UAV application for oil palm harvest prediction

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Abstract. Determination of UAV system configuration for oil palm harvest prediction application is an important step in plantation production maximization. The objective of this paper is to demonstrate how UAV systems can be used to produce high-resolution images that can be used to predict crops. The study is divided into two stages: UAV system configuration analysis and digital image processing to predict the crop. The UAV system configuration analysis consists of airframe, propulsion, avionic and ground control station. Airborne systems use a X-8 airframe controlled with Pixhawk avionics, electric motors, and a 20.2 Mega Pixel digital camera. The UAV system is used to produce a high-resolution digital image on a 6-year-old oil palm plantation in Labuhan Batu Utara, North Sumatra. This UAV system produces high-resolution digital image that can be used to calculate the number of plants. The number of plants in this particular area is then used as input to predict the crop. Estimated harvests of 6-year-old oil palm plantations produce an average of 50.5 tons per year per hectare. This result is bigger than the one of palm oil plantation management's estimation company which is 23 tons per year per ha.

1. Introduction

The study defines UAV based on definition from others organizations or researchers. The Radio Technical Commission for Aeronautics (RTCA) defines UAV or unmanned aircraft as an Aircraft operated without the possibility of direct human intervention from within or on the aircraft [1]. International Civil Aviation Organization (ICAO) defines UAV as a pilotless aircraft, which is flown without a pilot-in-command on-board and is either remotely and fully controlled from another place (ground, another aircraft, and space) or programmed and fully autonomous [2]. Regarding to Joint Publication 1-02, United State of America, UAV is defined as a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles [3]. Unlike the UAV definitions, the study defines UAV as a pilotless aircraft with electric battery power, can fly autonomously or be piloted remotely, can be hand launched take off, with a digital small format digital camera as payload, and can be recoverable [4].

UAV can perform to support military and civilian mission. UAVs military missions can perform as electronic intelligence, deception platform, target acquisition, surveillance, jamming platform,
battlefield damage assessment, psychological warfare platform, local conflict detection, basic missile, border patrol and target drone [5]. Regarding to the previous research, UAV also can performs as forest monitoring, disaster monitoring, traffic monitoring, commercial monitoring, aerial mapping photography, telecommunication relay and fisher guide for civilian mission.

Agriculture nowadays has become a knowledge-based industry in response to the economy and environmental considerations. To help meet the needs of observational data, aircraft and remote sensing satellites play a deeper role in agricultural management. National Aeronautics and Space Administration (NASA) Pathfinder and NASA Pathfinder Plus are the first two aircraft developed as part of an unmanned aircraft evolution series with solar cell fuel systems. AeroVironment Inc. developed the aircraft under the NASA Environmental Research Aircraft and Sensor Technology (ERAST) program. The two aircraft were built to develop the technology for the long period application. High-altitude aircraft tasked with conducting atmospheric research and functioning as a vehicle for communication. NASA's Unfold Aerial Vehicle (UAV) Pathfinder-Plus is used as a vehicle for image collections. Pathfinder Plus is a light winged UAV equipped with eight solar powered electric motors for nutrient status, forest re-growth after damage caused by Iniki Storm in 1992, sediment / algae concentration in coastal waters and coral reef health detection. Since 1997, the Pathfinder-Plus UAV is a large-scale propeller aircraft that has a record high flight of 21 km [6].

Aerial photography using UAV with payload a Canon S110 NIR camera on plantation cotton, maize, sorghum, millet and peanuts produce high resolution image that can be used to assess the spatial variability of yield, and yield response to fertilizer [7]. Unlike the previous research, this study uses UAV with payload small format RGB digital camera. The use of small format RGB digital cameras gives a sharp appearance to the canopy of oil palm trees in plantations. This sharp appearance makes it easier for digital data processing to predict the harvesting of oil palm plantations. In addition, this study also does not include soil and plant fertility qualities as a variable in making predictions of crops. Based on these objectives then UAV system configuration technology becomes an important requirement in achieving the goal.

2. Method

There are two main stages in the research as follow:
1. Determination of UAV system configuration that play a role in making high resolution digital image.
2. Processing of high resolution digital image data to obtain estimation of oil palm plantation production.

2.1. UAV system technology

UAV system technology generally has similar configuration with manned aircraft configuration. Prior research defines the configuration of manned aircraft consisting of airframes, operation interfaces, propulsion systems, avionics/control systems and other systems [8]. The complete configuration is presented in figure 1.
The fundamental difference between UAV and manned aircraft lies in the method of controlling the airborne system and ground control system. Manned aircraft is an aircraft system manned by humans inside, a different matter in UAV does not require humans to control the system. Meanwhile the UAV requires a ground control station to control and communicate with the airborne system, a different matter in manned aircraft that does not require a ground control station to control its technological system.

Based on figure 1 and the definition of UAV, the following describes the components of the UAV:

- **Airframe** is a major component of the system airborne consisting of fuselage, wing and tail unit components. Airframe component is the main part of the airborne system in which there is propulsion system, avionics, communication etc. Airframe technology in order to obtain the characteristics of strong, rigid, and lightweight usually use a composite structure. The composite structure commonly used for UAVs is CFRP (carbon fiber reinforced polymers) and GFRP (glass fiber reinforced polymers).

- **Propulsion system** is a component of airborne system that serves as a producer of thrust. The main component of propulsion system is aero engine with fuel or electric power consumption. Another important component of propulsion system, especially for low speed UAV, is propeller.

- **Avionics/ control system** is a UAV controller component within the UAV airframe. Control system consist of flight control system (FCS) and communication link. FCS consists of hardware and software that control UAV to fly manual with external pilot command or autonomously. Communication link is vital component to ensure continuous communication between airborne system and ground control station or satellite.

- **Ground control station** is a major component of the UAV system located on the earth's surface. The component acts as operational interface to UAV's airborne system. Ground control station also acts as component to command airborne system when needed to correct UAVs position or characteristics.

### 2.2. High resolution image processing

There are two main steps to process high-resolution image taken from UAV for palm oil harvest prediction. Uncontrolled image processing and palm oil plantation characteristics literature support two main steps of the research.
Uncontrolled image processing. Geometric correction is image transformation that causes the image to have the properties of the map in terms of shape, scale and projection [9]. The objectives of geometric correction are:

1. Rectify or restore the image to coordinate the image according to geographical coordinates.
2. Registering (positioning) the image position with another image that has been corrected (image-to-image rectification) or transform multispectral and multi temporal image coordinate system image.
3. Register the image to the map or transform the image coordinate system to map coordinates (image to map rectification) so as to produce the image with a certain projection system.

Based on American Society of Photogrammetry (ASP), Air Image interpretation is defined as the act of examining of aerial photographs for the purpose of object identification [10]. Based on Manual of Remote Sensing, photo interpretation is part of remote sensing defined as the measurement or acquisition of information from an object or phenomenon using a tape recorder in the absence of physical contact with the object or the phenomenon being studied [10]. Implementation of aerial photograph interpretation can be done in three stages:

1. General Examination, this stage specifies the properties or characteristics of the observed areas such as arrangement of reliefs, plant species, culture, and landscape state.
2. Identification, this stage specifies all the topographic details or situations in the aerial photographs based on the interpretation key of the aerial photographs such as the study of road arrangement, distribution and building type.
3. Classification, this stage includes supervised and unsupervised classification, usually used to classify a whole dataset into classes.

There are seven basics key interpretations that can be done to recognize an object [10][11]. Seven interpretation keys to recognize objects are:

1. Size, Size is an object attribute in the form of distance, area, height, slope and volume.
2. Shape, general framework or configuration of an object in both shape and form to facilitate interpretation.
3. Shadow, a situation that occurs when there are objects with a certain height get sunlight.
4. Site, site is a topographical location or situation that can assist the interpreter in identifying objects in aerial photographs.
5. Rona/ Tone, Rona reflects the colour or level of quality of the brightness / darkness of the object image in the aerial photograph.
6. Texture, the frequency of change of tone in the image.
7. Pattern, is a characteristic object in the form of regularity and style.

Oil palm plantation characteristics. Generally, oil palm plantations can be opened in areas with characteristics exposed to direct sunlight with 5 to 7 hours of irradiation per day. Good temperature above 18 °Celsius with optimum temperature between 28°–34° Celsius. The rainfall required per year ranges from 1500 mm to 4000 mm, but the optimum rainfall is 2000 mm to 3000 mm [12].

Oil palm plantations have a standard of maturity for harvest purposes. Standard of maturity is the standard parameter in which oil palm is feasible or not to be harvested. The following standard of maturity is based on the amount of crushed palm fruit. It is important to maintain the harvest at short intervals in newly yielding plants or young plants, as the fruit will spoiled out more than 10% within 5-7 days, the old harvest interval resulted in the number of fruits and the number of crushed palm fruit. Proper harvesting of appropriate standards of maturity can prevent harvesting of raw fruits and reducing the collection of crushed palm fruit. The harvest interval should not exceed 10 days in the first three years after yielding and should not exceed 14 days in older plants, during low fruit season extra checks are done so that harvesters do not harvest raw fruits to meet daily target standards. For crops between the first year harvest up to three, at least 5 crushed palm fruit per fruit bunches with intervals of less than 10 days. For older plants, the maximum maturity standard is 3-5 crushed palm fruit per fruit bunches before harvesting with intervals of less than 10 days. The harvest interval is no more than 14 days.

Plantations have the characteristics of peak harvests. The peak harvest is the time when the production of palm oil fruits to the fullest. Oil palm production continues throughout the year, but
generally has three harvest patterns: low yield (track), medium (regular month) and peak harvest. Monthly Distribution Pattern (MDP) is observed from existing harvesting records and when enough data made the average pattern is 5 years. In the peak month to be anticipated, additional harvests are calculated as per daily production estimates and additional transport by taking into account the addition of the number of trips.

Fruit oil palm that is ripe size of approximately 4-5 cm in diameter with reddish orange fruit colour. At harvest time, oil palm has a small possibility to produce maximum production or 100% so the survey to determine the percentage of plantation production. Calculating Harvest Density (CHD) with formula:

\[
CHD = \frac{\text{the number of trees that produce}}{\text{number of samples}} \times 100\%)
\]

3. Results and Discussions

Result and discussion divides into UAVs system technology and high resolution UAVs image processing. There are four components of UAVs system technology result and analysis as follow:

UAVs airframe component. Airframe component is part of airborne system that serves carrying all load including avionic, power supply, payload and electric motor. Airframe’s performance also ensures the objective of mission that can be achieved. Referring to the initial definition of the UAV system in this study, "UAV is a pilotless aircraft with electric battery power, can fly autonomously or be piloted remotely, can be handled take off, with a digital small format digital camera as payload, and can be recoverable ", the main function of this airframe is to carry small format digital cameras for aerial photography missions. There is some option for small format digital camera; one of the options is Sony RX100 20.2 MP. The Sony RX100 20.2 MP and equipment has 400-gram weight. The selected airframe is also possible to be flown by hand launched method, so the total airborne system weight is not too heavy for this flight method. Another component that should be a concern is the weight of the battery used. Currently widely used the type of lithium ion battery weighing 900 grams and power 10,500 mAh. Another consideration in the selection of airframes is the maximization of endurance with maximum weight limitation of airborne system.

These considerations provide one of the alternative airframe options in the X-8 configuration. UAV X-8 is an airframe-based UAV made of styrofoam which allows to be flown with maximum take-off of 3 kg by strengthening my structure using CFRP. The X-8 airframe configuration is shown in figure 2.

![Figure 2. X–8 airframe configuration.](image)

The components of UAVs propulsion. The main function of the propulsion system is to create a thrust force against the drag of the airborne system at a certain speed. Propulsion system in this UAV
system uses electric motor brand OS Electric Motor type OMA 5020-460 with power 1.184 Watt and weight 350 grams. Electrical motor selection can provide reliability, low vibration, and operational ease. Electric motor requires battery 6 cell with power 10.500 mAh. In addition, electric motor also requires Electronic speed control, the configuration is used ESC HW 100A-V3 with electric motor is presented in figure 3.

![Electric Motor](image1)

### Figure 3. Power system: (a) electric motor and (b) speed control.

UAVs avionic component. The main function of the avionic system is to control the airborne system to perform certain flying missions in accordance with the waypoints that have been made. In the small format air photo function, in addition to the control function, avionic data in the form of pitch and roll are used as input for geometry correction of high precision digital image from small format digital camera. Avionics in this UAV system use a Pixhawk as shown in figure 4.

![Avionic System](image2)

### Figure 4. Avionic system.

The components of ground control station. The main function of the ground control station is the interface between operators and airborne system. Ground control station on the UAV system consists of hardware and software in the form of mission planner program to plan airborne system flight mission, computer hardware and telemetry system. Ground control station of the UAVs system is presented in figure 5.
Figure 5. Ground control station.

There are two steps to process high-resolution image taken from UAV to predict palm oil harvest. The steps are uncontrolled image processing and oil palm harvest prediction.

**Uncontrolled image processing.** Geometric correction process with Image to Map method produces a geo-mosaic. The big error geometric correction using ArcMap 10.1 software using the first order polynomial transformation is often called affine transformation. The position difference between the two points (XMap, YMap) and (XSource, YSource) is called the residual error that is showed in figure 6. The total of these residual errors is calculated by the sum of the mean square roots of all points resulting in the RMS Error value. To simplify the determination of RMS, the maximum RMS Error is divided by 10,000 for UTM, while for geographic coordinate system if known $1° \approx 111,000$ m. RMS Error of $(2,06875 \times 10^{-10})°$ or $0,0000074475"$. If the RMS Error value is less than $0.00005°$ or $1.8"$ for a scale of $1: 50,000$, the geometric correction process can be considered quite accurate [6].

![Image of Ground Control Station](image)

Figure 6. RMS with geometric correction of mosaic Afdeling 2 Block 5B.
Based on the standards established by ASPRS 1990 on standard RMS scale and tolerable size, the scale of 1: 50,000 is 10 m. While the result of geometric correction is 2.2963125 \times 10^{-5} m or 0.022963125 mm, it means that the photo mosaic can be used for this research. The uncontrolled image processing on Afdeling 2 Block 5B produces 3821 palm trees and 43 planting trees.

Palm oil harvest prediction is done through a series of steps as follows:

**The determination of CHD.**

The determination of the CHD value is done in the following manner:

1. Determine the sample region that is in Afdeling 3 Blocks 3B and 4B. This area is chosen because it coincides with harvesting schedule and planting age of 6 years according to availability of photo mosaic of Afdeling 2 Block 5B.
2. Determining the number of sample trees through a field survey using Roscoe sample technique that is selected the tree to harvest as many as 74 trees located in blocks 3B and 4B as in table 2.3.
3. In the field survey, what is done is by directly measuring the harvest per tree and marking 74 trees.

For example, the Density of Harvest Dates of oil palms planting age of 6 years using data 69 trees is the number of trees that have fruit and 74 trees is the number of trees as the total number of samples then the PPA as follows:

\[
CHD = \frac{69 \text{ trees}}{74 \text{ trees}} \times 100\%
\]  

Calculating Harvest Density (CHD) of palm tree planting age of 6 years is 93.24%.

**Average production per tree.**

The determination of the average value per tree was sampled on Afdeling 2 Block 5B. The results of the sample data processing in Afdeling 2 Block 5B are presented in table 1 [6].

| No | Parameter         | Value              |
|----|-------------------|--------------------|
| 1  | Mean              | 12,44307692 kg     |
| 2  | Average standard  | 0,608378872 kg     |
| 3  | Median            | 11,8 kg            |
| 4  | Modus             | 9 kg               |
| 5  | Standard deviation| 4,904907276 kg     |
| 6  | Sample variance   | 24,05811538 kg     |
| 7  | Kurtosis          | 2,855155721        |
| 8  | Skewness          | 1,358276662        |
| 9  | Range             | 26,8               |
| 10 | Minimum           | 3 kg               |
| 11 | Maximum           | 29,8 kg            |
| 12 | Sample            | 65 trees           |

Standard deviation data processing shows the level of accuracy of a data. Standard deviations get better after blunder data is omitted. So the average value after removing 4 data weighing 12.44307692 kg can be used to estimate the production of oil palm plantation Afdeling 2 Block 5B.

**Estimated palm oil harvest.**

Determining the estimated value of oil palm requires the number of tree populations and estimated production per tree. The number of staple population in Afdeling 2 Block 5B is 3821 palm trees, 43 trees of insertion plants, and 93.24% of the Harvest Density (CHD). Production estimates are made to
determine the average and minimum production values in Afdeling 2 Block 5B. Then the estimation is done for a one-year harvest with an estimate of each ha. The result of data processing is calculated from the formula below [6]:

\[
Production	ext{ }Estimation\text{ }100\% = Number\text{ }of\text{ }trees\times(mean\pm\text{ }standard\text{ }deviation) \tag{2}
\]

\[
Estimated\text{ }Production\text{ }CHD = Number\text{ }of\text{ }trees\times(mean\pm\text{ }standard\text{ }deviation)\times CHD_{survey} \tag{3}
\]

| No | Status                        | Average (kg) | Minimum (kg) |
|----|-------------------------------|--------------|--------------|
| 1  | Crops 93,24% 1 Blok           | 50407,460 ± 19886,479 | 12162,984    |
| 2  | Plants Inserts 93,24% 1 Blok  | 136,877 ± 0,000 | 0,000        |
|    | Total Production              | 50544,337 ± 19886,479 | 12162,984    |

The calculation of oil palm harvest production with CHD 93.24% produces an average harvest of 50544 kg or about 50.5 tons per ha per year. Meanwhile, based on interviews with the plant manager for Afdeling 2 Block 5B, the figure is 23 tons per year per ha.

4. Conclusions
The study concludes a result as follow:
- UAVs technology system consist of airframe, electric motor, avionic and ground control station.
- UAVs technology provide high-resolution digital image with GPS data attribute.
- The mosaic of high-resolution images taken from UAV error meets the requirements for use in advanced calculations based on the 1990 ASPRS standard.
- Calculations with small-format aerial photography approach with UAV resulted in an average harvest prediction of 50544 kg or about 50.5 tons per ha per year, while real production in Afdeling 2 Block 5B obtained 23 tons per year per ha.

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