In-situ data collection for oil palm tree height determination using synthetic aperture radar

C Pohl¹ and C K Loong²

¹ Professor at the Institute for Geoinformatics and Remote Sensing, University of Osnabrück, Barbarastrasse 22b, 49076 Osnabrück, Germany
² Master student at the Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia, Block T06/FGHT, UTM, 81310 Johor Bahru, Johor, Malaysia

E-mail: chrispohl@uni-osnabrueck.de

Abstract. The oil palm is recognized as the “golden crop,” producing the highest oil yield among oil seed crops. Malaysia, the world’s second largest producer of palm oil, has 16 per cent of its territory planted with oil palms. To cope with the increasing global demand on edible oil, additional areas of oil palm are forecast to increase globally by 12 to 19 million hectares by 2050. Due to the limited land bank in Malaysia, new strategies have to be developed to avoid unauthorized clearing of primary forest for the use of oil palm cultivation. Microwave remote sensing could play a part by providing relevant, timely and accurate information for a plantation monitoring system. The use of synthetic aperture radar (SAR) has the advantage of daylight- and weather-independence, a criterion that is very relevant in constantly cloud-covered tropical regions, such as Malaysia. Using interferometric SAR, (InSAR) topographical and tree height profiles of oil palm plantations can be created; such information is useful for mapping oil palm age profiles of the plantations in the country. This paper reports on the use of SAR and InSAR in a multisensory context to provide up-to-date information at plantation level. Remote sensing and in-situ data collection for tree height determination are described. Further research to be carried out over the next two years is outlined.

1. Background

With Malaysia being the second largest palm oil producer in the world and the fact that palm oil ranks first in vegetable oil production on the world market, the palm oil industry became an important factor in the country. Sustainability in the production of palm oil is an important factor in the competitiveness of Malaysian palm oil on the global market. The oil palm is a perennial tree. It follows a growth pattern whereby its yield peaks at its prime age and deteriorates as the trees grow old. At the age of 25 and older, they produce lower yields and become uneconomical to maintain (figure 1). From the perspective of government, it is important to monitor the age of oil palms to control national yield and productivity. In forestry, remote extraction of age information is of great interest in the scientific community as an indicator for biomass estimation. However, not all plantation owners could provide this information accurately and voluntarily. Past research has shown

¹ To whom any correspondence should be addressed.
that tree height has a strong correlation with tree age [1-3]. This correlation has equally been established for oil palms [4]. By acquiring tree height information remotely, the age of the plantation could be estimated at a large scale.

Tree height is a key parameter in the investigation of age and productivity. It would be extremely valuable to MPOB to obtain this important information on a national scale. For management, it will be helpful to have an overview of the national oil palm age profile; while for the scientific community, it is a valuable parameter to derive biophysical information, e.g., Above Ground Biomass (AGB), carbon stock, and productivity.

Remote sensing can play an important role to support the monitoring and productivity of oil palm plantations. The proposed research concentrates on designing an information extraction system for palm oil plantations in the Tropics using synthetic aperture radar (SAR) satellite data as a source. So far, SAR has only been used to discriminate oil palm plantations from forest and tropical rain forest along with other land uses. Remote sensing, and radar remote sensing in particular, provides regularly updated spatio-temporal information on land use / land cover changes [5, 6]. Since monitoring entails continuous data acquisition, it is not possible to rely on optical remote sensing (VIR) alone, because persistent cloud coverage in tropical areas hinders cloud-free image acquisition. Examples show that it takes between one and seven years on average to capture a cloud-free scene [7]. On average, one has to wait 12 months or longer to capture a scene with less than 10 per cent cloud cover [8]. Another issue in optical remote sensing is the degradation of image quality through haze which is a very common phenomenon in Malaysia and other countries in South East Asia [9]. Synthetic aperture radar data do not only provide complementary information to VIR images, but the data contains unique information of its own. The SAR is an active sensor that operates independent of weather and daylight conditions, delivering cloud-, haze- and smoke-free imagery all year round at the time that it is needed. The challenge in this respect is the different nature of radar data in terms of information content and interpretation. Radar backscatter is sensitive to texture, size and orientation of structural objects, moisture content and ground conditions. For the application discussed in this paper the interaction of SAR microwaves with canopies, trees and soil is of interest. The longer wavelengths (e.g., L-band 15-20 cm) penetrate the canopy, and its backscatter data contains information that relates to leaves, branches, stems and soil conditions; the longer the wavelength the greater the penetration [10]. It has been proven that radar is sensitive to the structure of the canopy. The received backscatter intensity represented in the image is a composition of interactions with the crown, the trunk and the

![Figure 1. Fresh fruit bunches yield as a function of age](image-url)
ground surface. Using fully polarimetric SAR it is possible to derive a relationship between backscatter, texture and crop status [11]. If we consider an oil palm as a crop this is very interesting and helpful to derive certain information on different growth stages. This is very relevant information for optimized and sustainable oil palm plantation management. The project is designed to exploit the complementary nature of optical and radar sensors in support of oil palm plantation management.

The application of SAR in the context of oil palm monitoring is a novel and underdeveloped approach. Satellite SAR can produce digital elevation models (DEM) at less costs relative to counterparts like Light Detection and Ranging (LiDAR), real time kinematic Geographic Positioning Systems (GPS), and aerial surveys. Mapping of plantations using a DEM with geographical information is extremely useful for better planning of a plantation layout (e.g., terrain and road) during the set-up phase of a plantation or during a replanting program [12]. Moreover, an improved plantation layout with geographical information could help to scale up the application of mechanizing the plantation. With improved access to mechanization, a shortage of workers could be duly tackled and their productivity could be enhanced, which is one of the entry point projects (EPP) announced in the national Economic Transformation Programme (ETP) [13].

SAR has the potential to deliver other parameters regarding the oil palm plantation, such as moisture content (soil and plant), as well as aboveground biomass (AGB), and tree height. The results of this study would have a significant impact on Malaysia’s oil palm industry in terms of contributing up-to-date and large-scale information for the plantations. This application-oriented technique would help to add value to both the oil palm industry as well as the remote sensing industry.

2. Research Implementation

After an assessment of radar remote sensing advantages and limitations for oil palm plantation monitoring, research questions were formulated and a test site was defined. The satellite SAR data were acquired in May and June, 2015.

2.1. Research objectives

After a detailed literature study to extract the state of the art in radar remote sensing for forest, tree plantation and in particular palm oil plantation monitoring, the research objectives regarding improved information retrieval for oil palm age and growth were formulated, as follows:

1. to produce a DSM through InSAR processing.
2. to derive oil palm tree height from the offset of the DSM against a reference DTM.
3. to develop an empirical model to estimate the age of oil palm trees with its height.

2.2. Study site

The selected study site is a plantation of the Malaysian Palm Oil Board (MPOB) in Kluang, Johor, Malaysia. This research site was established in September 1979 and was formerly known as the Palm Oil Research Institute of Malaysia - PORIM Research Station. It is located 13 km from Kluang and 115 km from Johor Bahru (figure 2). The station is made up of two adjacent areas, the main station (486 ha) and a secondary station called Bukit Lawiang (404 ha). Oil palm breeding research and development is the main activity of these stations, which also house the largest oil palm germplasm collection in the world. An example of the plantation set up and palm trees is depicted in figure 3.

2.3. Remote sensing data collection

Two different SAR sensors are considered in this research: the Korean Multi Purpose Satellite No. 5 (Kompsat-5) and the European Sentinel-1A SAR. Kompsat-5 was launched in 2014 with a revisit cycle of 28 days. The SAR sensor is an X-band instrument operating at 9.66 GHz (3.2 cm wavelength), capable of deriving canopy height with subtle penetration, which makes its data suitable for this research. The Kompsat-5 scenes were acquired with VH polarization in repeat-pass high-resolution mode (1 m) over a 5 km wide swath. We collected single look complex (SLC) Level 1A data. The Sentinel-1A SAR sensor, launched in April 2014, operates at C-band. We obtained two VV
polarized scenes in SLC format during ascending orbits on 13 August and 6 September, 2015; both
dates were close to the in-situ data collection period. The choice of sensors is mainly based on budget
limitations. The Kompsat-5 data was provided for research purposes free of charge, while Sentinel-1A
data is open-access.

For verification and multi-sensor comparison we also acquired a high-resolution optical satellite
image product with only 4% cloud cover. The WorldView-2 scene from 23 March 2015 contains eight
multispectral bands at 2 m resolution and one panchromatic channel at 0.5 m resolution. Details are
summarized in Table 1.

![Figure 2. Location of the test site](image)

![Figure 3. Oil palm plot with signage, indicating field number, type of cultivar, area size and date
of planting (left); oil palm with unique geometry and planted with a 9m x 9m spacing (right).](image)

| Sensor       | Band / Polarization | Spatial Resolution [m] | Date of Acquisition Date |
|--------------|---------------------|------------------------|--------------------------|
| Kompsat-5    | X / VH              | 1                      | 12/05/2015, 13/05/2015, 02/06/2015, 26/06/2015 |
| Sentinel-1A  | C / VV              | 5                      | 13/08/2015, 06/09/2015 |
| WorldView-2  | PAN                 | 0.5                    |                          |
|              | 1 Coastal           |                        |                          |
|              | 2 Blue              |                        |                          |
|              | 3 Green             |                        |                          |
|              | 4 Yellow            | 2                      | 23/03/2015               |
|              | 5 Red               |                        |                          |
|              | 6 Red Edge          |                        |                          |
|              | 7 NIR1              |                        |                          |
|              | 8 NIR2              |                        |                          |
2.4. Ground data collection

The test site comprises all breeds of oil palms in heterogeneous conditions that serve for the collection of secondary data (cultivar, soil type) of the research. Palm trees were selected at random at plot-base and categorized into age groups. The sample trees were geo-located using the Global Position System (GPS). In addition, MPOB maps were used to obtain information on tree age, species and soil types. Ground Control Points (GCPs) were set up in open spaces to calibrate and co-register the acquired satellite images with a high spatial accuracy.

Ground data collection took place in September of 2015. Relevant parameters include tree species, height of the palm tree, and tree positions. GPS measurements and ground control points help to relate the collected information on the plantation and palm trees to geographic coordinates. The tree height data collection process is illustrated in figure 4.

![Figure 4. Sine method to determine tree heights (adapted from [14])](image)

The height of the palm trees was measured using a ground height measuring technique, i.e., sine method, as the most suitable for tropical forest [15]. This technique utilized a laser rangefinder to measure the distance from the observer to the tree top; tree height is then calculated geometrically as depicted in figure 4 [16]. Equation (1) represents the sine method to calculate tree height as

\[
HT_{\text{SIN}} = |\sin(\alpha_1)d_1 - \sin(\alpha_2)d_2|
\]

where \(HT_{\text{SIN}}\) is the height calculated using the sine method [16].

2.4.1. Tree height. The tree height was taken by a Laser Rangefinder, i.e., Nikon Forestry Pro, using the three-point measurement mode. It is based on the principles of the tangent method, as illustrated in figure 5. This mode was selected mainly because of the shape of oil palm crown, which resembles an umbrella. It has an apex that is hidden from sight beneath the canopy, making laser-targeting of the tree top difficult, especially under overlapping oil palm tree canopies. The tangent method allows for virtual apex-targeting using angle measurements, returning accurate results [17]. Besides, the oil palm is an upright tree that does not usually lean, which solves the weakness of tangent method.

For a tree height that is below seven meters, i.e., young and immature oil palms, a direct measuring method was applied. It involved attaching the end of a meter-measuring tape to the top of an extended pole and dropping the tape to the ground with a weight (figure 6).

In this fieldwork, tree heights were collected by two separate measurements per tree, namely measuring the height of tree trunk and tree top. In the oil palm industry, oil palm height is normally acquired on the basis of frond-41 (6th parastichy) as a part of uniform and standardized test guidelines [18]. The location of frond-41 is pointed out with the assistance of an experienced harvester and needs to be measured by the observer.
Tree height extracted from the satellite imagery reflects actual height from the tree top. Thus, tree top height collection is necessary to reflect the actual condition, as the tree trunk height alone cannot represent the actual scenario on the target surface. The tree top height was taken based on the possible backscattering location of the oil palm crown. It can be understood as the height at which fronds are exhibiting their largest horizontal surface area that is most likely to backscatter the incident radar signals. However, this largely depends on the wavelength of the radar sensor. The tree height measurements will be used to quantify and validate tree height information derived from InSAR using the methodology described above.

![Tree Height Diagram](image)

**Figure 5.** Determination of the tree height using the tangent method

**Figure 6.** Direct height measurement using a meter-measuring tape

2.4.2. **Tree age.** The staff on-site provided the actual tree age information. As there is a lack of comprehensive cartographic information on tree age for the plantation, we depended on field visits to confirm the age of all samples. On-site signage indicates the year of field planting (figure 3).

2.4.3. **Sampling strategy.** Maps of the estate were prepared beforehand to facilitate planning of the sampling location. The aim of the fieldwork was to collect as many samples as possible across all available ages. At the MPOB Kluang Research Station, oil palms were not planted in every consecutive year. The collection was designed with a random stratified sampling method. The stratified samples are grouped into a cluster of nine palms, forming a diamond shape. A cluster of palms has the same age. Each palm is labeled to facilitate identification. GPS coordinates are taken for palm number 1, 5 and 9 to form a straight line for recognition on the map.

2.4.4. **Field measurement results.** As the oil palms at MPOB Kluang are not planted/replanted every year and due to the limited working time, we managed to collect data from oil palm with ages that cover several maturity groups, as listed in table 2 and in table 3.
Table 2. Number of sample palms collected across different age groups.

| Age | Cluster | No. of Palms |
|-----|---------|--------------|
| 2   | 4       | 36           |
| 4   | 1       | 9            |
| 5   | 1       | 6            |
| 6   | 3       | 27           |
| 13  | 4       | 36           |
| 15  | 6       | 54           |
| 21  | 1       | 9            |
| 39  | 2       | 18           |
| Total | 22   | 195         |

Table 3. Number of sample palms collected sorted by maturity groups.

| Age                     | Cluster | No. of Palms |
|-------------------------|---------|--------------|
| Immature (2-5 years)    | 6       | 51           |
| Young (6-14 years)      | 7       | 63           |
| Mature (15-25 years)    | 7       | 63           |
| Old (26-40 years)       | 2       | 18           |
| Total                   | 22      | 195          |

3. Conclusions and outlook

A major achievement of this project to-date is the establishment of an industry – university relationship. Access to field information is particularly sensitive in the context of palm oil production. Therefore, the possibility to acquire in-situ data on a plantation that provides a controlled environment, such as the Kluang test site, is very valuable. Secondly, all necessary satellite imagery was collected for verification purposes, including nearly cloud-free, high-resolution optical data. The next step involves processing of the SAR data to generate an interferogram that will undergo phase flattening and phase unwrapping for producing a digital surface model. Using an existing digital terrain model, an offset (difference) between DSM and DTM will define the oil palm plantation tree heights. The ultimate goal is to derive a relationship between tree height and age of the oil palms using a linear regression model. This relationship will form a height-to-age empirical model to establish an equation that can derive age values from heights for oil palm trees in Malaysia. It is anticipated to finalize this research in early 2017.

4. References

[1] Avtar R, Takeuchi W and Sawada H 2013 Monitoring of biophysical parameters of cashew plants in Cambodia using ALOS/PALSAR data *Environmental monitoring and assessment* 185 2023-37
[2] Racine E B, Coops N C, St-Onge B and Bègin J 2014 Estimating forest stand age from LiDAR-derived predictors and nearest neighbor imputation *Forest Science* 60 128-36
[3] Nishizono T, Kitahara F, Iehara T and Mitsuda Y 2014 Geographical variation in age–height relationships for dominant trees in Japanese cedar (Cryptomeria japonica D. Don) forests in Japan *Journal of Forest Research* 19 305-16
[4] Tan K P, Kanniah K D and Cracknell A P 2013 Use of UK-DMC 2 and ALOS PALSAR for studying the age of oil palm trees in southern peninsular Malaysia *International Journal of Remote Sensing* 34 7424-46
[5] Thapa R B, Shimada M, Watanabe M, Motohka T and Shiraishi T 2013 The tropical forest in south east Asia: Monitoring and scenario modeling using synthetic aperture radar data *Applied Geography* 41 168-78
5. Acknowledgments

This work was supported by Universiti Teknologi Malaysia Grant Q.J130000.2709.00K71 and will continue under Grant R.J130000.7827.4F725 funded by the Ministry of Higher Education in Malaysia.