the production time can be reached more than 500Ha a day. The Orthophoto image could provide visual interpretation such as the individual trees structure, plant density, and parcel boundary area, while DEM could asses tree's height information and terrain topography with accuracy 3-6 pixel or 0.5-2.5 m.

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1. Introduction

Nowadays, in Indonesia's geo-information market, the application of remote sensing industry to support the agriculture, forestry, and aquaculture has increased. In general, these application or orders are fulfilled by

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spaceborne satellite imaging remote sensing technology. There are only limited requests for doing the aerial photography. This is caused by some reasons, such as the production cost, and limited infrastructures condition in the field. Unfortunately, many of Indonesian remote sensing industry just as a selling agent and do not have any platform to provide imagery by itself. Furthermore, in some application such as monitoring of the individual trees structure, the high resolution satellite imagery still cannot fulfill this. One of the advantages of the aerial photograph in comparison with satellite imagery is it can be used to observe each individual trees structure (Fig. 1).

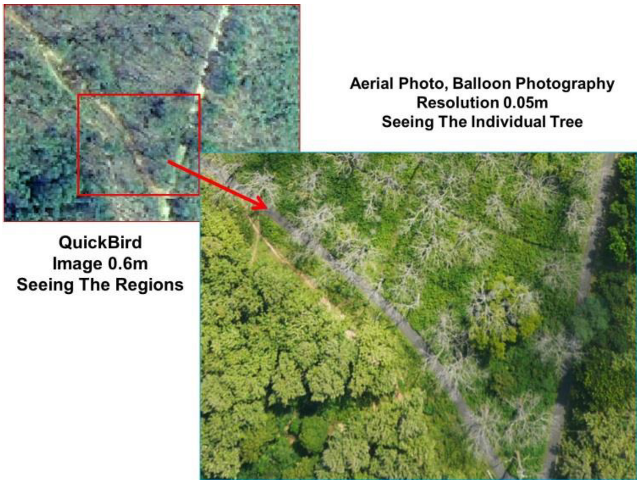

Fig 1. Comparison between high resolution satellite and aerial photography in teak wood forest

Many definitions for Precision Agriculture (PA) exist and many people have different ideas of what PA should encompass. Precision farming or precision agriculture is a farming or agro-industry management concept based on observing and responding to intra-field variations. It relies on new technologies like imagery and information technology. It is also aided by farmers' ability to locate their precise position in a field using satellite positioning system like Global Positioning System (GPS). PA is known has the capabilities to: (1) optimize production efficiency; (2) optimize quality; (3) minimize environmental impact; and (4) minimize risk [1].

Good precision information in agro-industry management will affect the production function of the farm, such as (1) Instantaneous yield monitoring (e.g. every week or every few meters); (2) Density/salinity/yield mapping; (3) Weed mapping; and (4) Topography and boundaries. In the exact plantation area, the map products are needed for some purposes such as monitoring the vegetation and its health condition, terrain analysis for hydrology, and biomass volumetric calculation. Some of the precise parameter measurements capabilities are needed such as the trees high, the canopy diameter, and the slope of terrain. This paper demonstrates the use of low-cost precise agriculture mapping system to answer some measurement problems. The system should have characteristics such as (1) good GSD (Ground Sampling Distance) less than 20 cm; (2) portable and easy in operation by local staff; (3) produce stereo viewing; and (4) good accuracy in sub-meter level. This system utilizes some hobby products, such as aero-modeling plane and digital point and shoot camera for reducing the cost. The challenge is to enhance its capabilities and the processing to become close to the professional instruments.

2. UAV-Based Remote Sensing System Architecture

In the last ten years, there are a number of studies that utilize Unmanned Aerial Vehicle (UAV) platform in the mapping system in the production of large-scale maps (> 1/10.000). One of them is built on Photogrammetry and Remote Sensing Laboratory, Department of Geodetic Engineering, FT-UGM since 2007 (see http://www.potretudara.com). The system is intended to fulfill the needs of low-cost mapping in a small regional coverage less than 15.000Ha [2, 3, 4, 5, 6].

Almost as the same as a conventional aerial mapping technique with manned aircraft, this system uses an unmanned aerial vehicle (R/C aircraft) as an airborne platform for carrying digital cameras (as imaging sensor) to take some aerial photographs at the position that has been arranged (flight plan). Furthermore, the aerial photographs are processed by digital photogrammetric technique to produce some basic products which are the orthophoto mosaic, and point cloud of digital elevation model. The personnel team for running the system consists of (1) a pilot who operates the aerial platform, (2) pilot navigational who monitors the flight plan; and (3) the surveyor for DGPS Survey and post processing. While the main instrument consists of a number of modules, namely (1) unmanned aerial vehicle equipped with avionics-autopilot; (2) imaging sensor (camera pocket size) and the cradle system; (3) ground control station; and (4) the photogrammetric processing software structure from motion algorithm. Basically, the workflow principle of the mapping system utilizing UAV platform is almost as the same as the conventional aerial mapping procedures, the main differences is the use of portable and smaller aircraft instrument model. The system consists of several modules, namely (1) air vehicle, (2) imaging sensor and its mounting, (3) data processing and visualization of results, (4) ground control station, and (5) database. Figure 2 shows a modular workflow between the modules.

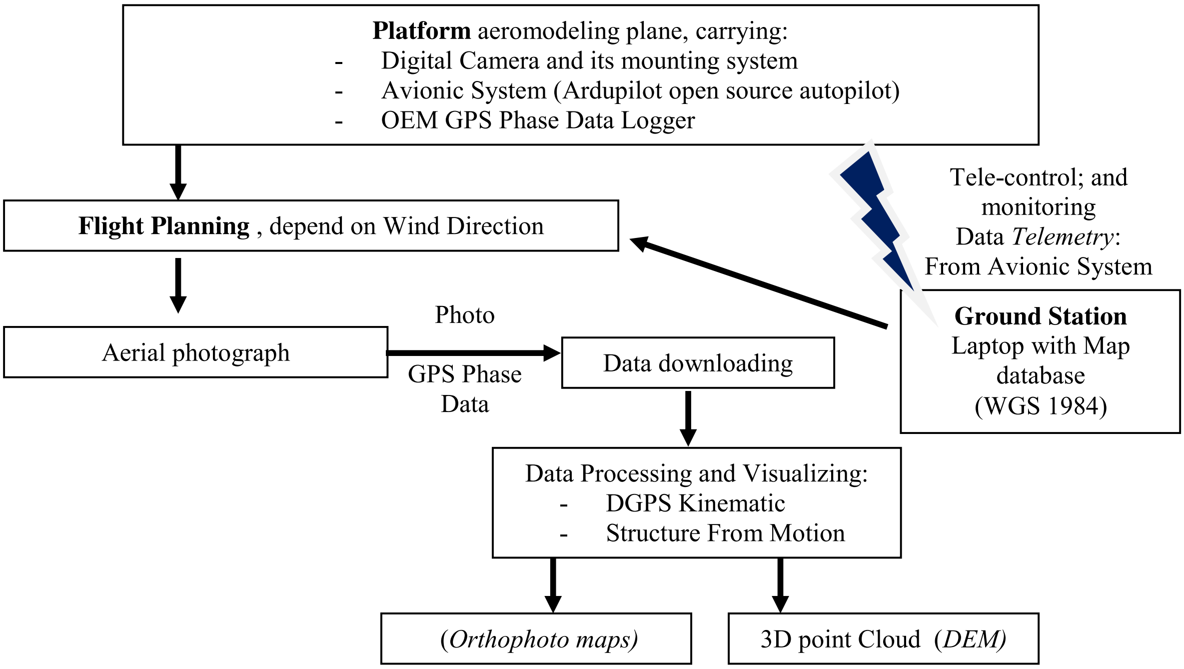

Fig. 2. System architecture of UAV-based remote sensing

The systems is utilizing R/C plane with a total weight <2.8 kg. UAV platform is relatively light that makes it easily disturbed by wind and air turbulence and making it difficult to follow the flight plan. Navigation avionics system consists of GPS navigation 10Hz, remote control, and R/F (Radio Frequency) Telemetry. The R/F Telemetry transmits GPS telemetry data and inertia data to the Ground Station. In certain types of air vehicles that are less stable platform, it needs co-pilot for stabilizing and leveling the plane automatically (auto-leveling). Working with aerial photography for remote sensing requires a camera that capable for running time-based or distance-based interval shutter. Script program on a Canon camera (CHDK) can be used, so that the time lag between exposures can be set. The use of a pocket camera with a small optical-electric sensor (CCD) size causes the coverage area on the photo frame much narrower, as consequences, the number of aerial photographs to be processed can be large or up to 500 photo frame per 300Ha coverage area. So, we need automation in the process of restitution of photos to handle the large number of these photo frames. Furthermore, the data vector (line map) obtained from the interpretation and digitization process on the orthophoto image. In general, the stereo-plotting processes have replaced by a stereo-matching in terms of production DEM data and the purposes of orthorectification correction. Production phase for interpretation and digitization is a bottle neck in the whole production process because it still uses manual operation. In general UAV-based remote sensing can record images with GSD values 5cm - 20cm from flying height of about 160m - 400m. In the case for precise agriculture, the GSD values <15 cm is sufficient to be able to see clearly the individual tree or some object boundary (Fig.3)

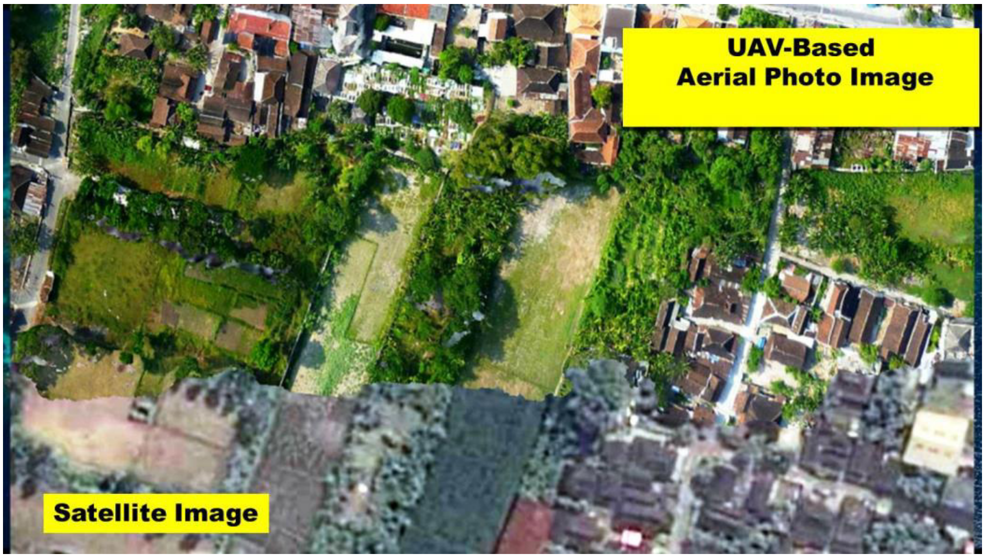

Fig. 3. Visual comparison between UAV-Based Imagery vs QuickBird satellite imagery

In contrast with conventional photogrammetric survey with manned aircraft and professional instruments, the UAV-based system is using instruments hobby / amateur / mass products stuff for keeping it cost down. In order to meet the needs of professional's quality, it needs some special treatment and improvements to increase capacity and provide accuracy that meet quality standards. Here are a number of efforts to improve the quality in the utilization UAV, as follows:

1. One of the dominant sources of error is the use of non-metric cameras lens quality. Working with non-metric cameras, there are a number of issues related to accuracy, namely: (1) The quality of the non-metric lens, and (2) the stability of the lens. This is systematic error, so, the issue of accuracy is solved by the procedure of In-Flight self-Calibration technique. The in-flight calibration can reduce the precision adjustment less than 2 pixels.
2. UAV platform has weight less than 3kg. So, when the weather is windy> 40km / h would be difficult to be able to follow the flight planning perfectly. In order to compensate this weakness, expanding the overlap area to 85% and 25% side lap area could be done, so there is no gap in coverage area. This condition will produce a large number of photos (more than 500 photo frame per 300 Ha). As a consequence, the automation processing is required to handle the photo restitution process.
3. The number of images and the large overlap area could help to facilitate process automation and improvement of the geometric quality of the final product. The automation process in Aerial triangulation with image matching algorithm becomes more reliable result, because of higher correlation between adjacent photo frames.
4. In general, the quality of the horizontal position can reach 2 times the size of the GSD or in range 10cm - 40cm depending on the current value GSD of aerial photograph. Meanwhile, the vertical accuracy can reach 3 times GSD or in range 50cm – 2.5m.
5. The main problem which is being the limitations of aerial survey techniques is the object cannot be seen due to

others higher objects covered. In general, the vegetation or higher rise buildings are the most barriers to be able to see objects parcel boundaries.

6. In a number of cases that require topographic product or a digital terrain model (DTM), the survey product from the air is not always able to see objects on the ground. In these conditions, it is necessary to reduce the data (filtering process) of digital surface models (DSM) into a terrain data (Figure 4). Filtering process cannot guaranty the final accuracy, because the object is not visible on the ground or cannot be measured directly.

Fig. 4. Ilustration of filetring process from DSM→DTM (brown)

3. Practical Application and Discussion

3.1. Application in Teak Wood Forest

This case is located at Teak Wood forest owned by PT Perhutani KPH Madiun. The purposes of aerial survey activities are to support calculation or assessment of wood or asset stock. So, the individual tree structures has to be seen clearly, than the tree structure such as high and canopy diameter can be measured from the imagery (Figure 5) illustrates the basic product, which are orthophoto, and digital surface model of the forest area.

Orthophoto image Shows different teakwood and 3D model (measuring high)

Fig. 5. Visual interpretation at teak wood forest

Some notes regarding to teak wood aerial survey, as follows:

1. In general, the geo-reference coordinates is not the main important things in the vegetation monitoring. The most application is the capabilities to measure the tree structure objects, which are the shape diameter of the tree canopy and the tree high. So, this can be main the advantage on using the close range photogrammetry for the processing.
2. In the higher density vegetation, it is difficult to see the terrain. So, the tree height cannot be measured directly, but it could be interpreted by interpolating the terrain from the tie-point as a spots high.
3. The tree height accuracy can be improved by using some oblique aerial photograph. As a consequence, it reduces the correlation between images. It makes difficult to make automatic tie-point matching in the forest area. Some code targets as a pre-mark should be placed in some area to make easy in tie-point matching.
4. For the future, it needs to evaluate the correlation between the tree structure (canopy, high, density) and the actual volumetric wood production.

3.2. Application for Calculating Area of Parcel in Paddy Field Areas

In cadaster application, both of the boundary and area information are important. Some comparison areas have been conducted to evaluate the geometry quality of Orthophoto product (Figure 6) shows the test area selected in paddy field close to the Menara Cigarette Factory. The comparison is done by measuring the area with terrestrial technique then compared with area digitized on orthophoto. Regarding to the technical specification from National Land Agency, all of the 20 test areas show that there are no significant differences between terrestrial and aerial mapping product. The statistical area differences are (1) average 1.02 sq.m; (2) max. 3.8 sq.m; and min. 0.74 sq.m. The individual test areas are varies between 0.025 Ha up to 0.088 Ha.

Fig. 6. Selected test area at paddy field

Although aerial image have high resolution ($\pm$ 5cm spatial resolution), it still have advantages and disadvantages especially for cadastre applications, such as:

1. In the open area such as paddy field, it is easy to see the boundary. Using high resolution image (< 5cm) it is suggested to mark the pole boundary with plastic tape (10 cm width) also.
2. Sometimes, the boundary corner cannot be seen, because it covered by vegetation. This is the main problem in

using aerial images.

3.3. Application in Palm-Oil Plantation

The study case is located at Palm-Oil Plantation owned by PT Jabontara Eka at Berau East-Kalimantan. The purposes of these mapping activities are to support calculation of stand per Hectare (SPH) or individual palm tree that can be measured from the imagery (Figure 7) illustrates the basic product, It could be orthophoto, and interpretation of the individual tree measuring.

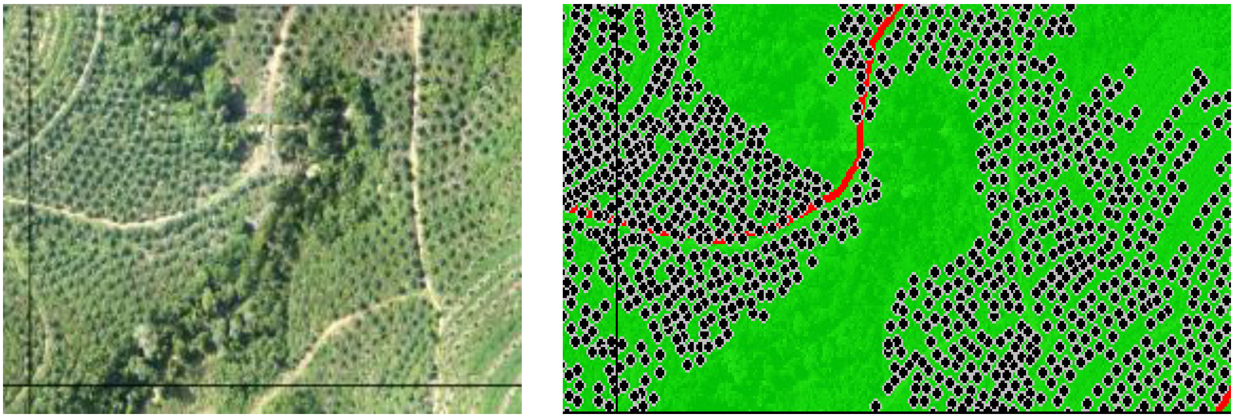

Fig. 7. Illustrations of mapping products for palm-oil counting trees

Some notes regarding to Palm-Oil plantation mapping using this tehnique, as follows:

1. In general, the most important is the capabilities to count the individual tree instead of the absolute coordinate's accuracy. The counting trees are done by visual interpretation based on the canopy. So, in the future, the challenge is to build an automatic method to count the trees. .
2. Sometimes, the Palm-Oil trees are planted in between the forest areas, or sometimes the tree is too young or too small to see. This cause the differences between tree counting result versus filed notes.
3. For the future, it needs to improve the accuracy and computing time on counting the tree. At least more than 95% interpretation accuracy should be obtained.

3.4. Application in Sugar Cane Plantation

This tudy case is located at sugar factory field owned by PTPN (Perkebunan Nusantara) near Iswahyudi airfield Maospati East Java. The purpose of the mapping activity is to support taxation calculation for sugar cane asset. So, the 3D information is needed to be able to calculate volumetric. Also, the high resolution imagery is needed to see the density of vegetation or others weeds vegetation (Figure 8). The 3D model shows that younger vegetation shorter than old vegetation. The accuracy up to 3 pixels same as 15cm (with 5cm spatial information) can be achieved in measuring shape and dimension of the object. For the future it is needed to be evaluated the correlation between volumetric that measured from the image with the actual taxation on the factory.

Othophoto (measuring planimetric) and 3D model (measuring volumetric)

GSD 5cm in still cannot clear to see individual plants

High spatial resolution (< 5cm) shows sugar cane crop density and dead area

Fig. 8. Illustrations of mapping products at sugar cane field

In general, this system have some interesting characteristics, which are (1) its cost-effectives; (2) can be operated by local staff; (3) appropriate in geometric accuracy (sub-meter); and (4) fast in production up to 500Ha pe day. Meanwhile, it also has some limitation capability such as (1) working in large area (> 5000Ha), there are too many number of aerial photo; (2) It still needs some Ground Control Points (GCP) for accurate georeferencing; and (3) working with small R/C Plane can only handling small payload sensor (<300gram).

4. Conclusion

This paper shows some practical experiences on using Unmanned Aerial Vehicle-(UAV) platform based for remote sensing in supporting of cost effective precision agriculture mapping. The UAV platform utilizes the R/C aeromodeling plane as the aerial platform that carrying digital pocket camera as sensor imagery. The two basic products of the system are orthophoto and digital elevation model (3D point cloud) with accuracy up to 2 pixel error for horizontal position and 5 pixel error for vertical. From the orthophoto product that shows planimetric information, the parcel area and the canopy diameter can be measured, while from the 3D model or digital elevation model product can be interpreted to get information related to the vegetation or tree structures such as tree high. For the future, what it need is to develop formula to find the relationship between the structural parameters of individual plants (Canopy, Height, Density) that can be measured by this system with the potential stock of the plants.

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