Low-cost RFID-based palm oil monitoring system (PMS): First prototype

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Abstract. Under collaboration with our local oil palm plantation enterprise, our research focuses on producing proof-of-concept by using RFID technology to monitor palm oil productivity. Passive RFID tags are used in the plantation field to uniquely identify each palm oil tree and their Fresh Fruit Bunches (FFB) production is collected and monitored by scanning the passive RFID tags using high frequency RFID scanners. This technology aims to convert the harvest data into digital information which can be processed and analyzed by PMS system and presented as informative outputs such as dynamic charts. This analyzed information is further used as input to a proprietary GIS system where it is mapped as color-coded spatial data which enables an accurate evaluation and monitoring of the overall plantation productivity.

1. Introduction
This first prototype is developed jointly with our industrial collaborator that runs commercial plantation as one of its core businesses. Among key processes involved in palm oil production include seed nursery establishment, site preparation, field establishment and maintenance, harvesting and collection, transportation to palm oil mill and replanting. To provide an accurate method of monitoring the harvested palm oil Fresh Fruit Bunches (FFB) production, the focus will be on harvesting and collection process and will conform to the industry’s best practices as listed in Table 1:

| Palm oil tree | 1. Each palm oil tree is usually commercially productive from the age of 3 to the age of 25. |
| FFB | “Fresh Fruit Bunch” which is the indicator of productivity of the plantation field is measured per hectare per year |
| | 2. A 3-year old palm tree will produce roughly 90-120kgs bunches |
| | 3. Each palm fruit bunch weighs around 2-70 kilograms |
| | 4. The steep FFB production ascent phase is usually between the ages of 3 to 10; year 10 to 15 is the plateau phase while the declining phase occurs after 15 years. |
| Blocks | 5. Palm oil plantations are usually divided into several smaller sections or blocks to enable effective plantation management. |

Harvesting of FFB commences between 24 to 30 months after field planting, depending on the soil type, agronomic and management inputs. Harvesting is usually done manually, which involves cutting of the bunches from a tree using a chisel in young palms and a sickle mounted on a bamboo or aluminium pole in taller palms and allowing it to fall to the ground by gravity.

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In view of increasing productivity, mechanized approaches have been adopted by plantations, an example being the tractor-mounted ‘grabber’. Although mechanization has gradually been introduced over the years, it has yet to replace the high labour requirements in the upstream sector and meet the stringent criteria of reducing labour costs, increasing productivity and improving product quality [2]. For this reason, one of key challenges this paper aims to tackle, is to provide a method of scaling up the level of mechanization using RFID scanners and tags technology which will further be discussed in this paper.

This paper is organized as follows; Section 2 will cover the key pain points and the hardware readers. Section 3 will discuss the users and the overall system. Section 4 will outline the overall development process and Section 5 will describe the system architecture and technologies used. Lastly, Section 6 will cover the conclusion and recommendations.

2. Key pain points
There are three key pain points that we identified after rounds of interview with our industry collaborator.

- No accurate tree identification scheme – There is no convenient method to uniquely identify the trees hence monitoring the productivity of each individual tree is difficult.
- Manually recording the harvest outputs– Recording the harvesting process is usually done manually by the field collectors who count the number of FFB and record them in a log book. This method is prone to human error and is also very labour intensive.
- Inaccurate analyzed data – Achieving accurate analyzed productivity information for the whole plantation is difficult as it requires manual sorting through the FFB records.

2.1. Hardware readers
Several hardware readers were reviewed such as advanced RFID scanner, hand-held RFID scanner, digital camera, omni-directional barcode scanner and fixed position reader (industrial gate) as shown below in Table 2 in attempt to identify the most efficient and cost-effective way of gathering the FFB records in the field.

| Hardware reader            | Durability | Labor intensive | Read range | price | Line of sight |
|----------------------------|------------|-----------------|------------|-------|--------------|
| Advanced RFID scanner      | High       | Low             | High       | High  | no           |
| Hand-held RFID scanner     | High       | Low             | Low        | Low   | no           |
| Digital camera             | Low        | High            | low        | low   | yes          |
| Bar code scanner           | low        | High            | low        | low   | yes          |
| Industrial gate            | High       | High            | High       | High  | No           |

To uniquely identify the trees, the readers require each tree to be uniquely marked by either using passive RFID tags or 2-D bar codes. Once all the trees have been uniquely marked, the readers can be used to automatically acquire the FFB records hence providing a faster, precise and more labour-effective method of gathering the FFB records in the field.

2.2. Why RFID technologies?
Although digital camera and bar code scanners are the most cost-effective methods, their main drawback is the need for a direct line of sight which is highly unlikely in the plantation. The main disadvantage of using the industrial gate is the need for each FFB to be tagged. This increases the costs and labour requirements hence more prone to human error. Therefore, after weighing the pros and cons of each of the hardware readers, the best option was deemed to be RFID technology to monitor the FFB production due to the following reasons:
- **High durability** – High tolerance of different types of adverse weather climates more effectively than other options such as barcode readers.
- **High Tag read range** - RFID technology has a high read range of up 10's of meters and does not need a direct line of sight hence more suitable to be used in the plantation field. [7]
- **Tag concealment** - RFID Tag need not be on the surface of the object. This also improves the lifespan of the Tag as it is less susceptible to Wear and Tear. [7]
- **Multi Tag Read capability** – RFID technology has this capability unlike barcode systems that can only read one tag at a time.
- **Read/write capability** – information can be read or written to RFID tags memory. It is not possible to write information to Barcodes.

Despite the above advantages, the hand-held RFID scanner has many drawbacks such as low read range, limited battery power and storage capabilities. However, it was still chosen as the desired method for this project due to the low budget allocated to this project.

3. The overall system

This system has only one level of access, top management users (GIS Managers and Administrative Managers), as it mainly deals with crucial and sensitive information. The overall system is composed of three main components namely RFID system, Central PMS and the GIS system as shown in the diagram below. Each of these will be discussed in more detail in the next section.

![Diagram of overall system components](image)

**Figure 1.** Overall system components.

4. Technology and architecture

4.1. RFID system

Several challenges were encountered when using RFID system to monitoring FFB production. As this component is designed to work in conjunction with a laptop to substitute for the memory and power limitations of a hand-held RFID scanner, this poses a major problem in real-world implementation as carrying a laptop in the field which is not feasible for the following reasons:

- **Limited laptop battery power**– Most laptops have a battery life for 3-4 hours [5] hence this system would not enable effective monitoring of the FFB production
- **Climate intolerance** – This system cannot be used in adverse climate conditions such as raining season.
- **Read range distance** – The hand-held RFID scanner has 1.5 inch read range distance which would be problematic for mature trees as palm trees are known to grow to heights of 20 meters long. [6]

Therefore, this system can only be used as a pilot system and proper advanced RFID scanners with at least 1 GB storage, 4 inch read range distance and sustainable battery life is highly recommended. Another challenge encountered was choosing the right RFID tags. Passive tags were chosen as they have several advantages over active tags. They are cheaper compared to Active Tags and have a greater lifespan as they are not constraint to the battery supply. Thus the maintenance is lower and Tag size much smaller and in greater variety [6].
Another obstacle faced was the tag placement and the best method to scan the tags to achieve accurate results. After intensive investigation, it was concluded that each tree should only have one unique tag throughout its lifecycle, and to record the FFB, the tag should be scanned as many times as its FFB production.

4.2. PMS
The core purpose of this system is to validate and analyze the FFB records received from the RFID scanners. Different types of dynamic charts will be used to represent the information in real time and in different levels/abstractions in order to review the information from different perspective and enable effective evaluation. The analysis is mainly based on the company’s grading system and business rules. The main types of analysis that can be carried out include:

(i) Harvest analysis
This analysis represents the overall plantation production as a pie chart. The percentage of good trees in the whole plantation is represented in green color, average trees in yellow color and bad trees in red color as seen in the Figure 2 below. The harvest analysis is based on the year and month selected and is useful in evaluating the overall productivity.

(ii) Block/Palm analysis
This analysis represents block productivity as cumulative bar graph. The analysis is based on industry’s best practice 5, which states each plantation will be divided into blocks/sectors hence it is necessary to show productivity based on block level for a deeper level of geographical analysis.

Like the harvest analysis, the year and the month has to be selected for the block analysis to be evaluated. For instance, according to the Figure 3, it can be determined that block 3 had the most average tree production while the rest of the blocks roughly had the same productivity performance. Identifying such irregularities in the plantation is crucial as it can help determine most productive or unproductive areas in the plantation.

(iii) Tree analysis
This analysis represents the performance of each tree throughout its lifecycle as a line graph. The scales are calculated based on the industry’s best practice 3 and 4 which states the FFB production ascent phase is usually between the ages of 3 to 10, the plateau phase between ages 10 to 15 and the declining phase occurs after 15 years. As seen in the figure below, the tree analysis conforms to this standard. This analysis can be used to further answer productivity analysis depending on palm oil phases. For instance, managers can identify phases that need more attention to increase productivity or what other extra resources are needed to ensure accurate monitoring of FFB production. Figure 4 shows the typical yield pattern measured in metric ton per hectare (mt/ha) for a period of 25 years of the palm.
4.3. **Allocation module**

In big plantation, it is expected that there will be many RFID scanners allocation conflicts. The purpose of this component is to enable effective allocation of RFID scanners to the field workers without any conflicts. This module achieves this objective by providing the following functionalities:

4.3.1. **New allocation.** For an allocation to be registered, the scanner ID, field collector’s name, start data and end date have to be specified. If for instance, to allocate scanner 5 to Mr. Sung from 1st - 10th January 2012, the system will confirm scanner 5 exists in the system and has not been allocated. Moreover, the system checks that Mr. Sung is free and has no other allocation to avoid multiple allocations.

4.3.2. **Scanners return date.** On the end date, each field collector is supposed to return the scanner to the GIS manager. This component eases this task by displaying all scanners that are due on the current day. The GIS manager has to enter the return date once the scanner is returned. It is important to note the end date and the return date can be different due to unforeseen circumstances such as the scanner becomes defective and has to be returned at an earlier date than the stated end date.

4.3.3. **Current day’s allocation.** This feature displays all the allocations of the current day, including the field collectors in the field and their respective scanners. This module aims to ‘give eyes’ to the GIS manager on what is happening in the plantation field in order to effectively manage the harvesting process.

4.4. **Grading system module**

This module is used to record the company’s grading system criteria for determining the status of trees, blocks and the overall plantation. A benchmark is based on the age of the palm oil tree as each year of a palm oil tree yields different FFB amounts as outlined in the industry’s best practice 4. To satisfy industry’s best practice 1, the grading system will start from the age of 3 till 25 hence only 22 benchmarks would exist. For example, for age 3, the following benchmark could apply.

| Table 3. Tree Benchmark. |
|--------------------------|
| Age | Good trees | Average trees | Poor trees |
|-----|------------|---------------|------------|
| 3   | 2          | 1             | 0          |

This means that for any tree in the plantation aged 3 years, whose FFB lower bound is 0, 1 or 2 would be graded as a poor, average or good tree respectively. This process iterates throughout the year until the next year where the tree will be one year older hence the benchmark for age 4 will be used and the cycle continues until the age of 25 years where the tree becomes unproductive and is cut down.
4.5. **Export module**

This module integrates the PMS system with the GIS system. Spreadsheet format is used for maximum compatibility across computer platforms. The main information that can be exported to GIS system includes:

4.5.1. **Analyzed tree information.** This includes the unique tree ID and its status depending on the company’s benchmark criteria. Once the basic export criteria namely block ID, year and month are specified, all the trees within the stated block will be displayed with their status stated as shown in Table 4.

| Tag ID   | Status     |
|----------|------------|
| A907865  | Good Tree  |
| A679102  | Average Tree |
| A829300  | Poor Tree   |

This information will later be relayed in GIS system, by mapping the Tag ID which coincides with the Tree ID in The GIS system. Thereafter, the tree properties such as the tree’s coordinates can be viewed and color-coded according to its status.

4.5.2. **Block status information.** This includes the block ID and its status determined by the PMS system depending on the company business rules and grading system. A block status determined by the maximum number of a particular status, for instance, if block 1 has a total of 700 good trees, 1000 average trees and 900 poor trees then the status of block 1 will be average. This process is done for all blocks in the plantation and displayed in a spreadsheet file format as shown in Table 5 above. The block ID would then be mapped in the GIS system. However, it is important to note that the block analysis is also indirectly achieved by the mapping of analyzed tree information. This is because, the trees would already be color coded hence having different percentages of green, yellow and red sections. Therefore the block status can also be determined by simply looking for the largest color portion. Nonetheless, this block status information is still required for instances where the portions are almost equal.

| Block ID | Status |
|----------|--------|
| 1        | Average|
| 2        | Poor   |

4.5.3. **Inactive tags UIDs.** Inactive tags refer to tags that have not yet been assigned trees in the plantation field. This information is required within The GIS system in order to ensure tag integrity and avoid anomalies such as assigning non-existent tags ID, or deleting already assigned tag IDs or assigning two different tag IDs to the same tree. One of the main obstacles encountered when developing this system was integrating the RFID system with the PMS system since they use different interface, routines, implementation structure, and method of communications. However, this problem was solved by using appropriate application programming interface (API).

4.6. **GIS System**

The main goal behind adopting the proprietary GIS technology is to model the oil palm plantation field as color-coded spatial data to enable effective monitoring of the growth and productivity of the oil palm trees. Additionally, The GIS system can be utilized for a number of other functionalities such as:

- Displaying/editing/deleting tree properties
- Mapping of the trees UID to its coordinates
- Color coding status of the trees
- Creating models of the plantation field blocks

The projection used by the proprietary GIS system is the Borneo Rectified Skew Orthomorphic (BRSO) Grid (meter) which is the main projection type used in Brunei and East Malaysia [3]. The conversion method used is Hotine Oblique Mercator which compensates the horizontal scaling by stretching the meridians; in order to preserve local angles, the poles are moved to infinity. Since no
map projection can preserve shape and size simultaneously, and the larger the mapped area, the more pronounced the total distortion, [4] PMS overcomes this challenge by representing the same information in different formats such as dynamic charts. One of the primary requirements of this project is to map the analyzed digital information achieved from PMS as spatial data in the GIS system in order to make educated geographical analyses. Analyzed information can be presented as dynamic charts in PMS can be further processed as spatial data in the GIS system in a few simple steps. CSV file format was chosen as the desired format for its simplicity and once imported in the GIS system a database table is automatically created. The GIS system provides concurrent, multi-user storage and editing of drawings in a centralized geospatial database hence users can reuse, edit drawings, images and other mapping components in the central DBMS without conflicts. In the end, the desired color-code tree spatial data can be viewed; hence the overall productivity can be analyzed in different abstractions such as in harvesting cycles (year and month) or block levels.

5. Conclusion and recommendations

In conclusion, the use of the high frequency RFID technology in the plantation enables an accurate way of monitoring the FFB productivity but the main achievement of the project is the mapping of the analyzed harvest information as spatial data in Manifold GIS system which enables efficient productivity analysis. However, there are other various innovative methods that could improve the competitiveness of this project such as use of GPS system. GPS system has several advantages over RFID technology as they automatically provide a set of geographical coordinates such as the latitudes, longitudes and elevation of the earth without the need of a GIS system [1]. Therefore, in case of the GIS system malfunction, the plantation productivity can still be gathered and monitored.

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