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TOWARDS SMART PALM OIL MILL FACTORY OPERATIONS USING IR4.0 TECHNOLOGIES

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Abstract:

Palm oil mill industries are commonly found in Malaysia. This is due to Malaysia's position as the second leading producer of palm oil worldwide. In 2021, Malaysia supplied a third of the world's palm oil next only to Indonesia. Recently, there is a trend of increasing price of palm oil in the market, marking higher demand and higher profitability for the palm oil industry players, including the palm oil mill operators. Towards supporting this greater demand, there are calls for action for palm oil mills to upgrade their "stone age technologies" in order to remain competitive. Sustainability of the operations for future palm oil mills need to be addressed now in line with the drive to adopt new IR4.0 technologies. IR4.0 adaptation in the palm oil mill will create new synergy in production, operation and maintenance management perspective. This paper reviews the current processes in a typical palm oil mill and followed by the potential adaptations of IR4.0 in the existing processes. Five main pillars of IR4.0, namely IoT, big data, cloud computing, machine learning and artificial learning will be discussed in relation to smart palm oil mills of the future. The expected outcomes include increase in the overall production effectiveness, as well as improvement in the administration and maintenance management of smart palm oil mills in the country.

Keywords:

Palm Oil Mill, Industrial Revolution 4.0, IoT, Big Data, Cloud Computing, Machine Learning

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Introduction

Palm oil is the world's most used edible oil and its traces is found in many consumer goods such as margarine, chocolate, ice creams, soaps, cosmetics as well as biofuel for vehicles and power plants. Palm oil mill industries are commonly found all over Malaysia and this is due to Malaysia's position as the second leading producer of palm oil worldwide. In 2021, Malaysia supplied a third of the world's palm oil next only to Indonesia. In terms of volume, Malaysia exported around 16.2 million metric tons and China was the major importer of Malaysia's palm oil in 2021. The importance of palm oil industry is suggested as the industry contributes 2.7% to the country's gross domestic product (GDP). Currently, in 2022, the price of crude palm oil (CPO) is elevated to between RM5,900 and RM6,000 per tonne as compared to RM4,400 in 2021, partly due to high demand of palm oil around the world.

Palm oil is considered one of the most efficient and cost-effective vegetable oils compared to other vegetable oils such as coconut, peanut, canola, corn, cottonseed, and rapeseed. Due to the intensive development in palm oil industry in the last decade, the palm oil production is up to eight times compared to other vegetable oil production (Nomanbhay, Salman, Hussain, & Ong, 2017). The palm oil industry requires a strict management, operational and production processes to ensure the productivity of the palm oil mill to reach the optimum level of oil extraction rate (OER) with optimum management efficiency (Kadir et al., 2018). However, most of today's palm oil mills operate conventionally which require a lot of manual work force and the use of existing old technologies to sustain the whole operation. The technological progress in the milling process is considered as stagnant; therefore, implementation of IR4.0 into palm oil mill operation is expected to help reduces operational cost by reducing manual labor and schedule most of the work force to relevant stations to yield better OER.

In Malaysia, the Malaysian Palm Oil Board (MPOB) is the government organization that govern palm oil industries. MPOB's main objective is to govern palm oil industries by developing policies that guide any small or big palm oil industry players including palm estate holders and palm oil mill operations. Currently, there are 89 companies registered as active members in the Roundtable Sustainable Palm Oil (RSPO) membership such as Sime Darby Plantation Berhad, IOI Corporation Berhad, Kuala Lumpur Kepong Berhad, and FELDA (Jamaludin et al., 2018). Several standards of palm oil required MPOB to audit which looks into production, environmental impact and self-sustain operation as well (Begum et al, 2019a; Begum et al, 2019b; Choy et al, 2021; Haan & Takriff, 2021). The Roundtable Sustainable Palm Oil (RSPO) and Malaysian Sustainable Palm Oil (MSPO) are two of the standards well known in industries adopted in Malaysia (Jamaludin et al., 2018).

This paper focuses on the palm oil mill perspective. Palm oil mills are mainly designed to produce or extract crude palm oil (CPO) from palm fruit. Every palm oil mill designs come with different throughput based on the capacity of the estate owned by them, or operating around them including independent small holders. It is suggested that the total cost incurred in palm oil mill depends on the throughput capacity, hence, higher throughput capacity tends to have higher cost-effectiveness to produce CPO (Man & Baharum, 2011). The following section provides a review of literature on past industrial revolutions and the technological innovations brought about by the current IR4.0. This is followed by a review on the conventional palm oil mills operation, as indicated by the process flow involving several processing stations and related functions such as mills' security and laboratory. Then, the feasibility of IR4.0 technologies to be introduced into the palm oil mills operation are discussed. In particular, the

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implementation of IoT, big data analytics, machine learning, cloud computing and artificial intelligence are covered. The last section provides a brief discussion and concludes the paper.

Literature Review

With regards to the industrial revolution (IR), the first IR emerged in England to solve insufficient food issue by revamping the agriculture sector to increase yield to tackle the increased in population. It is also known as agricultural revolution due to improvement mainly on agriculture to increase the output of crops (Clark, 2002). Every industrial revolutions serve the same purpose to breakthrough current technologies which resulted in increase efficiency by introducing new technologies or systems in a few aspects such as quality, service and real time decision-making aids (Mohamad et al., 2018). Technology advancement mobilization shows that palm oil industries require robust system to improve the operational efficiency in terms of management and operation in the palm oil mill. Big data is one of the pillars of the Industrial Revolution 4.0 (IR4.0) that empowers the deployment of data analytics in numerous sectors such as autonomous computation in the monitoring system (Mat Lazim, Mat Nawi, Masroon, Abdullah, & Che Mohammad Iskandar, 2020). Ubiquitous computation allows the industry to deploy devices to monitor readings in an autonomous manner as a large spectrum of machinery are found in palm oil mills (John et al, 2019, Mohammad et al, 2021, Ungurean et al, 2014). Sensors are widely used to measure data based on the parameters of interest, while WiFi or GSM are the methods used to transfer data to the cloud or locally based on the database design.

Internet of Things (IoT) is another technological pillar of IR4.0 that allows the sensors to communicate by bridging it with the cloud service hence allow the sensors to stream data to the cloud database (Mat Lazim et al., 2020). IoT devices benefit the management by allowing remote monitoring of each nodes' reading and therefore, engineers or technical staff will reduce their needs to physically travel and check the factory in order to check each nodes. Cloud computing allows data processing in the cloud where data computation can be done on non-peak hour directly on the cloud (W. Z. Khan, Ahmed, Hakak, Yaqoob, & Ahmed, 2019; Nugur, Pipattanasomporn, Kuzlu, & Rahman, 2019; Sharma, Shamkuwar, & Singh, 2019). Data acquisition and big data allows management to analyze and optimize based on operation, environment and economic aspect. Optimization on the processes in palm oil mill requires a more systematic approach to assess the feasibility of the palm oil mill operation based on supply chains, operational processes, operational costs and maintenance costs (Foong, Lam, Andiappan, Foo, & Ng, 2018).

Overview of Palm Oil Mill Operations

In general, each station designed for the palm oil mill serves different purposes with an ultimate goal which is to extract and recover the palm oil. Nonetheless, some stations are designed to provide self-sustained capability to the estate and mill operation such as a power generation turbine to provide electricity and water treatment plant to provide usable water source. Figure 1 shows stations designed dependently to operate the palm oil mill for crude palm oil extraction purpose (John et al, 2019; Mohammad et al, 2021). The following are the common stations found in most palm oil mills: weighbridge, loading ramp, sterilization, threshing, digester and pressing, depericarper, kernel plant, clarification, power generation, raw water treatment, effluent treatment, laboratory, mill security, and mill administration. Figure 1 shows the overall process to extract palm oil from palm fruits and the self-sustain model for a palm oil mill following major stations in the palm oil processing.

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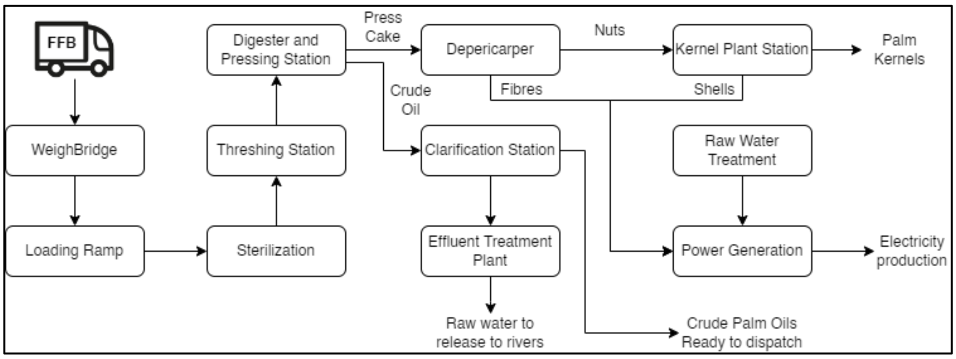

Figure 1: Stations in Palm Oil Mill for Crude Palm Oil Extraction

Meanwhile, Figure 2 below shows the detailed process of palm oil mill operations; it covers from the time the fresh fruit bunch (FFB) reaches the palm oil mills to the end product as crude palm oil (CPO). There are byproducts produced from palm fruits such as fibres, shells, kernels and effluent discharge. However, those byproducts are later used in other stations to sustain the palm oil mill such as feed fibres and shells as burning fuel to the boiler to power up the steam turbines. Untreated effluent discharge release to the nearby river body will deplete the oxygen and suffocate any aquatic life form (Madaki & Seng, 2013). Therefore, palm oil mills usually treat the effluent discharge before releasing it to nearby rivers to reduce the risk of polluting any rivers and to endanger the population dependent on the river as their water source.

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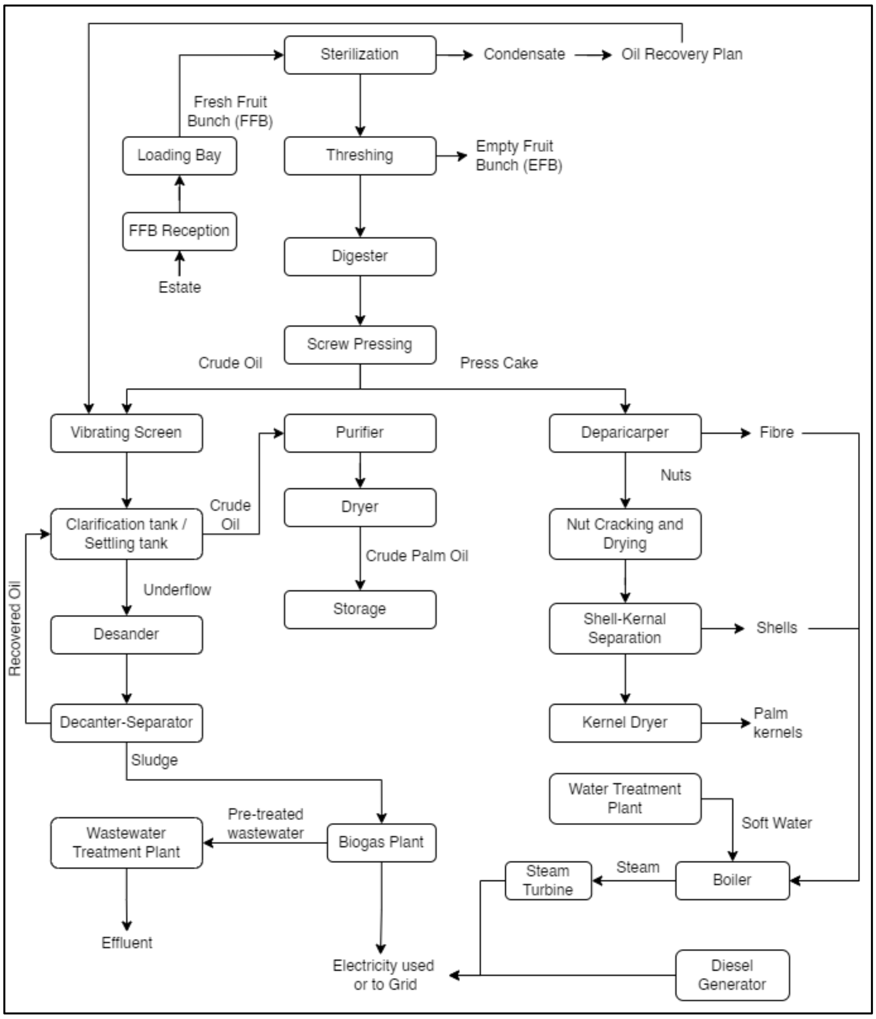

Figure 2: The Detail Operation of Palm Oil Mill for Palm Oil Extraction

Weighbridge

Weighting device plays an important role in the palm oil industry. Weighbridge's function to determine the quantity of the raw material such as palm oil fruit bunch and petrol fuel for the mill's operation usage. Weighbridge is commonly found in palm oil industry to weigh the transporter to accurately calculate the net weight of the FFB. Based on the weight measured by weighbridge, the price of the FFB will based on the weight and the current market unit price. In order to obtain the net weight of FFB, the weight of the transporter need to be deducted out from the gross weight of the transporter while carrying the FFB. Systematic program should be introduced to keep track all the outsourced supply delivered to the mill which is safer for company to manage and monitor (Kannan, Basaruddin, & Hashim, 2017). Data acquisition enabled for weighbridges encourage smarter way to process locally and globally (Jianzhong, Feng, & Mingshan, 2013). Majority of plantation companies do receive palm fruits from smaller plantation as an outsourced input to increase the fruit bunch supply to sustain the mill full capacity operation. Most of the time, tracking the smaller plantation record will be tedious and required systematic documentation to avoid dispute. Every machines require maintenance based on the machine's specification designed (Katipamula, Brambley, & Brambley, 2005) and therefore, the weighbridge needs maintenance and recalibration from time to time.

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Loading Ramp

Fresh Fruit Bunch (FFB) reception in palm oil mill requires a loading ramp and redirect the FFB into the cage and transport to other stations. It creates a buffer time for the sterilizer to cook the FFB while occupying cages. Some plantation uses tension cables or capstan to pull the cages into their desired location such as sterilizer or thresher stations. Some mills also empty the cage using overhead hoisting crane which lifts the cage to the thresher platform and tips the fruit out of the cage on to a feed regulating device which is usually situated on top of the thresher machine. FFB handling when transport to the mill and unloading it to the loading ramp poses effect on OER losses. The effect of FFB stack on each other might create bruising hence, it will lead to OER losses where free fatty acid (FFA) will be higher on bruised palm fruits (Wahyu Krisdiarto & Sutiarso, 2016),(Kumaradevan, Chuah, Moey, Mohan, & Wan, 2015). Misconduct in handling FFB also result in FFA increase due to incorrect SOP when transporting the FFB from plantation to palm oil mill (Imaroh & Efendi, 2020).

Sterilization Station

Sterilization station sterilizes the FFB transported by the cages to soften the FFB for threshing action later on for easier fruit detachment. After the FFB are loaded into the cages, the cages will be conveyed to the sterilizers to be sterilized. Steam is usually used as the medium to sterilize the FFB. Triple and forth peak sterilization processes are used to cook the fruitlets from 0-40 pounds *per square in gauge (psig)* depending on the load and the ripeness of the FFB (Kumaradevan et al, 2015; Dion & Parker, 2013).

Threshing Station

The main objective for the threshers are to remove fruitlets from the sterilized FFB by resorting to continuous rotation method by the thresher which causes the FFB to rotate and uplift FFBs to induce potential energy when the FFB drops. The detached fruitlets will then delivered to the digester by the conveyor system of screw design while segregating the fruitlets and the empty fruit bunch (EFB). The EFB will then be conveyed out by the EFB inclined conveyor.

Digester and Pressing Station

The purpose of digestion is to rupture the oil cells in the mesocarp of the fruits whereas the pressing is to extract oil from the mesocarp of the fruits and separate the fibre and nuts. The oil and sludge will be sent to the clarification station, while the cake fibre and nuts will be sent to the depericarper station.

Depericarper

Palm oil mill processes palm fruit to extract crude palm oil primarily from the mesocarp. However mesocarp fibres, endocarp and kernel are left over in the extraction process (Nomanbhay et al., 2017). The depericarper station segregates kernels and fibres from the cake conveyed from pressing station by the cake breaker conveyor. Winnowing column separate the fibres from the nut by blowing up the light fibres where the nut with higher weight compared to fibres will fell into the nut polishing drum. The separated nuts are sent to nut silos for storage whereas the fibres are sent to boiler as biofuel. Nuts stored in silo to act as retention reservoir for kernel plant.

Kernel Plant

The kernel plant station breaks nuts using a machine called ripple mill in order to extract the kernel and separate kernels from shells. Recovery of the broken kernels are one of the ways to

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reduces the kernel losses as well. It is important to ensure that all the kernels and broken kernels are extracted properly. Kernel storages are prepared to house kernels in the kernel bulk silo for further usage such as kernel oil extraction in-house or out-sourced to other kernel crushing plant. On the other hand, another by-product is palm kernel shell and it is useful because it provide burning fuel source to boilers while selling the excessive shells to other buyers. The average kernel extraction rate (KER) recorded by Malaysian Palm Oil Board (MPOB) maintained at around 5.3% in the palm oil industry for 2020 and 2021.

Clarification Station

Clarification station is also called the oil room and it refines crude palm oils extracted from the digester and press station to reduce the parts per million content in crude palm oil. It will separate the diluted crude oil into oil and sludge, which is a mixture of water, solids and oil. Purification done on the diluted crude oil to recover as much palm oil to improve the OER for the mill performance. The clarification station main objectives are to produce crude palm oil that contains no impurities such as moisture, dirt and sand while maintaining good quality and throughput. In order to separate the crude palm oil from impurities, many machineries such as tank pumps are required. There is a dedicated piping system designed for effective clarification. Generally, the difference types of operation require difference type of continuous clarification tank, separator and purifier.

Power Generation

Power generation in palm oil mill mainly depends on the available combustion fuel sources such as steam turbine and gas turbine. Usually steam turbine uses steam to generate power to operate the mill. The stored energy released from shell and fibres by burning it off will convert the energy into “heat energy”. The heat energy in the furnace will transfer to the pipe and heat up the water running in the pipes. Waters heat up and reaches boiling point and changes state to gas state which is steam. The thermodynamic steam energy will power up the turbine and transfer the heat energy to mechanical energy. Then, the alternator will convert the mechanical energy from the turbine blade rotation into electrical energy.

Raw Water Treatment Plant

Raw water treatment plant is necessary to supply water source for mill operations, domestic and estate usage in the plantation. Impurities in raw water found in the pond requires water treatment before being supplied to the estate or for mill’s usage. The source of the water comes from the water catchment area (usually a pond or a well). A pump house is required to pump the water from the well and pond to start water treatment plan. Numerous types of tanks are used to treat the water such as sand filter tank, water tank, containment and sedimentation tank.

Effluent Treatment Plant

One of the undesirable by-products produced alongside crude palm oil, palm kernel, fibres and kernel shells are the effluent also known as palm oil mill effluent (POME). POME is the most difficult and expensive effluent discharge to deal with by mill management due to large volumes of POME in tonnes are generated over time (Madaki & Seng, 2013). The effluent will undergo some treatment processes before being released into nearby rivers without polluting it. Untreated POME released to nearby rivers will deplete oxygen in a water body of river resulting in suffocating the aquatic life and polluting soils in the river (Mohammad, Baidurah, Kobayashi, Ismail, & Leh, 2021). Most of the processes in palm oil mills generates POME such as palm oil extraction and cleaning process. POME also contain suspended cellulosic

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materials like palm fibre, fat, grease and oil residues (Madaki & Seng, 2013). The two main processes that contribute to effluent are sterilization and clarification where the condensate from the sterilization and the sludge is filtered in the clarification. The sludge from the clarification has higher level solid residues compared to the condensate from sterilization. Both of the sources contain some degree of nonrecoverable oils and fats. According to research, the estimation of 0.5-0.75 tonnes POME is generated for every tonne of FFB processed in a palm oil mill (Yacob, Ali, Shirai, Wakisaka, & Subash, 2005). That is probably 50-75% of the conversion rate of FFB into POME. It does look like the majority of the mass turned into waste. Y. Tan et al study showed that the advantage of POME utilization to generate positive energy to sustain palm oil mill operation. It also reduce the emission of greenhouse gas to the environment from POME (Tan & Lim, 2019).

Laboratory

The laboratory set up in the palm oil mill mainly to analyze the quality of the product in line with the specification in order to maintain the optimum quality of the oil. However, it is also responsible to detect faulty in any of the milling process. The tests are implemented to provide feedback on required information to the mill engineers and management team. This is crucial to manage the efficiency for the mill processes and to maintain the quality of the final product. FFB grading is also one of the crucial inspections needed due to the ripeness of FFB do factors into OER. There are multiple grades of FFB start from overripe, ripe, under ripe, unripe, empty and rotten FFB. Other than ripe FFB usually does not provide high contain of palm oil, instead the bunch absorb palm oil especially in sterilization process (Kumaradevan et al., 2015). The yields of palm fruits are depending on the age of the palm tree as well. Prime age of the palm tree is in the range of 9 to 18 years as the peak of their yields (Ferdous Alam, Er, & Begum, 2015).

Mill Security

Mill security is one of the most important administration tasks which need to be handled in a systematic way to ensure that the assets of the mill will be securely guarded. Losses due to poor security will impact the operations and the overall business of the palm oil mills. The Auxiliary Police (AP) are usually employed to carry out the responsibility to safeguard the security of the mill. The register of every transporter entering the premise done by AP and they have to scan every vehicle to ensure the vehicle’s weight is not tampered with.

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IR4.0 Feasibility For Smart Palm Oil Mills

Industrial Revolution 4.0 (IR4.0) were introduced back in 2015 by Klaus Schwab of the World Economic Forum (WEF) to adopt technologies into the industry (Mahmud, Assan, & Islam, 2018). It opens up opportunities to companies where there are 9 pillars of technologies that support the IR4.0. These technologies consist of big data, the Internet of Things (IoT), autonomous robots, cloud computing, cyber security, system integration, simulation, augmented reality and additive manufacturing (Erboz, 2017; Mat Lazim et al, 2020). Additionally, artificial intelligence often complements autonomous robots while both can be categorized as the multi-agent system (MAS). MAS often relates to smart machines, sensors, controllers and robotics with network connectivity to control production systems to achieve better control (Benotsmane, Kovács, & Dudás, 2019). IR4.0 is the core technology to transform conventional factories into smart factories that increase efficiency in productivity, and this include palm oil mills as well.

Table 1 below proposes the use of selected and relevant IR4.0 technologies into the palm oil mill processes such that it will facilitate, digitize, modernize as well as leaping forward the operations of the palm oil mills which is currently said to be still adopting 'stone age' technologies (Kairi et al., 2020). The following sections will then discuss how a smart palm oil mill factory can be designed and implemented using IR4.0 technologies.

Table 1: The Introduction of Select IR4.0 Technologies into Palm Oil Industry

Stations	IOT	BDA	ML	CC	AI	References
Weighbridge	x			x	x	(Jaya, Suharjito, & Yossy, 2020),(Yang & Wang, 2012), (Kannan et al., 2017),(Jianzhong et al., 2013),(Wang, 2018)
Loading Ramp	x	x		x	x	(Kairi et al., 2020),(Zhou et al., 2019),(Kaur et al., 2018),(May & Amaran, 2011),(N. Khan, Kamaruddin, Sheikh, Yusup, & Bakht, 2021),(Jamil, Mohamed, & Abdullah, 2009)
Sterilization	x	x	x	x		(Musabayli, Osman, & Dirix, 2020),(Bahri, Fatimah, Muhammad Jalil, Amri, & Ilham, 2021),(Hasanah, Machfud, Sukardi, & Erliza, 2013)
Threshing Station	x	x				(Hasanah et al., 2013)
Digester And Pressing Station	x	x		x		(Mohamad et al, 2021),(Hasanah et al., 2013),(Shen, Kee, & Shing, 2021)
Depericarper	x	x		x		(Shen et al., 2021)

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Kernel Plant Station	x	x		x		(Manimaran, Abd, & Mohd, 2020)
Clarification Station	x	x	x	x		(Kairi et al., 2020), (Mohamad et al, 2021),(Hon, 2020)
Power Generation	x	x		x		(Hasanah et al., 2013),(Zailan et al., 2021), (Abdullah et al., 2018)
Effluent Treatment Plant	x	x				(Irvan, Husaini, Simanungkalit, Sidabutar, & Trisakti, 2018)
Mill Security	x		x	x	x	(Verma, Singh, & Dixit, 2022),(Kumar, Kumar, Malathi, Vengatesan, & Ramakrishnan, 2018),(Saini, Ahir, & Ganatra, n.d.),(Ullah, Member, Ahmad, & Member, 2018),(Rami, Chirra, Uyyala, Krishna, & Kolli, 2020)
Mill Administration		x		x		(Tosida, Wihartiko, Solihin, Kustiyo, & Miftahul Huda, 2020),(Hirbli, 2018),(Shen et al., 2021),(Jamaludin et al., 2018)

IoT = Internet of Things, BDA = big data analytics, ML = machine learning, CC = cloud computing and AI = artificial intelligence

IoT Implementation

A study by Lim et al (2021) have identified several uses of IoT in the palm oil milling operations. The most primary use is for process monitoring. In the process monitoring in mills, IoT is used together with cloud computing for dynamic process optimisation. IoT can also be used along with smart image processing for equipment defect detection. IoT can also be used for remote access of process control as well as for smart production management together with big data analytics. The usage of IoT sensors in the vicinity increase the efficiency of workload by reduce any redundancy of measure readings in certain application such as temperature, humidity, current, voltage, vibration, water level and etc. Sensors alone does not classify as IoT sensors, by coupling it with network capability to transmit data signal to cloud database allow wider read and write spectrum. Users and owner of the facility able to read the relevant data anywhere, anytime when needed to ensure the facility in good shape if the data can define the facility health state. RFID was one of the older day technology but it is still consider a part of IoT (Musabyli et al, 2020). RFID and IoT-enabled sensors reduce the hassle in the weighing process by scanning the RFID tag or identify by the sensors to acquire the detail information of the transporter. Every transporter needs to enter weighbridge twice to tally the net weight of the FFB (Yacob et al, 2005; Tan & Lim, 2019; Ferdous Alam et al, 2015). Adaptation of IR4.0 into camera surveillance allows machine learning to identify the information of each vehicle

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passes through the weighbridge. Overall information such as the total transaction of palm fruit and the frequency should be included in the software to enable data analytics.

IoT-enabled sensors fit in on machineries such as hydraulic equipment, capstan motor, thresher, digester, pressing machine, vibration screen and etc. will enable to maintenance management team to monitor the operation of the equipment. Abnormal sensor data received from relevant equipment will prompt the maintenance management to schedule preventive maintenance to reduce unplanned maintenance. Inspection of wire rope for the capstan motor is necessary and tend to exhibit severe health hazard such as cable wire snapping which result in severe injury. Electromagnetic detection method used in hall sensors to detect defects on the wire rope (Zhou et al, 2019; Kaur et al, 2018). Sensors data provide insight to schedule inspection to reduce the likelihood of accident to occur. Any unplanned maintenance occurs will result in plant shutdown such as lifting cranes. Not all machines in palm oil mill will have back up units to run when needed. Shen et al. (Shen et al., 2021) suggested that the usage of temperature sensors for palm oil mesocarp fibers extraction allows the process to maintain the n-hexane temperature at 68°C. However, supercritical CO_2 technique extract residual oils from mesocarp fiber requires temperature 90°C with 19.8% highest yield (Mohamed, Yusup, Wahyudiono, Machmudah, & Goto, 2014). Therefore, varies extraction method and solvent requires different optimum temperature have highest yield.

Big Data Analytics Implementation

Big data refers to large amount of data record in the database locally or in the cloud service. Big data analytics involve IoT sensor's data or manual input data stored to process and portrait result for users to understand and optimize the current facility management operation. Reliability for every assets depend on the key performance indicator (KPI) measured by IoT sensors or manual instrument input by staffs. Data such as mean time to repair (MTTR) and mean time between failure (MTBF) were commonly used in compute reliability for machine based on the time. Time based maintenance (TBM) is commonly used in facility to indicate the health status of machine. Thresher, sterilizer and power generation utilize analytics to compute the reliability to indicate whether maintenance is required to avoid any unexpected shutdown happens. Failure mode effect analysis and fault tree analysis were used in palm oil industry to identify the root cause of failures occurs in the past and study those failures to reduce the likelihood of reoccurrence (Abdullah et al., 2018). Computation of reliability from historical data shows that it is capable to indicate the percentage of reliability based on predicted run time and optimized the preventive maintenance scheduled based on the desired percentage of reliability versus asset operational runtime (Bahri et al., 2021). Optimization of preventive maintenance schedule result in 18.3% cost saving for palm oil mill Kertajaya (Hasanah et al., 2013).

A study suggested that big data analytics on palm kernel to determine the highest fatty acid concentration in palm kernel stearin based on iodine and saponification values. A fuzzy logic system were designed to simulate the most optimum iodine and saponification values to achieve C12 composition of fatty acid at 54.8 to 64 wt% for palm kernel stearin (Manimaran et al., 2020). There are rules applied in the fuzzy logic system to study the relationship of fatty acid composition, iodine and saponification. From the result, the fuzzy logic system is capable to determine the fatty acid composition for C12 in the palm kernel stearin based on iodine and saponification values. It shows that the higher the value of iodine and saponification, the higher the fatty acid composition of C12 in palm kernel. It is possible to establish IoT platform to

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monitor iodine and saponification based on the output of palm kernel to achieve Smart Manufacturing with IR4.0 (Manimaran et al., 2020).

Machine Learning Implementation

Support Vector Machine (SVM), Hidden Markov Model (HMM) and Artificial Neural Networks (ANN) are some of the more popular methods used in machine learning as classifier (N. Khan et al., 2021). These methods can be used in the palm oil mill industry whereby machine learning on surveillance camera enable the algorithm to pick up the vehicle plate number and identify the driver's identity which greatly increase the security. It is also able to reduce dispute with the camera footage. It can serves as a check point where workers are not allowed to bring any asset out from the palm oil mill. The implementation of machine learning in surveillance camera allows the facility to monitor the activities in the facility to detect any anomaly activities such as accidental event. Any anomaly activities detected by the machine learning prompt an alert to the management to tackle the issue without any delay (Verma et al., 2022)(Saini et al., n.d.). HMDB-51 and UCF101 are database with human motion footages which used to feed into the machine learning method for convolutional neural network (CNN) and deep bidirectional LSTM (DB-LSTM) network. It is suggested that using CNN and DB-LSTM produced results to analyze action recognition for footages achieved 87.64% and 91.21% accuracy for HMDB-51 and UCF101 database respectively (Ullah et al., 2018). CNN commonly used for image recognition with the use of convolutional layers to filter the images and classify the image more accurately compared to ANN (Rami et al., 2020).

Cloud Computing Implementation

IoT sensors should be fitted to measure the temperature, current and vibration parameter on the machines such as hydraulic equipment and capstan motor. In conventional method, grader will grade 30% of the FFB load from the in-house or outsource supply. Machine learning in surveillance camera enable image capturing to identify the ripeness of the FFB 100% as compared to 30% with the conventional method (Mahmud et al, 2018). Sterilizers often come with monitoring system and interactive panels for setting but it lacks of network connectivity to enable remote access control. Ubiquitous computing encourages machineries to enable network connectivity to open up opportunities hence, remote access control with intuitive performance dashboard to allow the management level executive to monitor the setting and the current temperature and pressure in the sterilizer. The sterilizer is basically a pressure vessel and it is dangerous when too much pressure holding the vessel if the safety valve is faulty. It can cause disastrous accident in the mill to happen. The data from the sensors allow the system to plot graph on the sterilization cycle chart. Machine learning allows the algorithm to analyze the sterilization cycle to detect any maintenance attention needed. Maintenance activities can be scheduled based on the chart if abnormal trend of the chart is observed. Preventive maintenance can be scheduled and carried out earlier before failure occurs (Wang, 2018; Zhou et al, 2019). Suggestion to install water leaking sensor at the tell-tale hole enable technical team to discover possible early leakage occurs on the pressure vessel body. Such monitoring system allow the manager to remote control the setting without entering the site. Upon critical error occurs, manager able to remote shutdown the sterilizer and release the pressure to avoid pressure build up. The inclusion of sensors such as vibration and pressure fit onto the motor allow maintenance scheduling based on the reading of the vibration which recommend wearing on the bearing and misalignment of the thresher's shaft. The FFBs have to pass through crusher before entering the second thresher for recovery where the worm screw requires time-based

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maintenance where Computerized Maintenance Management System (CMMS) will reduce the hassle to record maintenance information.

The digester and the worm screw press requires IoT power meters to monitor the current output of the system. The worm screws are used to press the oil while the current sensor measure the current draw from the motor that shows the efficiency of the worm screw. Higher current draw and lower OER will prompt maintenance to replace the worm screw. The current readings also relate to the oil content in the fibre of palm fruits. Most of the boiler existed in palm oil mills do not have proper computerized monitoring system, with user-friendly interface and does not allow remote control of the boiler such as feeding speed and etc (Abdullah et al, 2017). A full fledge monitoring system will have a user-friendly UI where it is easy to read with the dashboard and remote control is possible. In power generation system, most of the accessories do have manual instruments and valves to read and control it. IoT technology encourage the usage of sensors by replacing manual instruments and opt for cloud services to access and monitor the system anywhere. Asset management is always done manually in the older palm oil mills. CMMS can greatly reduce the hassle of manually recording data. Analyze data is possible when IoT is being deploy due to computation can be done with software. A proper CMMS are always recommended to record the work order for maintenance as to further enhance maintenance scheduling for the assets in the mill. Big data analysis for maintenance data in palm oil mill is crucial due to the enormous amount of machinery. Unwanted event often result loss of production time hence profit loss. Preventive maintenance allows maintenance team to ensure the machinery to operate effectively and reduce the likelihood of unwanted breakdown. Preventive maintenance reset the reliability of the machinery by restore the machinery before failing. Reliability in machinery depends on the duration interval of preventive maintenance scheduling while not affecting the operation of the palm oil mill (Bahri et al, 2019; Kaur, 2018). The ledger used to manually record the OER and the general data such as FFB load registering into the facility and oil level in oil tanks is recommended to replace with a computerized system. The benefit to record in a computerized system on the Cloud is to reduce human error and accurate computation.

Artificial Intelligence Implementation

Surveillance cameras are usually fit in places for security purpose. Such application register worker enters and exits the premise which is useful to calculate their work time. Artificial intelligent provide supports to the surveillance camera face recognition capture face image of staff and worker who enters the premise and compare with pre-captured image trained in the artificial intelligent (Kumar et al., 2018). Artificial intelligent allow the site to identify and record every individual enter and leave the premise. It creates awareness to all staffs, workers and other visitors that their actions take into account which promote to lower crime or unwanted behavior. FFB grading in palm oil mills are usually done with manual check by mill executive which require worker assistance to reduce the FFB grading time. Every transporter palm fruit need to grade before accepting the load. Artificial intelligent for FFB grading uses fuzzy logic to analyze the ripeness of the palm fruits buy using camera to capture images. Image process grade based on the RGB color of the palm fruit by removing the background of the image to classify it as underripe, ripe or overripe. It achieve 86.67% accuracy in FFB grading using fuzzy logic based on the 3 categories (May & Amaran, 2011). Another FFB grading uses neuro-fuzzy to examine 45 palm fruit images and achieve 73.3% accuracy in ripeness classification (May & Amaran, 2011).

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Discussion

In 2016, the Editorial Board of the Palm Oil Engineering Bulletin Issue #121 (Oct - Dec 2016) stated that palm oil mills are still using technology from the "stone age" (Kairi et al, 2020; Palm Oil Engineering Bulletin #121). In 2020, a group of researchers also argued that the palm oil milling process has been stagnant for decades since the 1950s without any major changes especially related to process control and automation (Kairi et al, 2020). Mohd Bakri et al (2020) discussed the need for mechanization aspects in the palm oil manufacturing sector and the needs of this sector in supporting the idea of Agriculture 4.0). Agriculture 4.0 is an agricultural revolution that sees the use of sensors or IoT, big data analytics, artificial intelligence, and many other technologies that fit current needs. Moreover, since the 1980s, around 48 new technologies have been generated from research at MPOB and all of them involve aspects of mechanization and automation of engineering (Mohd Bakri et al, 2020). According to Mohd Bakri et al (2020), the existing physical innovation must be in line with Agriculture 4.0 and if it is to be seen more globally, the palm oil manufacturing sector needs help from enabling technologies brought by the 4th Industrial Revolution which combines the aspects of cyber-physical system (CPS).

To summarise the IR4.0 technologies feasible for implementation into palm oil mills as covered in the previous section, **Figure 3** shows the feasibility of current palm oil mills to implement IR4.0 into the production line. The Supervisory Control and Data Acquisition or SCADA with Human Machine Interface (HMI), IoT sensors, CCTV camera with machine learning, CMMS and work task system should be largely adopted and used in the palm oil industries to increase productivity, security and reliability.

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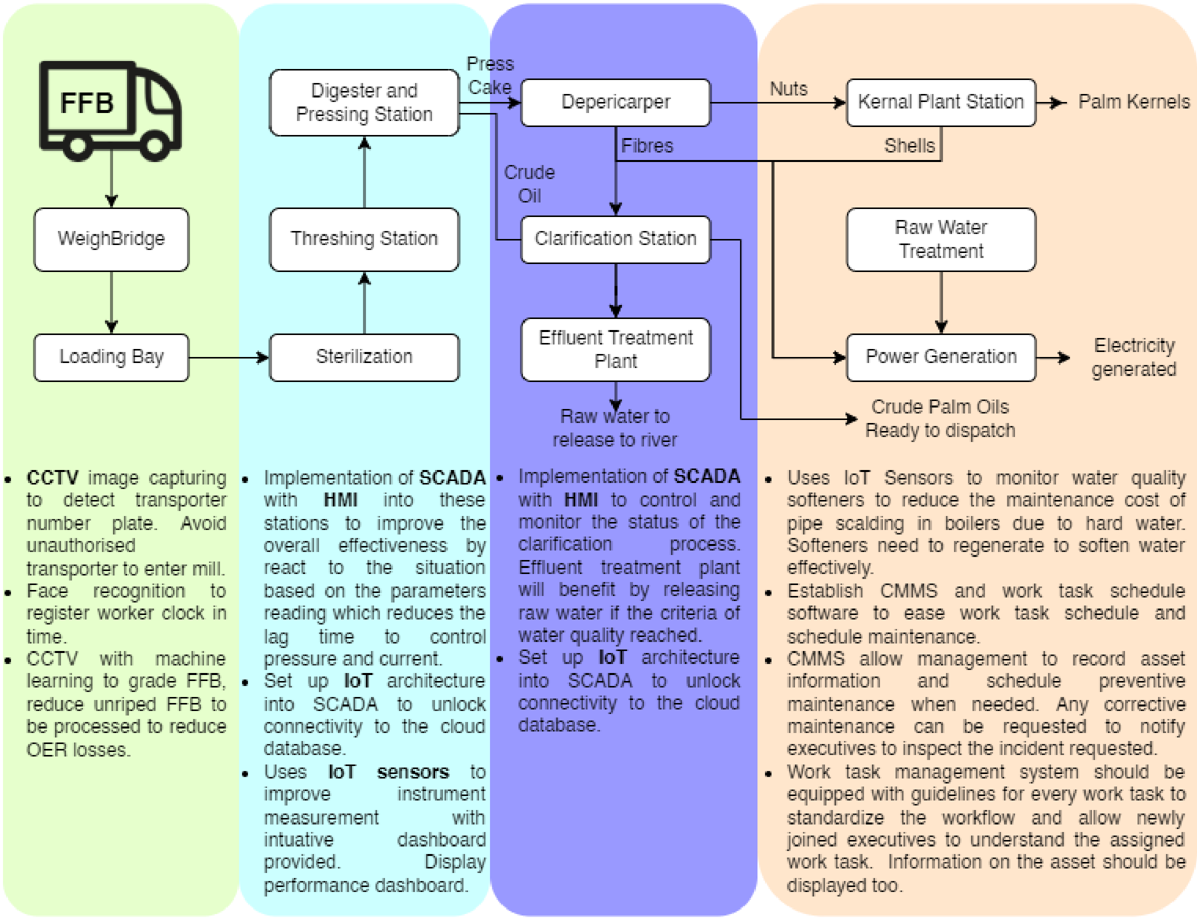

Figure 3: Feasible IR4.0 Implementation into Palm Oil Mills

There are certain palm oil mills use SCADA to automate the controls such as control pressure of the worm screw to get a better CPO extraction. Link a few machineries to the SCADA system to create a robust event processing which react based on the current condition met. However, mill management often consider cost of operation and maintenance when opting for new technology which result in low technological advancement despite more cutting-edge technology existed in the market. Therefore, in-house design and development in mills often provide better yield in OER and reduce operational cost but it takes time for it to happen. Implement IoT into SCADA equipped machineries greatly unlock potential in terms of remote controlling machineries and reduces intense labour.

Palm oil mills operators often have pain points such as breakdown of equipments and old technology or machinery. During the height of the COVID-19 pandemics, labour shortage problem was very acute to the operations of the palm oil mill sector, from the estate to the mills operation. Therefore, it is imperative that palm oil millers adopt 4IR technologies to do more with fewer workers. The combination of 4IR technologies, mechanisation and agronomy innovations is essential towards higher productivity. This is because the most potential of 4 IR technologies such as IoT, big data analytics, cloud computing, and artificial intelligence (AI) are able to automate processes and therefore increase profits and reduce risks at every stage of the value chain, and enhance efficiency along the way. The digitization measures will also reduce the dependence of mill operators on foreign workers which is usually associated with

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the outflow of money abroad as well as the occurrence of social problems involving foreign workers as well as can make manufacturers more innovative, productive, and competitive.

Introducing Systematic Management Scheduling System in palm oil to request and assign job tasks to executives is a great addition to palm oil millers. It unlocks the ability for mill managers to request job tasks and any available executive can accept the work task which can reduce the lag time. However, daily routine job task can be automatically scheduled in executive's schedule equipped with procedure guideline so that newly joined executives can refer to it. Further, CMMS has a good potential to be introduced in the palm oil mills as it enable a more systematic recording of maintenance activities (either corrective, preventive or predictive maintenance) which is currently not widely use in palm oil mills. Machine learning for image capture provide classification based on the situation, where palm oil mills tend to afraid of bottle neck in certain process such as clogging occurs in depericarper which clog up the columns. CCTV with machine learning provide alert support to identify the specific location condition.

Conclusion

As the palm oil sector is a huge contributor to Malaysian economy, palm oil mills operations need to transform themselves and adopt digitization and automation as much as possible. Further, as palm oil mills are highly dependence on labour (and currently are shortage of labour), hence, it is imperative for the palm oil sector to digitise their operations as the next step towards increasing productivity (Teo, 2019). Existing palm oil mills in Malaysia still depends on intense labours and heavy machineries to operates which somehow reflect technological advancement level in the palm oil industries. Most palm oil mills in the country are still either adopting technologies considered as IR2.0 or IR3.0, hence the move forward to enhance IT and computers deployment in the mill production line, particularly to automate the processes will greatly benefit in reducing labour need. The digitisation move will also reduce the mill operators dependency on foreign workers, which some have said brought with it income repatriation and social problems. Furthermore, demand for palm oil is growing in tandem as world population grew. Hence, technologies such as IoT, big data analytics, cloud computing, machine learning and artificial intelligence are some of the enablers that allow producers to be more efficient and productive. It is inevitable that the industry needs to tap into technology innovations to remain competitive.

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