CHEMICAL ENGINEERING TRANSACTIONS

VOL. 88, 2021

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Petar S. Varbanov, Yee Van Fan, Jiří J. Klemeš

ISBN 978-88-95608-86-0; **ISSN** 2283-9216

DOI: 10.3303/CET2188211

Circular Economy and Industry 4.0 Technology Integration Framework for the Oil Palm Industry

Chun Hsion Lim[a,*], Yik Wei Loh[b], Dominic C. Y. Foo[c], Wendy P. Q. Ng[d], Hon Loong Lam[c]

[a] School of Engineering and Physical Sciences, Heriot-Watt University Malaysia, Jalan Venna P5/2, Precinct 5, 62200 Putrajaya, Malaysia.
[b] Department of Chemical Engineering, Universiti Tunku Abdul Rahman, Jalan Sungai Long, Bandar Sungai Long, Cheras, 43000 Kajang, Selangor, Malaysia.
[c] Department of Chemical and Environmental Engineering, University of Nottingham Malaysia, 43500 Jalan Broga, Semenyih, Selangor, Malaysia.
[d] Petroleum and Chemical Engineering Programme Area, Universiti Teknologi Brunei, Jalan Tungku Link, Gadong BE1410 Brunei Darussalam
l.chun_hsion@hw.ac.uk

Palm oil is a sustainable resource with high potential to substitute fossil fuels as the raw material for cleaner energy and chemical production. The oil palm industry is highly dependent on manual labour operation, especially its upstream operation, i.e., plantation. With the rapid development of process automation, robotic, internet-of-things (IoT) and big data analysis, adaptation of Industry Revolution 4.0 (IR4) has proven to be a great strategy to improve process efficiency. Each of the IR4 component/technology may be integrated for its specific feature, such as robotic drone with artificial intelligence data analysis to process captured image. Such technology could be further upgraded with more IR4 technologies integration. This paper proposes a novel circular economy framework to evaluate the potential of implementing IR4 technologies in the oil palm industry. Upon identify viable IR4 technologies for the industry, the cost of investment between the new and existing technologies were compared. Return on investment (ROI) and capital investment were used as the selection criteria to assist the palm oil stakeholders in the decision-making process. Graphical pinch analysis tool is adapted to identify an optimum solution. A case study involving oil palm plantation in Malaysia is analysed. An investment on spray drone for pesticide application was proven to have higher ROI, as compared to the spray tractor and existing practise of using knapsack sprayer. While another drone application for tree health and fruit monitoring has a positive ROI too, it is not possible to invest in both technologies due to budget limitation. Based on circular economy concept, investment into the spray drone and modified drone with smart spectrometer for tree health and fruit monitoring are better strategies to minimise IR4 investment.

1. Introduction

Palm oil is one of the main sources of edible oil, renewable energy and chemical products. Despite the huge demand and market potential, there are various factors causing inefficient production of palm oil and palm oil-based products. Some of the main challenges include high labour dependence and labour shortage in the plantation site, and non-optimum production in the mill and refineries (Alam et al., 2015). In order to improve the production efficiency, development towards Industry Revolution 4.0 (IR4) is a promising strategy to automate the process for labour reduction and to adopt smart technologies for process optimisation.

Various studies have shown the potential IR4 technology applications in the palm oil industry. For instance, artificial intelligence was used to analyse near infrared spectrum of oil palm fruit to determine the ripeness (Silalahi et al., 2016); while microwave sensors were developed for the same application by You et al. (2020). Soil monitoring system with moisture, pH and tilt sensors can be integrated with WiFi module for quick and real-time access of data via internet connectivity (Rawi et al., 2020). Application of smart devices such as drone in the oil palm plantation site enable huge reduction in labour dependency. A news article stated that land coverage of a drone for data collection is about 500 times of a human, and use of artificial intelligence-based system could

Paper Received: 14 June 2021; Revised: 3 August 2021; Accepted: 7 October 2021
Please cite this article as: Lim C.H., Loh Y.W., Foo D.C., Ng W.P., Lam H.L., 2021, Circular Economy and Industry 4.0 Technology Integration Framework for the Oil Palm Industry, Chemical Engineering Transactions, 88, 1267-1272 DOI:10.3303/CET2188211

speed up image processing time from 14 days of manual processing with 20 people to 4 hours (Raghu, 2019). In the mill and refineries, IR4 technology can be applied to predict and manage maintenance schedule. For example, predictive maintenance algorithm via artificial neural network was reported to able to minimise equipment failure cost, loss of production, and optimise equipment maintenance schedule (Suresh et al., 2020). Image processing technology also could be used in processing plant to detect pipe defect for preventive measure (Yin et al., 2020). Application of cyber security were discussed in Lim et al. (2020) and suggested that it is more suitable to be implemented in later stage due to the high investment cost at current state. Despite the research on various IR4 technology applications, the current state of the palm oil industry is yet to be able to fully adapt to the swift advancement of the technologies. Qua (2019) stated that the palm oil industry consists of all spectrum of industry revolutions, where oil palm plantation site is mostly at Industry 1.0 stage (with huge labour dependency), mill is in Industry 2.0 stage (mass production), and refineries and oleochemical are in Industry 3.0 stage (incorporated computer and automation such as Programmable Logic Controller). The lack of process improvement in the plantation site is mainly due to the fact that most farmers are small and medium stakeholders with limited budget and knowledge, which render them from moving towards long-term benefits for process improvement. A detailed framework to study IR4 adaptation options is essential to assist the industry in moving toward IR4.

In general, IR4 enabler consists of multiple types of technology such as robotic, smart sensor/spectrometer, Internet-of-Things, big data analysis, augmented/virtual reality, cloud computing, and cyber security (e.g., blockchain). The various integration potential of IR4 technologies show that investment strategy into IR4 technology is not a linear process of technology selection. Some IR4 enablers might be compatible with others for potential future upgrade, while others may have limited integration potential and usage. A systematic strategy is crucial to avoid investment in IR4 technology pathway that is incompatible for further upgrade. Adaptation of circular economy could help preventing this issue by identifying close-loop IR4 enablers that may be integrated with each other. The huge numbers of investment options create a complex problem for the stakeholders to determine the best decision that meet their expectation and budget.

This paper introduces a novel circular economy investment framework for IR4 technologies for the oil palm industry to investigate the potential multi-integration of each IR4 technology. Financial Pinch Analysis approach is adopted to determine the optimum solution based on the return and investment budget. This approach has been proven to be an efficient tool to determine the optimum investment option based on the annual return and investment budget (Bandyopadhyay et al., 2016). The technique has also been adapted in the selection of energy conservation (Roychaudhuri et al., 2017) and carbon dioxide emission reduction projects (Foo, 2017).

2. Methodology for circular economy framework and graphical pinch for IR4 technology

As discussed in the previous section, IR4 technologies consist of multiple enablers that could be integrated for modification. This section discusses the adaptation of circular economy concept in evaluating IR4 implementation in the oil palm industry. In general, circular economy focuses on waste recovery and minimisation. Due to the rapid development in IR4, some technologies might be easily replaced by newer and better technology within a short duration. Investing into such technologies could lead to sub-optimal use of resources, especially if it is not compatible with future upgrade. This paper proposes a novel adaptation of circular economy concept in IR4 technology investment framework, so to consider future upgrade potential during the selection process. The investment consideration framework should consist of the integration of multiple IR4 enablers for investment in stages. This is particularly important for the diverse group of oil palm stakeholders, who have difference range of investment budget and expectation. In the proposed circular economy framework, the existing technology is first considered. Potential new technologies for the same application are then evaluated, including the basic IR4 technology and its subsequent upgrades capability.

Figure 1 shows an example of a circular economy framework for pesticide application technologies and potential drone utilisation in oil palm plantation. In general, drone can be used in oil palm plantation to minimise labour dependency for tasks that required huge land coverage, access to remote and/or hazardous area. Figure 1(a) shows the existing labour-intensive practises of using knapsack sprayer in applying the pesticide. Figure 1(b) shows an improvement of technology, i.e. with tractor to increase the efficiency. Note that despite spray tractor may not be considered as part of IR4 enabler, it should be considered in the framework as it is one of the common practises in the agriculture industry for pesticide application. Figure 1(c) shows the IR4 application of drone for the same task. High coverage and accessibility of drone could reduce the labour decency significantly. With the adaptation of circular economy concept, the alternate usage and potential future upgrade of IR4 technology were considered. Apart from pesticide application, drone can be used for remote visual inspection of fire, smoke or pipe rupture with existing camera as shown in Figure 1(d). Alternatively, drone has the potential to be modified for new parts such as inclusion of smart spectrometer sensors and AI system to enable tree health and fruit ripeness detection via image processing in Figure 1(e). In the proposed circular economy framework, the upgrade sequence of IR4 is critical to maximise the utilisation of new investment. In this case, most spray drones in the market can easily be modified to replace/inter-change spray tank with smart spectrometer; while existing smart spectrometer drone may not be compatible with spray tank as the drone was not designed to operate with heavy load. Investment into spray drone could be a future-proof technology as compared to smart spectrometer drone.

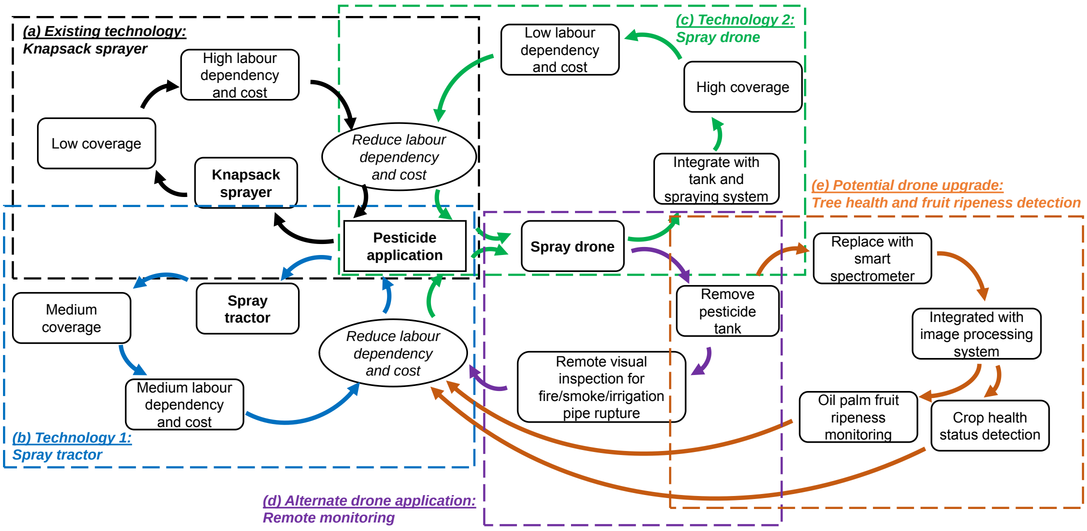

Figure 1: Circular economy framework for investment of pesticide application technologies; (a) Existing technology - knapsack sprayer, (b) Common agriculture technology - spray tractor, (c) IR4 technology - spray drone, (d) remote monitoring with drone, and (e) future upgrade of spray drone with smart spectrometer.

Upon understanding of the potential investment options and the future upgrade potential, a systematic evaluation approach is required to understand the feasibility of investment and to determine the best investment option for respective stakeholders. Return on investment (ROI) and total investment cost were proposed to be the evaluation criteria for the technology selection for investment. ROI is a performance measure based on the ratio of net return and total investment cost, which is a good indicator for technology investment comparison. However, the generic concept of ROI may not be applicable to access IR4 technologies investment in the oil palm industry due to the lack of reported data on IR4 technology, as such technology is rather new to the industry. This paper proposed a modified approach to determine the ROI based on cost reduction from implementing the new technology over the existing practises and capital investment cost, $CAPEX_i$ as shown in Eq(1). In the latter, profit gained is calculated based on the cost difference of existing, C and new technology, I_i over a given years of operation, Y. Note that the cost element C in Eq(1) includes the cost of operating the existing practise/technology, $OPEX$, for years of operation, Y, and its capital cost, $CAPEX$, as shown in Eq(2). On the other hand, I_i element in Eq(1) is determined based on the annual operating cost, $OPEX_i$ of the new technology, i, over years of operation, Y, with capital investment cost, $CAPEX_i$ as shown in Eq(3).

$$ROI_i = \frac{Saving\ from\ cost\ reduction}{Capital\ investment\ cost} = \frac{C - I_i}{CAPEX_i} \qquad \forall\ i \in I \qquad (1)$$

$$C = OPEX \times Y + CAPEX \qquad (2)$$

$$I_i = OPEX_i \times Y + CAPEX_i \qquad \forall\ i \in I \qquad (3)$$

In general, investment with highest ROI that fulfilled the stakeholder’s ROI expectation and within their maximum budget limit will be selected. This resembles the classical sink-source allocation problem in process integration (Foo, 2017). In this case, financial pinch analysis technique (Bandyopadhyay et al., 2016) is adapted to determine the optimum matching of IR4 technology for the respective stakeholder. Figure 2 shows an example of the graphical tool known as financial pinch diagram for optimum project selection (Bandyopadhyay et al., 2016). As shown. the financial pinch diagram is plotted with the saving (by cost reduction) of IR4 technology versus its investment cost, where the slope of the segment represents the ROI of the respective technology. Prior to plotting the pinch diagram, all considered technologies (sink) are arranged in ascending order of their ROI. This study only considered a single source of funding coming from the stakeholder, resulting in single segment on the fund composite curve (see Figure 2). When multiple funding sources (e.g. bank loan or other investor) are considered, more segments will be added in the fund composite curve (see details in (Bandyopadhyay et al., 2016)). The fund composite curve is first plotted at the origin of the pinch diagram. The solution is considered feasible where the fund composite curve stays entirely below and to the right side of the technology composite curve. In other words, the fund has to be sufficient to cover the total investment cost of the technology. Besides, the ROI value of the technology (represented by the slope) has to be higher than the expected ROI of the fund. In the case where only a single technology is needed (such as selection of different drone model for the same application), the technology with the highest ROI will be selected as the best option. As shown in Figure 2, Technology 1 is not feasible as its ROI value is lower than the stakeholder’s expectation. Both Technologies 2 and 3 are feasible, but Technology 3 will be selected as it has the highest ROI value.

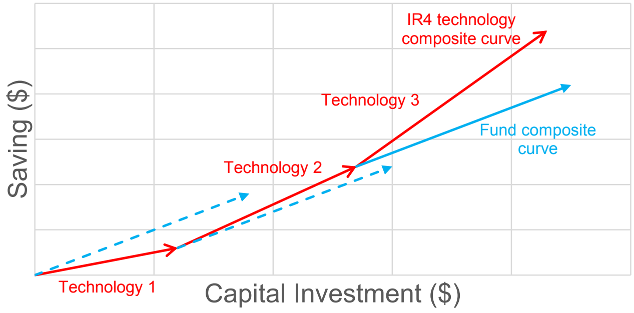

Figure 2: Financial pinch diagram for IR4 technology selection

3. Case study for fertiliser application in the palm oil plantation

To demonstrate the application of the proposed method for IR4 technology evaluation, a oil palm plantation case study is illustrated. In this case, IR4 technology is considered for an established 11,380 ha of oil palm plantation in Malaysia. It is aimed to reduce its labour dependency in pesticide application and site monitoring. Table 1 summaries the data of various technologies used for both the activities. According to the oil palm stakeholders, application of pesticide is similar to fertiliser application practise which is usually conducted twice annually. Typically, the activity is carried out during the non-monsoon seasons for better efficiency. As a result, the optimum duration for application is about 3 months each time. The requirements of labour cost and energy were calculated based on the assumption of the total coverage of 22,760 ha of plantation land, and to be completed within 6 months duration. According to input of industrial experts, knapsack sprayer is typically used in the current practise of pesticide application, where this technology was used as the base case for comparison. Spray tractor (T1)(Wong, 2020) and the new IR4 technology, i.e. spray drone (T2) (DJI, 2021) were included to evaluate the investment potential. Spray tractor has been implemented in some established oil palm plantation site. However, its efficiency and applicability are highly dependent on the terrain of the site. Drone application has the advantage in terms of high accessibility and coverage. Note that only 3 units of spray tractor and 2 units of spray drone are needed to cover 22,760 ha in 6 months. However, 4 units were allocated for each technology in this case study to account for unexpected equipment downtimes, training purpose, and simultaneous coverage of multiple sections in the plantation site. The operating cost for spray tractor was calculated based on the diesel consumption of 5.5 L/ha and local diesel price of 0.55 $/L. Besides, the cost of spray drone was calculated based on electric consumption for battery charging (i.e. 0.91 kWh for a full charged battery with 10 min of flight time at full load) at industry tariff of 0.11 $/kWh. Due to the frequent charging cycle of drone, additional cost for battery replacement was considered. Each unit of equipment was assumed to be handled by an operator, with salary of 800 $/month.

For tree health and fruit ripeness monitoring, the current practise of most stakeholders is to visit each tree for visual observation. Due to the labour-intensive nature, the monitoring process is usually executed during the harvesting process. However, manual observation is impossible to cover all areas. This creates issues of low efficiency in detecting unhealthy trees and potential low oil palm yield due to ineffective ripped fruit detection. These lead to the missing of optimum harvesting time. Established oil palm plantation may utilise satellite image to identify unhealthy tress. However, this option is associated with high cost, confirmation on site, and failure to detect oil palm fruit ripeness due to the huge canopy of leaves. Typically, each tree is capable in producing 12 – 14 fresh fruit bunch annually. It is best to monitor each tree with at least once per month to achieve the optimum harvesting frequency. The basis of comparison is based on the requirement of whole plantation site coverage every month. Apart from human visual inspection, a multispectral drone with live normalised difference vegetation index (NDVI) analysis view was considered (Poladrone, 2020). The drone consists of blue, green, red, red edge and near-infrared band sensors to detect tree health status and fruit ripeness. The drone is reported to have 27 min of flight time with 0.09 kWh at full charge. This is significantly higher efficiency as compared to the spray drone, as it does not carry additional load of pesticide. The ROIs for all technologies were calculated based on 5 y of operations. During data collection, the plantation manager revealed that the company is comfortably to invest approximately 60.8k$ (250 kMYR) into new IR4 technology and a ROI of 0.5 is expected in 5 y operation.

Table 1: Cost data for various technologies

	Pesticide application technology			Oil palm tree and fruit monitoring	
	Knapsack	Spray tractor (T1)	Spray drone (T2)	Farmer	NDVI drone (T3)
Coverage (ha/d·unit)	1	48	80	5	18
Number of units	127	4	4	76	22
CAPEX:					
Price ($/unit)	50	13,000	15,000	-	10,000
OPEX:					
Labour ($/ha)	26.78	0.84	0.84	5.34	1.55
Operating cost ($/ha)	-	3.03	0.06		0.008
Battery ($/y·unit)			2,400		170
ROI	-	23.9	39.9	-	10.7

Figure 3 shows the financial pinch diagram for this case study. The result shows that implementation of T3 had proven to be infeasible due to the limited budget despite it fulfils the ROI requirement. It is a potential investment subject to the increase in investment budget. Alternatively, partial investment or investment in stages could be another strategy to reduce labour dependency for tree health and fruit ripeness monitoring. For instance, drone monitoring could be executed on remote or hazardous area. Both T1 and T2 are feasible solutions that fulfilled the ROI expectation and within the given budget. From the comparison, investment into spray drone (T2) has shown greater ROI due to the higher coverage capability and lower operating cost. Based on the circular economy framework for IR4, investment into spray drone could also be beneficial for alternative future applications. The spray drone can be used for fire or smoke detection purpose with its existing manoeuvre camera. It may also be modified by replacing the spray tank with multispectral sensors for the application of T3. However, detailed cost investigation is not viable for the time being due to the lack of information on the integration cost between different types of drone, especially from different manufacturers. The study has shown that investment into IR4 technology has greater potential for replacing old practises. Noted that the ROI calculation of T1 and T2 were based on knapsack sprayer as the base case, which might not be accurate for some established stakeholders who implemented spray tractor. If T1 was used as the basis, the ROI of T2 is calculated as 19.2, which proves that drone investment is still a better option as compared to tractor in cost reduction. The framework and calculation model can be adjusted to evaluate other plantation site with different land size, investment fund and ROI expectation.

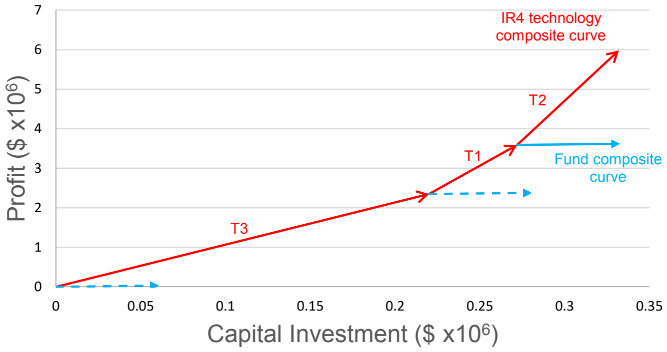

Figure 3: Financial pinch diagram for IR4 technology comparison and selection

4. Conclusions

In view of the complex adaptation strategy of IR4 technology, this paper introduced a novel circular economy framework to consider various integration options of IR4 enablers for the oil palm industry. Case study on labour dependency reduction with drone application on pesticide application, and tree health and fruit monitoring were conducted on an oil palm plantation site in Malaysia. Results show that drone application for pesticide application has higher return on investment in comparison to the common agriculture spray tractor, i.e. 39.9 and 19.2 respectively. Drone application for tree health and fruit monitoring had proven to be infeasible in this case, due to its high investment cost. The study also discussed the advantages of drone for alternative applications and future upgrade in the circular economy point of view. For instance, camera on drone can be used for preliminary fire or smoke monitoring devices in the remote area, and integration of smart spectrometer and image processing system. Nevertheless, lack of information on the integration cost of multiple IR4 technologies limits this study to investigate the potential of upgrading IR4 technology, such as replacement of spray tank for multispectral sensors across different manufacturers. Currently, modification of IR4 technology requires special service from experts where the cost could vary significantly for different cases. This aspect could be addressed in future works once the modification process is more common, or if a universal modular design is implemented. Future works also could include consideration of social issue associated with introduction of IR4 in the industry, so to minimise the impact of replacing labours with machines. This may be done via a systematic approach and with an optimised transition period.

Nomenclature

C – Total cost of existing technology, $
$CAPEX$ – Capital cost of existing technology, $
$CAPEX_i$ – Capital cost of new technology, i, $
I_i– Total cost of new technology, i, $
$OPEX$ – Operating cost of existing technology, $
$OPEX_i$ – Operating cost of new technology, i, $
ROI_i – Return on investment of new technology, i
Y – operation year, y

Acknowledgements

The financial support by Universiti Tunku Abdul Rahman Research Fund: IPSR/RMC/UTARRF/2020-C2/L08.

References

Alam A.S.A.F., Er A.C., Begum H., 2015, Malaysia oil palm industry: Prospect and problem, Journal of Food, Agriculture & Environment, 13(2), 143-148.

Bandyopadhyay S., Foo D. C. Y., Tan R. R., 2016, Feeling the Pinch? Chemical Engineering Progress, 112(11), 46-49.

DJI, 2021, AGRAS T16, DJI <https://www.dji.com/t16/info#specs> assessed 15.06.2021.

Foo D., 2017, Extended graphical technique for the evaluation of carbon dioxide emission reduction projects, Process Integration and Optimization for Sustainability, 1, 269-274.

Lim C.H., Loo V.L.K, Ngan S.L., How B.S., Ng W.P.Q., Lam H.L., 2020, Optimisation of industry revolution 4.0 implementation strategy for palm oil industry in cyber security, Chemical Engineering Transactions, 81, 253-258.

Poladron, 2020, Phantom 4 Multispectral, Poladrone Malaysia, <https://www.poladrone.com/products/phantom-4-multispectral.html> assessed 15.06.2021.

Qua K.S., 2019, Revolution in palm oil, Oils & Fats International, 35(7), 30-33.

Raghu A., 2019, Drones that do the work of 500 farmers are transforming palm oil, TheStar <https://www.thestar.com.my/tech/tech-news/2019/11/20/drones-that-do-the-work-of-500-farmers-are-transforming-palm-oil> assessed 08.06.2021.

Rawi R., Hasnan M.S.I., Sajak A.A.B., 2020, Palm oil soil monitoring system for smart agriculture, International Journal of Integrated Engineering, 12(6), 189-199.

Roychaudhuri P. S., Kazantzi V., Foo D. C. Y., Tan R. R., Bandyopadhyay S., 2017, Selection of Energy Conservation Projects through Financial Pinch Analysis, Energy, 138, 602–615.

Silalahi D.D., Reaño C.E., Lansigan F.P., Panopio R.G. Bantayan N.C., 2016, Using genetic algorithm neural network on near infrared spectral data for ripeness grading of oil palm (Elaeis guineensis Jacq.) Fresh Fruit, Information Processing in Agriculture, 3, 252-261.

Suresh A., Nandagopal M., Raj P., Neeba E.A., Lin J.W., 2020, Industrial IoT Application Architectures and Use Cases, CRC Press, Boca Raton, Florida, US, 145-153.

Wong Agricultural Engineering, 2020, 2in1 Sprayer Machine (pesticide & fertilizer combination), Wong Agricultural Engineering Sdn Bhd., <https://wongagri.com/product/2in1-sprayer-machine-pesticide-fertilizer-combination/> assessed 15.06.2021.

Yin X., Chen Y., Bouferguene A., Zaman H., Al-hussein M., Kurach L., 2020, A deep learning-based framework for an automated defect detection system for sewer pipes, Automation in Construction, 109, 102967.

You K.Y., Wee F.H., Lee Y.S., Abbas Z., Lee K.Y., Cheng E.M., Khe C.S. Jamlos M.F., 2020, A review of oil palm fruit ripeness monitoring using microwave techniques in Malaysia, IOP Conf. Series: Materials Science and Engineering, 767, 012007.