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The Role of Smart Waste Management in Smart Agriculture

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The agriculture sector and its development have played an important role in nurturing the modern civilisation. Agriculture produces food through the utilisation of resources, including nutrient, water and soil. Traditional agriculture has met with concern over the emission of greenhouse gas (GHG), drainage of water resource, consumption of fertiliser and production of waste. Optimising agricultural productivity is essential to meet the growing food demand associated with the rapid population growth worldwide. Smart agriculture (SA) is the approach focusing on agricultural practices that increase productivity and resource resilient while reducing GHG emission. SA has incorporated optimal farming management on water usage, fertiliser application and crop's production through internet-of-things (IoT) and various sensors. A significant amount of solid wastes are generated throughout the agricultural practices. The waste within the system can be precious resource provided an effective waste-to-resource loop is present. The scheduled waste collection system is cost ineffective and not optimum. In smart cities, the sensor-based networks have been used to monitor the waste load in a container and the route of the waste collector to improve the collection efficiency. However, the integration of smart waste management in the SA is still limited. IoT and sensors can improve the waste management loop through the optimisation of waste collection, transportation and utilisation for resource recovery. This review aims to provide an overview of the role of the effective waste-to-resource loop within a smart agricultural system. This could present a better insight on the important elements in defining the role of smart waste management in SA.

1. Introduction

Agriculture is an important sector concerning global food production and security. It is associated with environmental impacts, revolving around water usage, greenhouse gas (GHG) emission, waste production, energy consumption and fertiliser utilisation. Sustainable agriculture aims to provide the solution for balancing agricultural production and environmental exploitation. Climate-Smart Agriculture (CSA) brings in innovative solutions for increasing yields, improving climate resilience and promoting a low emission from the agricultural sector (Andrieu et al., 2017). Precision Agriculture (PA), providing the optimal input at the most optimal time, contributes to increased yield with a lower input cost and leads to a reduction in environmental pollution and labour (Shirish and Bhalerao, 2013).
The Internet-of-Things (IoT), IoT-enabled sensor network and cloud computing allow the transmission of real-time data among several parties, offering monitoring, predictions, decision planning and making. The IoT is a network of physical objects where respective real-time data can be collected and exchanged through sensors, software, and connectivity and communication services (Ojha et al., 2015). The IoT has been expanded and applied for agro-industrial and environmental fields (Talavera et al., 2017), precision agriculture and ecological monitoring (Popović et al., 2017), restaurant food waste management (Wen et al., 2018), waste collection at high priority areas in smart cities (Anagnostopoulos et al., 2015), wireless sensor network on smart bin for waste management (Ramson and Moni, 2017) and some more.
The use of IoT and smart sensors have been used in the agricultural sector and its associated ecological monitoring. The agricultural sector produces a significant amount of waste, regardless of the income level. In Malaysia, the agricultural waste comprises 61 % of the total generated waste (UNEP, 2017). The waste within

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the system can be precious resource provided an effective waste-to-resource loop is present. The sound management and disposal or the agricultural waste (AGW) are of significant concern to improve its environmental performance. There is still limited study on the role of smart technology for the agro-waste sector. This paper aims to (1) review the concept of a smart waste management system for smart agriculture (SA), (2) propose an architecture layer facilitating the above framework, including its infrastructure, data needed and possible application of the acquired data. This paper focuses on the agricultural activities for crop's production and excludes animal husbandry.

2. Smart Waste Management for Smart Agriculture (SA)

This section consists of two sections. The first section presented the elements in the framework of a IoT-enabled smart waste management in SA. The second section identified and discussed the possible components for designing the architecture layer based on the IoT platform to realise the presented framework.

2.1 Framework

The core element of the proposed concept is to expand the framework of SA, which normally included CSA, precision farming and ecological monitoring, with the use of IoT, sensors and servers. The new expansion is associated with the built-in of a smart waste management system within the existing SA framework as shown in Figure 1.

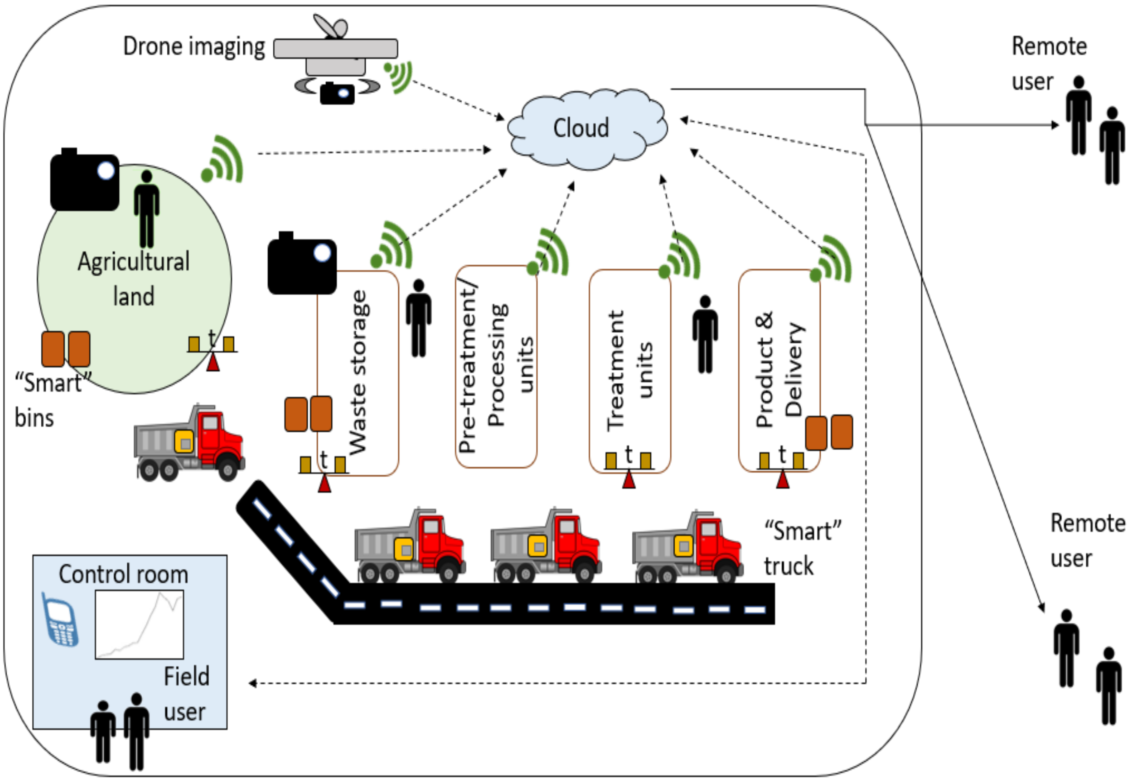

Figure 1: A simplified framework for an IoT-enabled smart waste management in SA

At the agricultural land, "smart" bins with radio-frequency identification (RFID) tags and global positioning system (GPS) modules are placed. Signals will be sending for "smart" trucks when the bins are a quarter to full. The bins are weighed, and the record will be transmitted to the cloud that can be assessed among users. When the trucks entered the waste storage site, the waste is being weighed again to match the quantity of the waste being collected at the agricultural land. The waste pre-treatment unit will convey the signal regarding their treatment capacities. Upon receiving such information, the suitable amount of AGW will be transported to the waste pre-treatment unit by the trucks. A similar approach is applied to the waste pre-treatment units and the treatment units. Due to the characteristics of AGW, such as high in cellulose and lignin, bulkiness, fibre-rich and carbon-rich, pre-treatment technologies such as alkali pre-treatment, thermal and thermos-chemical, ultrasonic pre-treatment, particle size reduction, cell lysate and more, are commonly applied to break down the recalcitrant polymers via physical, thermal or chemical treatment (Ward et al., 2008). Treatment units for the AGW can be categorised into waste-to-energy generation or a product generation. The former includes incineration, pyrolysis and anaerobic digestion (AD) whereas the later includes composting and AD. Depending on the type of products, the mode of transportation, storage, delivery, post-processing/ upgrading and their respective infrastructures can be either co-shared or structured differently.

2.2 Possible components for the architecture layer

The architecture layers for the proposed framework is presented in Figure 2, where the important components within each layer are being identified and discussed. The physical layer represents the five important stages of the proposed framework, namely the agricultural stage, collection and storage stage, pre-treatment stage, treatment stage and the products and delivery stage. The communication and service layer represents the type of communication services for the acquisition, transfer, storage, analysis and access to the information. The application layer proposes the infrastructure where the "smart" element can be applied and to obtain the information which serves as the input for the management layer. The management layer proposes on how the obtained real-time data can be analysed, presented, managed and used for.

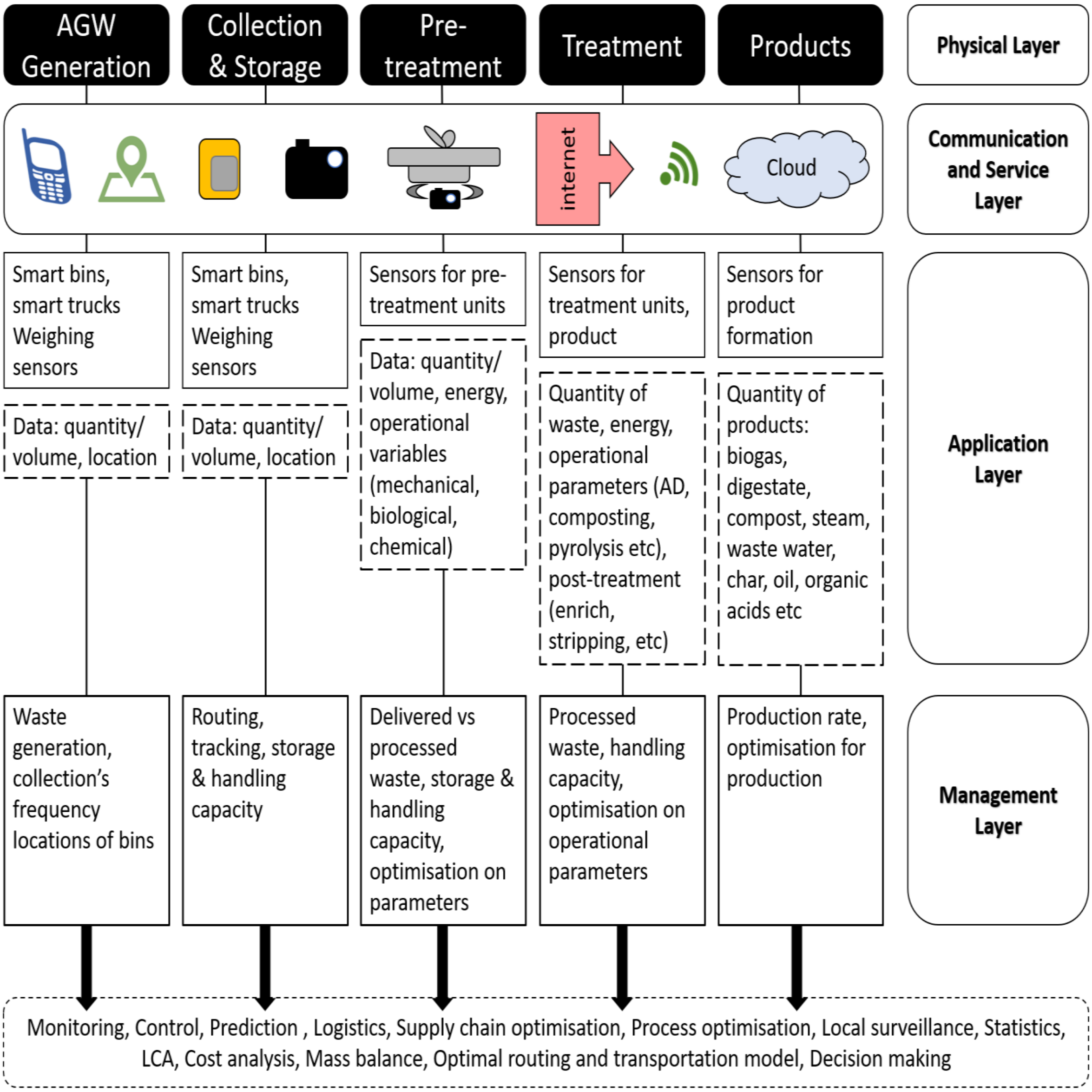

Figure 2: Proposed IoT architecture layers for smart waste management in SA

The quantification of the waste available to be collected is important in initiating an effective management loop. Wen et al. (2018) showed a 20.5 % increase of waste collection in their case study in Suzhou China that practised RFID-tagged “smart” bins, dynamic/ automatic weight sensors and integrated circuit card reader for collection truck for restaurant food waste management. “Smart” bins enable optimal collection when the bins are filled or reached the minimum amount for collection. High collection frequency can lead to wastage of time, fuel and manpower whereas low collection frequency has a risk of overflow, creating the nuisance and spread of illness to the public (Ramson and Moni, 2017). In their study, wireless network smart bins were employed to monitor the unfilled level of the bins and the locations. IoT-enabled smart bins have been used for high priority waste collection in smart cities as presented by Anagnostopoulos et al. (2015) in conjunction with dynamic routing models. The allocation of RFID-tagged smart bins and automatic weight sensors at all stages can (1) reduce the illegal transportation of waste outside the loop, (2) comparing the waste being collected and received, (3) optimise the process where the operation is being carried only when needed, for example, based on a minimum effective volume of waste and prioritised area, (4) transporting waste to the next stage based on the handling capacity of either the pre-treatment unit or treatment unit.

The use of sensors and IoT have offered real-time critical data to facilitate optimal design and feedback loop. The main application includes monitoring (air, soil, water, plant and animal), control (irrigation, fertiliser, pesticide, illumination and accessibility), logistic (production, commerce and transport) and prediction (environmental condition, production estimation and crop growth) in the agro-industrial and environmental fields, with temperature, humidity of the air, soil moisture and solar radiation as the universal variables measured for agricultural application (Talavera et al., 2017). In addition to such variables, new variables are needed for the pre-treatment units, the treatment units and the product units.

Energy crops and plant residues are categorised as lignocellulosic biomass. Pre-treatment is needed to break down its physical structure and to enhance its biodegradability/ solubilisation. The pre-treatment includes mechanical, alkali treatment, fungal treatment, enzymatic digestion, ensiling and composting. Among these, mechanical (grinding, extrusion), biological (enzymes treatment, ensiling and composting) have been reported in a full-scale application (Carrere et al., 2016). The paper compared the pre-treatment methods and concluded that mechanical treatment has a low risk of recalcitrant compounds formation but has high electricity demand. Biological treatment has the advantage of low energy demand and scalability but associated with cost and substrate specificity.

The choice of pre-treatment is associated with the following treatment unit, as each treatment unit has its requirements on the input feedstock and different products (Rentizelas et al., 2009). The major output includes energy-production in the form of heat, steam or bioelectricity (incineration, pyrolysis, gasification, fermentation, microbial fuel cell, AD) and products (char, digestate, organic acids) (Beyene et al., 2018). For instance, in the AD, the biogas production is affected by many factors, including temperature, pH, volatile fatty acids, NH_3-N, organic loading, C/N, substrate degradability and more. This is complicated by the fluctuation in the quantity and quality of feedstock.

The installation of the appropriate sensory devices to obtain such variable is a major concern. As pointed by Ward et al. (2008), the monitoring of the AD is complex as it is a multi-variate biological process with few reliable on-line sensors for the measurement of important parameters. The study categorised the monitoring processes into four categories, namely the (1) basic sensory devices for temperature, pH, conductivity, oxidation/reduction potential (2) gas phase measurements with sophisticated tools such as gas chromatograph (3) infrared spectroscopy for monitoring volatile fatty acid, chemical oxygen demand, total organic carbon and alkalinity on-line in the liquid phase (Steyer et al., 2002) (4) others approaches including respirometry method, denitrifying agents (5) software sensors which predicts parameters that require expensive equipment or are impossible to measure directly, i.e. on-line estimation based on a mass balance-based model. This can be complicated further if several technologies are integrated to manage the waste. More studies can be performed to review on the specific requirements on the important variables for each technology with its respective sensory devices, and possible integration with other treatment technologies.

For the production stage, the design area and the sensory devices are dependent on the treatment unit installed. Incineration allows the complete combustion of waste, with ash as the final residual. Pyrolysis which combusted and gasified the organic matter (OM) to produce biochar, bio-oil and gases. The AD that decomposes OM under the absence of oxygen produces biogas and liquid digestate. The biogas may require post-treatment such as NH_3 stripping, upgrading for methanation or enrichment, sulphur removal and more, and depending on the final needs. The liquid digestate will need a curing area for stabilisation and pathogen deactivation.

Sensory devices, including for variables monitoring and IoT-enabled smart tags, could lead to high investment and operational cost. The frequent need of changing the RFID tag due to heavy duty; the accuracy of sensors and the capacity of information storage are the major limitations (Wen et al., 2018). Another major concern is the energy usage. Recent advancement includes a low-power communications device, the energy-smart concept for the remote environment such as battery-free multi-source energy harvesters and ultra-efficient sensors (Shaikh and Zeadally, 2016) or low power sensors and renewable energy-powered passive RFID tag technology (Md. Ferdous et al., 2016).

As presented by Popović et al. (2017) on its IoT-enabled platform for precision agriculture and ecological monitoring, the platform enables data collection, prototyping end-user analytic functions such as smart spraying and irrigation, assessment of marine environment and feedbacks from researchers and end users. The management platform for commercial food waste management includes real-time data demonstration, statistics and queries, analytical processing, local surveillance, abnormality warning and process procedure (Wen et al., 2018). The acquisition and aggregation of real-time data on these five main components allow (1) evaluation, such as cost-benefit analysis and life-cycle assessment (2) monitoring for sound collection, transportation and disposal of AGW (3) identifying potential illegal disposal or emergency, such as the spilling of waste, maintenance and system breakdown (4) facilitate decision making and making prioritisation for investment (5) supply chain design, such as p-graph (P-graph, 2015), optimisation modelling, optimal scheduling and more.

De Meyer et al. (2014) identified the optimisation approaches for bioenergy supply chain, including mathematical programming (aim to obtain optimal value of the decision variables), heuristics (aim to obtain satisfactory but not always be the optimal solution) and multicriteria decision analysis (aim to compare the variables using many criteria to decision making). The main decision variables identified in the study are categorised into (i) strategic (facility location, capacity and technology, biomass sourcing and allocation) (ii) tactical (inventory planning, transportation, routing, scheduling) (iii) operational (monitoring and controlling, transportation, scheduling). Lam et al. (2013) performed a novel two-stage optimisation using mixed integer linear programming (MILP), which is the macro-stage (synthesis and optimisation of supply network) and micro stage (optimisation and allocation of waste), for sustainable waste to energy (WtE) supply chain to identify the optimal operation, logistics, technologies to obtain product and location. The data can be optimised to determine the optimal biomass allocation networks while optimising the economic and environmental performance of the supply chain was modelled through MILP (How and Lam, 2017). Optimisation techniques utilising the obtained data thus facilitates decision making and the supply chain design, that could be integrated with the upstream data from the SA.

3. Conclusion

This paper presented a proposed framework for SA based on a smart waste management perspective. This study underscores the roles of IoT in smart waste management towards SA. The real-time and continuous acquisition and analysis of decisive variables allow the identification, monitoring, improvement and optimisation of various components along the design of the supply chain, including collection means and frequency, transportation mode and frequency, the performance of pre-treatment and treatment units, and the generation of desired products. The information is important for decision making by analysing the investment cost, waste collection route, the sitting of facility and infrastructure, technologies of waste treatment. Promoting the SA through the optimisation of the farming practice (fertiliser usage, irrigation etc.), the resource management of the AGW could be optimised in parallel. For the software management, the challenges include data storage capacity, low energy-powered sensors, maintenance-eased sensors, access to the internet, internet security and sensitivity or accuracy of sensor’s readings. Regarding the hardware, there have been extensive reviews on the critical parameters on several pre-treatment and treatment technologies. More insight is needed to select and prioritise parameters that can be measured and obtained continuously by sensing devices on the selected technologies. This can be expanded further when there are two or more technologies being employed in the management system.

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