Using LAPER Quadcopter Imagery for Precision Oil Palm Geospatial Intelligence (OP GeoInt)

N. Abu Sari[1], M. Y. Abu Sari[2], A. Ahmad[1], S. Sahib[1] and F. Othman[3]
[1] *Fakulti Teknologi Maklumat dan Komunikasi, Universiti Teknikal Malaysia Melaka, 76100 Durian Tunggal, Melaka, MALAYSIA*
[2] *Anjung Technology Sdn Bhd, 75450 Ayer Keroh, Melaka, MALAYSIA*
[3] *Malaysia-Japan International Institute of Technology, UTM, 54100 Kuala Lumpur, MALAYSIA*
nasruddin@anjung.my

***Abstract*— Maintaining consistent productive health of perennial crop such an oil palm is challenging, yet crucial for sustaining optimum yield. Oil palm production requires precision farming (PF) solution which conventionally makes use satellite remote sensing techniques to capture agricultural data. Nevertheless, such techniques suffer from constraints due to low spatial and temporal resolution as well as autonomy issues. Proliferation of micro unmanned aerial vehicles (UAVs) has made production of digital aerial imagery (DAI) become cheaper and easier. DAI conjugated with advances in photogrammetry workflow and analytics post-processing enable powerful geovisualization manipulation. Advance geovisualization manipulation of DAI has promising potentials to leverage precision oil palm (POP) farming. The study reported in this paper aims to adapt UAV-based personal remote sensing (PRS) techniques in producing DAI geovisualization and mapping to accommodate POP provisioning. A Study were carried out using Low Altitudes Personal Remote Sensing (LAPER), a customized micro UAV quadcopter, for acquiring oil palm DAI, and extensive post-processing workflow in producing oil palm explorative geovisualization and actionable base maps. Various simple yet insightful and actionable oil palm base maps were generated from the workflow. The paper concludes that LAPER is capable of adequately supplying temporal geospatial data for provisioning POP and oil palm geospatial intelligence (GeoInt) and oil palm planters can make use of LAPER imagery for geovisualization tasks for suggesting systematic actions in plantation management.**

***Index Terms*— LAPER; Oil Palm GeoInt; Precision Oil Palm; Remote Sensing.**

I. INTRODUCTION

Oil palm is currently the world major edible oil source and its spin-off products are ubiquitous in global consumer daily consumptions [1]. Oil palm cultivations have supply global populations with important source of calories and nutrients. Oil palm's highest oil yield per acreage trait and lowest price in the global edible oil market feature have made it the world most efficient oil-bearing seed crops [1,2,3].

Since early 1930 oil palm cultivations have been one of the most profitable land uses in the tropics region [3]. Proliferations of wealth in developing countries together with continuous worldwide human population growth have concomitantly caused an increase in consumption of edible vegetable oils [4]. Consequently, the global demand for palm oil was soaring dramatically [4,5]. The rising demands for edible oil have driven extensive oil palm agricultural production expansion activities worldwide which to the extent infringed the ecologically high-valued tropical rainforests [6,7]. For the past two decades, oil palm planters were pressured to halt expansion and opt for immediate plausible yield intensification strategies [8]. Despite debatable, there are strong possibility that sustainable plantation management and yield intensification effort could reduce or even eliminate the need for deforestation [8,9]. Plausible yield intensification strategies could meet the soaring demand for palm oil and increasing income to planters, while simultaneously reassuring global food security, eluding tropical deforestation and minimizing environmental negative footprint [7,8,9,10].

II. BACKGROUND STUDY

A. *Challenges of Oil Palm Farming Field Tasks*

Sustaining oil palm cultivation operations are labour intensive. These operations rely heavily on manual production field tasks and tight schedules of labour force for achieving the goal of maximum production yields (Table 1).

Table 1
Oil palm Input - operation tasks and its burden

Operation Task	Operation Burden	
	Cost	Frequency
Harvesting	medium	22-36 /year
Manuring	high	2-4 /year
Frond Pruning	medium	1-3 /year
Weed Control	medium	1-3 /year
Pest Control	low	1-2 /year
Drainage Repair	low	1 /year
Assessment Scouting	low	as needed
Sampling Specimen	high	as needed

For an illustration, the Malaysian Palm Oil Board (MPOB) reported as 2017 Malaysia has 5.7 million hectares of land planted with oil palm, consisting of 5.0 million hectares of mature and 0.7 million hectares of immature oil palms [2]. An average planting density of 135 palms per hectare would projected approximately 770 million palms, each being manually scouted, harvested, manured, pruned, weeded and otherwise cared for by a large pool of 550,000 oil palm workers. Therefore, maintaining consistent perennial crop health of oil palm across myriads of plantations terrains is a challenging task yet crucial for sustaining optimum national accumulative yield [11]. Despite oil palm is the most efficient oilseed crop in the world seemingly plantations are poorly lack of apparent modern PF [12].

B. *Precision Oil Palm Farming*

Many people have different ideas of what precision farming (PF) should encompass. There are varying definitions for PF exists in the literatures. PF is a farming management concept based on observing and responding to within-field spatial variations or in other words, within-plantation of oil palm [13]. PF generally relies on new technologies such as remote sensing imagery and information technology. It is also assisted by the ability to locate precise position in a field using satellite positioning system, commonly known as Global Positioning System (GPS).

In this study, we adopted the generic definition of *Precision Oil Palm* (POP) as *that kind of practices that increases the number of (correct) intervention decisions per unit area of land per unit time* with intended net benefits [14]. This shifts the focus, away from the larger, full-fledge framework of Oil Palm PF to simply involving the fineness or the precision of decisions in both space and time. This generic definition does not imply any particular technology or set of instrumentations. The decisions can be made or enhanced through the usage of electronic equipments such as sensors, GPS, GIS, VRT etc., but more importantly they can also be made by humans (after all farmers are the real stewards) [13].

In achieving sustainable POP plantation management, continuous, affordable, accurate, reliable and high temporal spatial information are substantially required, especially information on plant health and performance [1,15]. Due to these requirements, in real practices, hitherto oil palm plantation operations are devoid of modern PF [1,8,12,15].

C. *UAV for Oil Palm PF*

Proliferation of micro UAVs has made production of digital aerial imagery (DAI) become effortless to the masses. DAI conjugated with advances in photogrammetry workflow and analytics post-processing enable powerful geovisualization manipulation. Recent widespread use of micro unmanned aerial vehicle (UAV) together with advanced photogrammetric processing has been identified as an emerging technology that appropriate to leverage oil palm yield intensification and plantation general operations [12,16-18].

Oil palm yield intensification is seen to be as a sensible way to reduce potential yield gap [19]. Oil palm within-plantation spatial variation has been indicative for potential yield gap causal. Within-plantation spatial variation is induced by the tree's intrinsic bio-physical attributes and environment determinants such as soil, water, air, climate, nutrition, pests and disease and planters' practices. Each oil palm tree integrates the net effects thus revealing the resulting physiology response in the individual tree vigour. Detection of individual tree vigour is possible by employing aerial imagery [12,18].

Personal Remote Sensing (PRS) techniques using LAPER allow individual palm tree to be monitored systematically [12,17]. Through aerial digital imagery information extraction, the resulting within-plantation spatial variation severity can be assessed, thus indicates the magnitude of inefficiency in oil palm production unit [12,17-22].

D. *Oil Palm Geospatial Intelligence*

Geospatial Intelligence (GeoInt), is an intelligence discipline comprising the exploitation and analysis of geospatial data and information to describe, assess, and visually depict physical features of both natural and constructed, and geographically referenced activities on the Earth. Knowledge creation is great opportunity that can be applied to perennial cropping in which analysis techniques to generate knowledge such as agrointelligence, and plantation intelligent have been carried out by non-profit organizations such as International Plant Nutrition Institute (IPNI) [23, 24]. However, this paper intent to introduce Oil Palm Geospatial Intelligence (OP GeoInt) as an alternative approach to conventional satellite-based PF in geovisualization exploration.

E. *Aims of the Study*

With the widespread of oil palm cultivation awareness among planters, interest on sustainable oil palm yield intensification has been thriving. The study reported in this paper aims to adapt UAV-based PRS in producing DAI geovisualization and mapping to accommodate POP provisioning. Study were carried out using 1) Low Altitudes Personal Remote Sensing (LAPER) customized micro UAV quadcopter for acquiring oil palm DAI, and 2) Extensive post-processing workflow for producing oil palm explorative geovisualization and actionable maps. The results achieved on several oil palm plantation study sites are described in detail to support the claimed effectiveness of the developed workflow in supporting oil palm PF.

III. METHODOLOGY

A. *Methods*

Oil palm tree-related maintenance inputs consist of operation tasks applied toward each oil palm tree. These tasks also known as management interventions are listed in Table 1. Tree-related interventions are mostly revolving with spatial movement around the oil palm tree. All activities performed are recorded using android mobile application with timestamp and GPS location data. Furthermore, getting timely and accurate information about palm trees' health, growth progress and yield performance based on a management block as well as possibly yield quantization on per tree basis are crucial for oil palm plantation management to plan and execute for the right interventions. The ability to get information of where and when to execute any given task is also essentially provide extra leverages and precision. Timestamp and GPS location data are geospatially recorded using an open-source application developed by Fulcrum mobile application which is available at http://www.fulcrumapp.com. With the aim of getting these extra leverages, we proposed a workflow is to make use of LAPER acquired DAI such that will enable planters to extract geospatial information and conceivably create geospatial knowledge about their oil palm plantation assets.

Smallholders' farmers comprise 33% of total oil palm planters in Malaysia. So, our value proposition to smallholding plantation is to give the due consideration and support them for oil palm yield intensification as well. So, we have adopted an overall affordability in materials selection, and operation simplicity to ensure successful ensuing deployment among oil palm smallholders.

Embracing low cost, practicality, simplicity and modernity has been our study underlying principles. Whenever possible we would opt for open source software and hardware. Nonetheless the technique and workflow that we used is incorporating quite advanced aerial robotics control system, IMU/INS (inertial navigation system/inertial measurement units) navigation system and electronic propulsion subsystem. The on-board flight controller hardware is employing dual combination of nonlinear digital Kalman-filter and PID (proportional–integral–derivative controller) control systems. IMU/INS navigation system is equipped with assortment of sensors including GPS, barometer, accelerometer, gyroscope and magnetometer. Electronic propulsion subsystem of the quadcopter is using highly efficient and lightweight brushless dc motor power-driven with electronics speed control (ESC) and high power-density lithium-ion polymer (LiPo) battery.

B. Materials

Materials involved in this study include study sites with oil palm plantation, Kumbang v2 quadcopter which act as LAPER that is equipped with navigation and image acquisition equipments and image post-processing software. These three items are described in detail as follows:

1) Study Sites

There are five study sites involved for collecting digital aerial imagery of oil palm plantation plots as listed in Table 2.

Table 2
Study sites list

	Study Site Location	Plot Info	
		Area	Age
a	Lorong Langsat, Sinaran Baru	6.4 ac.	Adult
b	Sri Mendapat, Tanjung Sembrong	4.0 ac.	Adult
c	Bukit Perah, Merlimau Pasir	5.0 ac.	Young
d	Jalan Pahlawan, Merlimau Pasir	1.4 ac.	Adult
e	UTeM Campus, Ayer Keroh	3.0 ac.	Old

Study site plot a) and b) are located in Johor state while the remaining c), d) and e) are in Melaka state of Peninsular Malaysia. Two of the study site plantation locations in state of Johor are shown in Figure 1.

2) Equipments

Due to its relevance for plantation terrain environment, LAPER using quadcopter is more advantageous to collect oil palm digital imagery [1]. The LAPER quadcopter extended range capability and agility is preferred by this study to leverage PRS full potential on oil palm. Quadcopter vertical agility especially its vertical take-off and landing (VTOL) capability besides its resilient 3D flight trajectory path-following capability are among the special features of the LAPER to ensure the success of all flight missions.

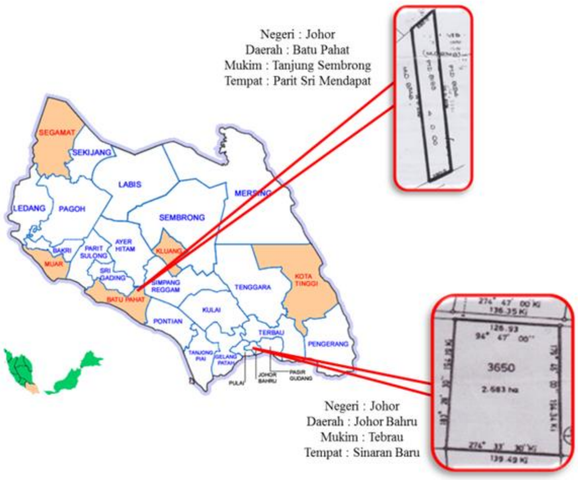


Figure 1: Locations of study site in Johor state: Johor Bahru and Batu Pahat district.

The hardware and software used in this study are as follows:

Hardware:

1. UAV airframe - Kumbang v2 quadcopter
2. Autopilot Flight Controller - Pixhawk
3. Digital Camera – Canon S100
4. Ground Station – Laptop HP450
5. RC Controller and Radio Telemetry unit
6. Battery – 10,000 mAh 6S LiPo cells
7. Battery chargers and battery tester
8. Dell Precision T7500 Desktop Workstation

Software:

1. Mission Planner ver. 1.3.39
2. CHDK ver. 1.3.0
3. Agisoft PhotoScan Professional ver. 1.2.5
4. Virtual Surveyor ver. 3.1.0
5. Carto Builder Ver. Online
6. ArduCopter ver. 3.3.x

Items A, B and F are opensource software products, items C and D are propriety licensed software, while item E is cloud software as a service (SaaS) which has a free subscription option.

C. UAV Digital Aerial Imagery Mapping Workflow

There are several workflows described by various researchers for UAV digital imagery mappings, however the existing workflows are designed for general applications i.e. not focusing at certain crops such as oil palm [98,8]. Here, we established a workflow dedicated for creating actionable maps of oil palm, the primary commercial crop for Malaysia. In doing so, we have adopted the common workflow and further tuning it in order to acquire enhanced levels of imagery post-processing output of the respective oil palm study plots. The overall study workflow is shown in Figure 2. For clarification, the details of each component are also shown.

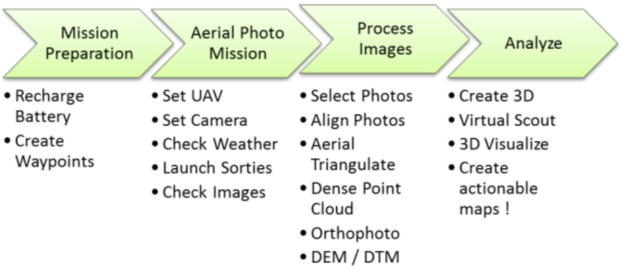


Figure 2: Workflow for creating oil palm actionable maps

D. Mission Preparation - Flight Planning and Control

All UAV flight mission planning and flight mission execution and monitoring were done using Mission Planner, a free, open-source and community-supported application for autopilot project (http://ardupilot.org/ardupilot).

Table 3
Tasks list of base-map creation workflow

Task	Time and Monetary	
	Hours	Cost
Charging Battery	4	Low
Waypoint Creation	0.5	Low
Flight Mission	0.5	Low
Image Stitching	4	Medium
Digital Map Products	4	Medium
GIS export	0.5	Low

1) Pre-Mission Preparation

The entire workflow routine is best to be presented in simpler tasks list so that encourage planters’ interests as in Table 3. Repetitive missions will require only re-charging rechargeable batteries of UAV quadcopter, RC transmitter and camera. Recharging LiPo batteries is best completed within 24 hours before the mission expedition. Creating mission flight waypoint in each plot is only need to be done once, and reusable in the subsequence aerial imagery acquisitions. For getting accurate measurement result, non-metric digital camera needs periodical pre-calibration and ground control points (GCP) are required for performing error correction. However, in practice due to repetitive missions this procedure can be minimized or eliminated entirely.

2) Planning Mapping Waypoints

Correct mapping waypoint is the key success of the aerial imagery acquisition mission in getting useable results. Optimized mapping waypoint will further enhance the mission routine and reduce post-processing computation load. In this research, we are using opensource Mission Planner that has pretty good mapping tools. It supports various auto-waypoint generation tools that work very well. From our 3-year usage the mapping outcomes were very good. A single sortie waypoint distance-travelled from take-off point to landing point has to be in the range of UAV air-time limitation. In Figure 3 it is shown the mapping waypoint of a single-sortie flight prepared for surveying Bukit Perah study site.

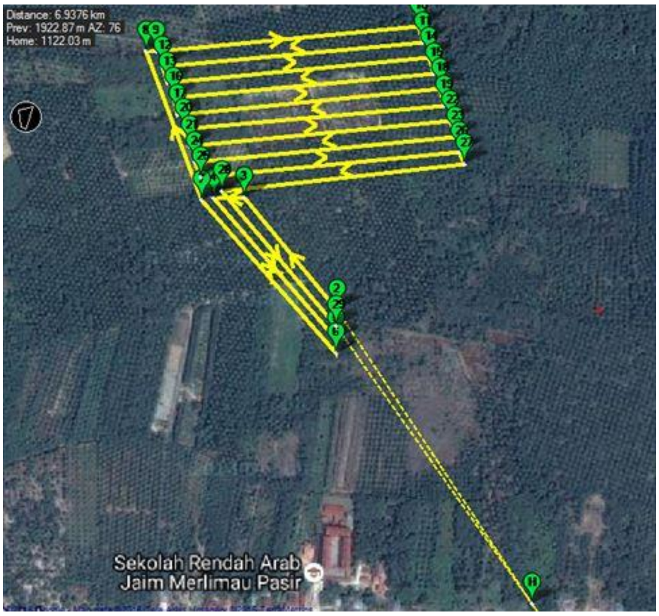


Figure 3: Mission Planner entire waypoints for Bukit Perah

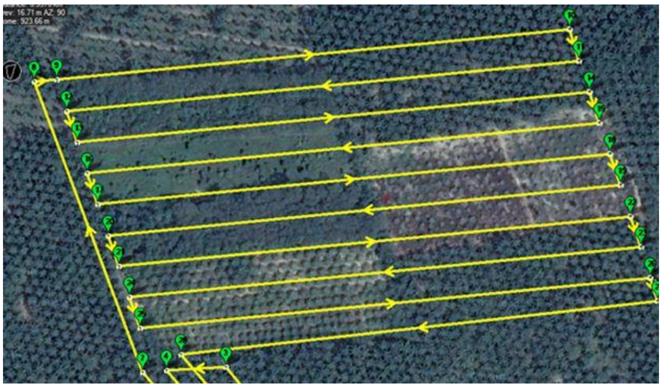


Figure 4: Waypoints of Bukit Perah plot of interest (POI)

E. Aerial Imagery Acquisition Mission

All mapping flight missions were executed and controlled using autonomous waypoint flights command. Ground control station (GCS) laptop and radio control transmitter (RC Tx.) were used for monitoring and stand-by manual intervention purposes only. The real mission execution usually last for 20 – 35 minutes per single sortie. Figure 4 depicted the aerial footprint in a single sortie of Kumbang v2 which has a total of 6,973m flight travel distance.

1) Acquisition Expedition Timing Factor

In tropical land, it is quite normal occurrences that the outdoor air starts becoming windy 3 hours after sunrise thus creating motion in oil palm fronds. As sun shines brighter, air tends to get hotter and less favourable breeze starts building-up. Wind usually breezes stronger in the midday up to late afternoon. Moreover, it is also common in tropical land to have quite occasional rain in the late noon of the day. Therefore, executing the imager acquisition mission in the morning will avoid unexpected bad weather problems.

Hence, based on our experiences of various regular missions carried out since 2013, the best calm air window to execute aerial mapping over the oil palm foliar terrain is usually between 8:00 AM – 10:00 AM. Calm air windows allow motionless fronds situation. Motionless fronds will give static crown impression in the later stage of stitching multiple overlapping images thus yielding crisp stitched mosaic and orthophoto. Appropriate timing of mission deployment usually minimizes and possibly eliminates unwanted artefacts especially on oil palm crown-top. Figure 5 shows aerial photos of Bukit Perah POI.

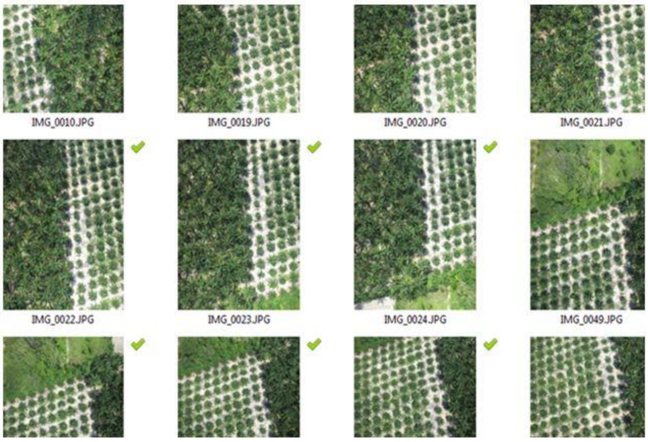


Figure 5: Aerial Photos of Bukit Perah POI

F. Post-processing

After every successful aerial photograph acquisition mission, we need to pre-selected clear (bright), crisp (sharp) digital and overlapping photos set of oil palm plantation as shown in Figure 5. Thanks to the GPS-camera and UAV navigation GPS/INS, this feature enable us to acquire the necessary geo-referenced UAV imagery.

1) Using Agisoft - 3D Modeller

All the digital photos were processed using Agisoft PhotoScan photogrammetry suite to produce preliminary digital mapping products such as dense point cloud, photos mosaic, orthophoto, digital elevation model (DEM) and textured 3D mesh.

2) Using Virtual Surveyor – Terrain 3D Geovisualizer

Completed digital models (DEM, Textured DSM etc.) generated by the 3D modeller suite are imported by Virtual Surveyor (VS) for generating plantation terrain 3D geovisualization. Virtual Surveyor is geovisualizer tool used for insightful knowledge construction. Virtual Surveyor transforms modelled oil palm plantation terrain UAV imagery into easy, interactive yet powerful visualization.

G. Analyse

1) Exporting into Online GIS

The 2D base-map (orthophoto) is exported into online mapping solution, so that planters can simply deploy GIS solution without hassle of having in house IT infrastructure. The example is shown in Figure 6. Base map storage is done on cloud using Carto Builder online.

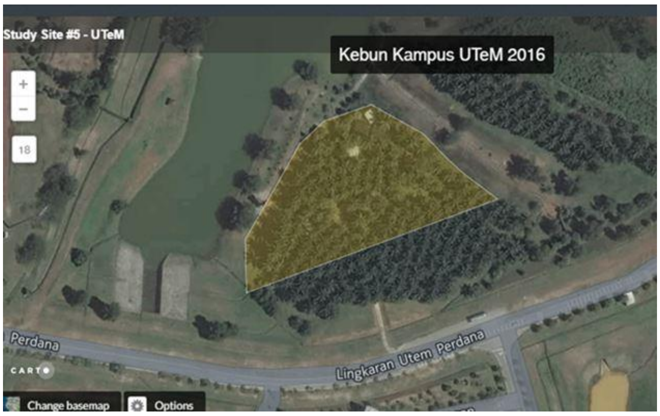
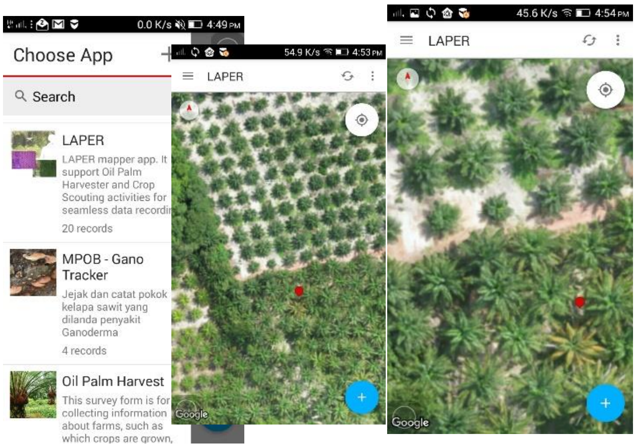


Figure 6: Kebun sawit base-map overlaid on Carto GIS

2) 3D Interactive Geovisualization

The final step in the workflow is to engage interactive geospatial data exploratory using geovisualization and imagery analysis techniques. Geovisualization which is shorter term for Geographic Visualization refers to a set of tools and techniques supporting the analysis of geospatial data through the use of interactive visualization. Interactive geovisualization communicates geospatial information in the manners that, when combined with experienced human understanding, allow for powerful data exploration, insightful knowledge construction and constructive decision-making processes.

Imagery analysis is the extraction of useful information from any type of sensor-related imagery data projected either in 2-D or 3-D formats. Combining Imagery analysis with interactive geovisualization enable planters to understand, illustrate, and glean insight from their oil palm geospatial data.



LAPER
LAPER mapper app. It
support Oil Palm
Harvester and Crop
Scouting activities for
seamless data recordi
20 records

MPOB - Gano Tracker
Jejak dan catat pokok kelapa sawit yang dilanda penyakit Ganoderma
4 records

Oil Palm Harvest
This survey form is for collecting information about farms, such as which crops are grown,

Figure 7: Fulcrum android app showing Bukit Perah data

IV. RESULTS AND DISCUSSION

In the actual oil palm plantation production study sites, UAV-based aerial imagery mapping products could be used for various purposes such as monitoring soil condition, oil palm phenology and its health condition, terrain analysis for hydrology, and biomass volumetric calculation. However, this paper will only focus on oil palm tree-related maintenance activities.

In this section workflow results from Bukit Perah which is one of study plot in Melaka are presented. The essential elements of the workflow result are discussed here in detail to support the claimed effectiveness of the developed workflow. Figure 7 shows the take off site and target plot of the study area.

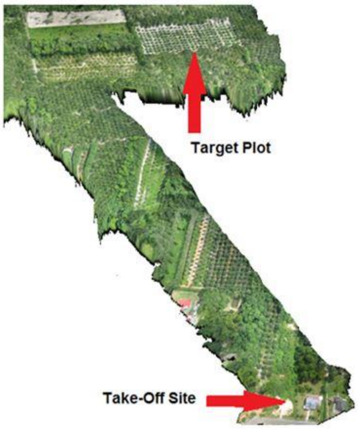


Figure 7: Selective point-to-point flight over plot of interest

A. Localize and Selective Acquisition Area

The flexibility and agility of quadcopter UAV allow us to do point to point fly-over routine. As a result, we are able to be selectively doing PRS over plot of interest (POI). As shown in Figure 7, the distance from take-off site to target plot of study site is about 1100 m. Selective point-to-point flight over plot of interest enables better result that contributes to rapid provisioning oil palm plantation PF operations. In order to implement a successful POP farming, continuous geospatial and chronospatial data feed are needed. On the contrary, PF using satellite remote sensing is disadvantageous due to limitation in spatial resolution.

Figure 8: Orthophoto of Bukit Perah POI

B. Result Interpretation - Rapid Assessment

The target plot of interest (POI) in Bukit Perah study site comprises a multi-plot of oil palm smallholder type (shown in Figure 8). UAV flexibility permits rapid aerial data acquisition and in turn leading to rapid intuitive interpretation and assessment. Through the Geographic Visualization technique, the following interpretations are being drawn out.

Figure 9: Instant vantage overview of multi-plots status

1) Instantaneous Vantage Overview

By virtue of aerial photography inherited vantage overview, information on a block level as well as on a per-tree level and at different perspectives can be quickly glanced and interpreted (Figure 9). Interpretation of agronomy related features becomes almost instantaneous. Multi-plot status such as stressed trees plot, healthy young re-plantation, over matured and fallow area immediately revealed. This will enable rapid intuitive interpretation akin to an agronomist level. The fully autonomy of using quadcopter UAV for such purpose is far advantageous compared to conventional satellite remote sensing systems that are primarily owned and managed by developed countries such as USA, France and Japan.

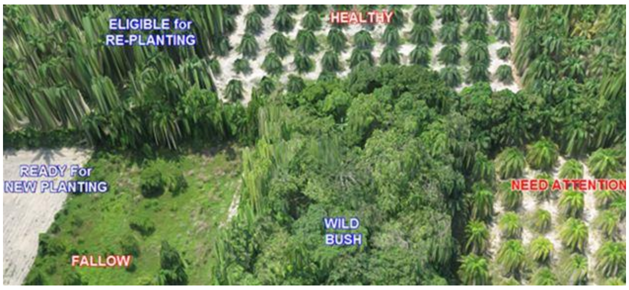


Figure 10: Insightful geospatial information

2) Insightful Data and Geospatial Intelligence

Furthermore, experienced planters can immediately utilize the insightful geospatial data and geospatial information to increase their geospatial intelligence (Figure 10) in oil palm phenology, vegetation, foliar and environments such as identification fallow plot, wild bush plot, and over-matured oil palm plot which less productive and eligible for replanting, and severely malnourished oil palms etc.

Oil palm geospatial intelligence comprises of exploratory and analysis of geospatial data and information to describe, assess, and visually depict physical features (both natural and constructed) and geographically referenced activities on the plantation or its vicinity. Deeper image analysis induces knowledge creation. This feature is shown in Figure 11 and Figure 12 whereby unwanted no man’s land mushing fringe bush and disease outbreak surveillance visually depicted. Oil palm plantation geospatial intelligence data sources include workers field scouting notes and feedbacks, and those imagery and mapping collected by UAV aerial imagery. Figure 13 shows the crown aggregating to create tree vigour knowledge. In contrast, this unable to be carried out using conventional satellite remote sensing systems due to low spatial resolution (meter level).

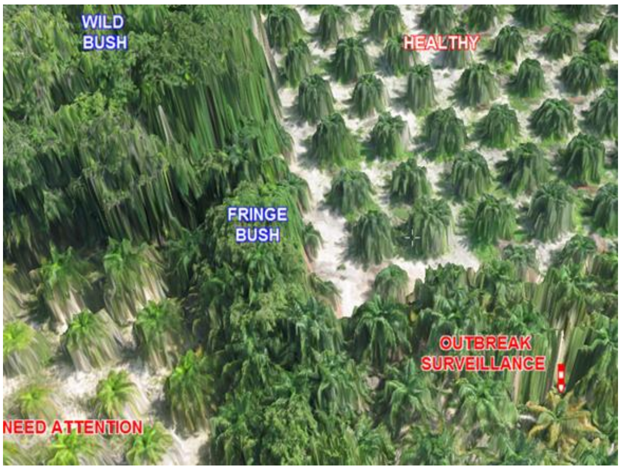


Figure 11: Exploratory image analysis to extract information

Figure 12: Ortho-rectified of photo in Figure 11

Figure 13: Crown aggregating to create tree vigour knowledge

C. Result Interpretation – Cultivation Knowledge Creation

This research workflow development goal is seeking the means to create meaningful data-driven visualizations that facilitate efforts to achieve action-driven POP farming provisioning. Data-driven visualizations enable us to do geospatial information extraction by engaging interactive and exploratory oil palm geovisualization.

One of the POP farming aims is to improve efficiency in oil palm production unit. Through optimizing oil palm tree scouting-based tasks the cost and time in production unit, efficiency could be improved. As shown in Table 1, one of the costly and time consuming yet important oil palm tree input task is assessment scouting. Interactive oil palm geovisualization is able to surrogate this expensive and tedious task.

Interactive Oil palm geovisualization is a map metaphor technique which enables rapid per-tree stand-visualization. Smooth, fluid and responsive interactive geovisualization leverages map metaphor technique to subsequently induce knowledge creation in POP farming context. Figure 14 shows the virtual Field Scouting obtained from PRS.

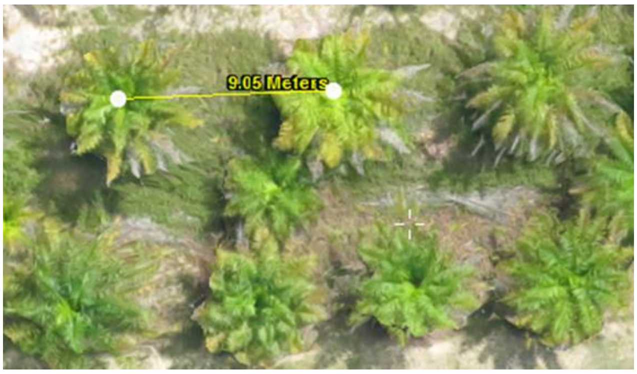


Figure 14: Virtual field scouting

1) Virtual Field Scouting

Virtual Surveyor interactive *geovisualization* techniques on very high resolution images captured from quadcopter UAV allow user to carry virtual field scouting. Satellite remote sensing images have constraints in terms of temporal and spatial resolution for such purpose. On the other hand, *in-situ* notebook observation record taking usually causes cluttered data or perhaps misplaced data and other numerous human limitation related problems etc.

In the case of smallholders, using UAV could reveal phenology features that will promote and enable the smallholders to make prompt decision for a specific targeted area within a shorter time period (based on the gathered and exposed information). To some extents, it acts as surrogate agronomist for smallholders. In Figure 15, it is obvious that ailing and retarded oil palm can be visually identified based on plant anomalies detection of individual trees.

Figure 15: Plant anomalies detection

2) Interactive Off-site Mapping Task and Spatial Accuracy Mitigation

In the context of oil palm repetitive day-to-day operations, strict precise location requirement is mitigated by the nature of agro-activities requirement involved. Although spatial accuracy assessment always comes into highest attention, in this paper we have eases it to a practical degree. All the produced base-maps are using the same source of orthophoto that has lateral accuracy below 5cm and maximum error of 3 pixels (equivalent to 15 cm). For such a relatively bulky oil palm tree physical sizes (dimension) –

these accuracy figures warrant us to mitigate accuracy concerns. After all, these base-maps are intended to assist plantation activities only. Hence the accuracy reported by the photogrammetry processing in the appendix below is rather superfluous for oil palm repetitive operation. However, the systematic error introduced by consumer grade GNSS sensor is considerably in the excess of ± 3 m. Considering 9-m standard oil palm's tree-to-tree distance (inter-trunk spatial) and combined with worker's local knowledge is sufficient to compensate any slight oil palm trunk position difference error found in between actual ground and map generated coordinate. (Note: BMP and GAP recommended planting inter-trunk spatial distance is 8 – 10 m apart.). Figure 16 shows several tree-to-tree distances measured based on virtual field surveying of the UAV orthophoto.

Figure 16: Virtual field surveying

V. CONCLUSION

The results of on-going research on using LAPER quadcopter imagery for precision oil palm geospatial intelligence or OP GeoInt have been described. One of the major stumbling blocks that hindered the deployment of POP farming is lack of consistent operational geospatial data. By the virtue of having actionable basemaps, planters can start deploying geospatially tracked activities. This will make oil palm geospatial and spatiotemporal (chronospatial) data generation become reality. As the rich time-series operational data (geospatial and chronospatial) is continuously accumulated, a comprehensive POP farming implementation becomes more viable and shall emerge effortlessly. Thus, this paper concludes with following summary:

A. Intuitive and Insightful Maps for POP Farming is Possible

The proposed workflow enables planters to make use of quadcopter UAV acquired digital imageries to produce various base-maps for provisioning intervention actions in oil palm plantation management. These maps are simple yet intuitive and insightful to empower agronomist and planter to become more productive. The ability to get information of where (and possibly when) to execute any given task is also essentially provide extra leverage to support POP farming.

B. Quadcopter UAV is the Right Choice

Micro quadcopter UAV with decent digital camera to act as LAPER is capable of providing high quality insightful geospatial data that immediately translate into actionable data. Due to sparsely distributed mosaic of smallholder plots with different small sizes, locations, varying landscapes and plantation undulated terrains, the choice of quadcopter over fixed-wing UAV was obligatorily made and turned out to be well justified.

C. LAPER Effectiveness is Proven

Low-cost, practicality, modernity and simplicity are vital elements embedded in the research goals. The field-tested outcome of a moderately low-cost Kumbang v2 quadcopter system proved that LAPER can be practically and dutifully applied in POP farming production environment. LAPER is effectively capable and dutiful workhorse to supply continuous geospatial data for generating oil palm geospatial intelligence. Oil palm geospatial intelligent simply leverages POP farming operations.

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