Development of Racking and Irrigation System for Industrial Revolution 4.0 Vertical Farming

Vijayapragas Muniandy *(Author)*
Faculty of Engineering & Technology
Tunku Abdul Rahman University College
Kuala Lumpur, Malaysia
vijayapragasm@tarc.edu.my

***Abstract*—This paper presents a design for multi-layer vertical farming rack to be used as an integrated component in fully automated farming of ginger plants with minimum interactions of humans, in line with Industrial revolution 4.0. The vertical rack is designed in parallel so an Automated Guided Vehicle (AGV) can travel along in the middle for data collecting, observation and retrieving purposes. The whole rack system can hold 96 plants, consists of two 19 m rows. Each row has two stacks of plants. 64 units of plants will receive LED treatment, where else the balance 32 unit of plants will not have LED installed for experiment purposes. Rack will be equipped with protrusions to assist robot with its position sensor. Also, each plant containment will be equipped with required LED lights and watering system, complete with waste water drainage path. AGV was tested along the racks to test its stability and reachability of the arm in retrieving plants tray. This test was carried out using dummy load to test the overall strength, vibration and accuracy of the AGV arm. All tests passed satisfactory.**

Keywords*— *Agriculture, Automated Guided Vehicle, Industry Revolution 4.0, Vertical Farming

I. Introduction

Compared to the traditional farming method, vertical farming is discovered to be a better option for urban area. Vertical farming able to provide greater amount to production with minimum land occupy. Using the Controlled Environment Agriculture (CEA) technology, this modern idea uses indoor farming techniques. The artificial control of temperature, light intensity, soil humidity, and gases makes growing crops indoor become possible and also improve the food security [1]. A real time investigating and monitor system will detect the changes at the surrounding including soil's pH value and carry out the corresponding action to secure every single plant is not polluted. The primary goal of vertical farming is to optimize the use of land in cropping to solve the problem of the scarcity of land. It can solve the problem of scarcity of land caused by the traditional ginger farming and perform a better quality and quantity management by fully automation concept. Therefore, the design of the racking should fulfil the requirement of the production rate and also applicable with the robot design. The design of racking system is required to able for robot to reach and able to hold the maximum loads of the plants which will changing the load with time. The waste drainage system is a consideration of the racking design. The piping system is attached with the racking system to provide water and nutrients to the plants. Moreover, this project is purposing to improve the quality and quantity of ginger and also change the cropping method of traditional faming by high automated and integrated system.

Hence, the objectives of this research are:

1.To design a racking system with waste drainage system for automated vertical farming system.

2.To carry out stress analysis and quality evaluation on the designed racking system.

3.To design an irrigation system for the rack to optimize the farming condition and analyze the pressure drop of several types of fluids in the piping system using simulation.

II. Literature Review

A. Food Security

Referring to the report published by STAR newspaper on Tuesday, 14 Feb 2017, Agriculture and Agro-based Industry Minister Datuk Seri Ahmad Shabery Cheek mentioned that over-reliance on food imports could further depreciate the currency value of Ringgit [2]. If we continue to rely on imports to solve the food shortage, the vicious circle will never be end. Ministry's statistics showed that Malaysia's gap between food imports and exports had been widening in the past decade. In 2015, food import bills alone hit almost RM45.4 billion while exports of only RM 27 billion left the deficit of more than RM18 billion. Its balance of trade for food worsened from a deficit of RM11bil in 2009 to RM18.1bil in 2015. With prediction of population growth, population of Malaysia will reach about 50 million at 2050. The demand for food is expected to increase by 70 to 100%. Consequently, food security needs to be given more serious attention as it is an important element in Malaysia's economic growth while meeting the basic needs of millions population. In order to ensure secured food security, Malaysia needs collaboration of government institutions with the private sector to work together to increase food production by utilizing agro-biotechnology, investing in rural areas, and minimizing marginalization of smallholders and other shareholders. The Ministry of Agriculture and Agro-based Industry (MOA) has organized various seminars, workshops and memoranda of understanding (MOU) between ministries, private firms, agencies and shareholders to ensure continuous supply of food [3].

Tunku Abdul Rahman University College (TAR UC) collaborated with Peking University from China to conduct the Agriculture 4.0 – Ginger Research. The new collaboration will be focusing on Agriculture 4.0, which is an analogy to Industry 4.0. Agriculture 4.0 revolves around the use of digital and automation technology to improve precision and efficacy in indoor farming. The new collaboration will be primarily focusing on the cultivation of Bentong ginger. This project is about an indoor vertical farming project with integration of automation concept. The status of the ginger and surrounding environment criteria will be observed by the sensors and collected by the AGV robots and fixed position sensors. The data will send through the internet to the server to provide a real time information. This information will be carried out by the Big Data Analysis and send the notification to the farm owner to make the decisions for the growth of the ginger. Bentong Ginger was chosen as the project target crop because this kind of ginger very easy infect by the bacteria. This project not only solve the problem of Bentong Ginger, but also save the food security of our country. Any harmful substances will be detected in earliest stage and then provide solutions in real time to reduce damage and loss to farmers and consumers.

B. *Hydroponics: Vertical Farming*

Irrigation, for many countries is an old art but for the whole world is a modern science. Nowadays, the source of irrigation water was supplied by the following sources such as surface water, groundwater, municipal water supply, grey-water, and agriculture or industrial wastewaters [4-6]. The water and nutrient are proposed to supply to the ginger by dripping tube and the waste water will channel to the waste drain. The location of dripping tube needs to be avoided at the top of the ginger because it may damage the leaves of the ginger and also the ginger may fall down while it is mature. Since the ginger is planned to grow using hydroponic method, several factors need to be considered such as water irrigation, fertilizer and substrate selection. Several of substrate has been identified, such as coir dust, burnt paddy husks, EFB fiber, perlite, vermiculite, rockwool, coco peat, and recycled Bentong soil. Since ginger plant will contaminate its soil for at least 5 years after it harvested, using recycled soil is not a good option. Coco peat was selected for this research due to cost effective and sustainable.

C. *Types of Rack Assembly*

As for the racking design, there are several types of the rack which widely used in the market had been studied and analyzed [7-9]. The boltless racking design was studied for its working principles and concept. The boltless concept able to achieve high flexibility of assembly and disassembly. The boltless racking for light duty able to 350 kg which is reliable and sustainable. The cantilever racking system also had been studied on its working principle and design. For cantilever racking design, it is easier for the AGV robot to retrieve the plant but the safety concern will be higher. The pallet shuttle racking system is half-automated by motorized pallet system which more flexibility and time saving but the capital cost will be higher and the AGV robot has no reason to perform in this system.

In this research, the racking design must meet the design specifications and the requirement of farmer. The racking design must fulfil the parameter of ginger sacks and also coordinate with the design of AGV robot. Besides, the racking design also need to be safe, versatile, increased productivity compared to traditional farming, saves time, and saves space and land occupancy [10].

III. METHODOLOGY

The required physical parameters for both plant and rack are as follows: The diameter of the sack is around 19 inches or 48 cm; The height of the sack is around 11 inches or 28 cm; The net weight of sack is 9 kg and the harvest size is 15 kg. The AGV is designed to carry as much as 30 kg without any vibration and positioning error. The height of the AGV is around 1.8 m and the width is around 1m to 1.4 m. The safety factor of the racking system should not less than 1. The cost of the material as low as possible due to the financial capacity of farmer. The flexibility of the design must be high so the productivity of the AGV has to higher than manual operation and can be used to farm plants other than ginger in future. Figure 1 shows the layout in ginger farm established in Tunku Abdul Rahman University College for this research.

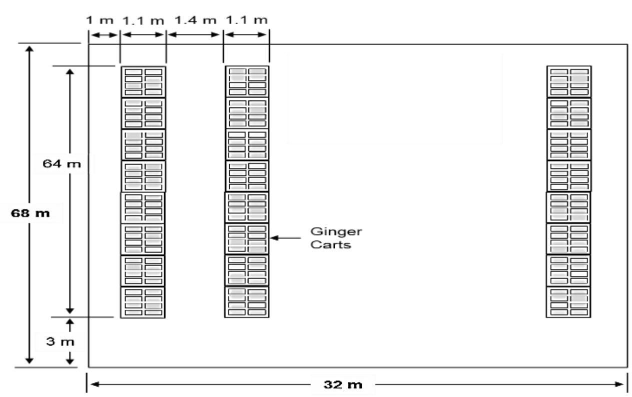

Figure 1. Ginger farm layout

The rack is designed and built using aluminum profile, which has enough strength to support the weight of matured ginger plant including the sack, coco peat and significant amount of water with minimum factor of safety of 3.0. Also, the rack is also designed to house multiple mounting points for power line, sensors and LED lights. Figure 2 shows the general dimension the vertical rack.

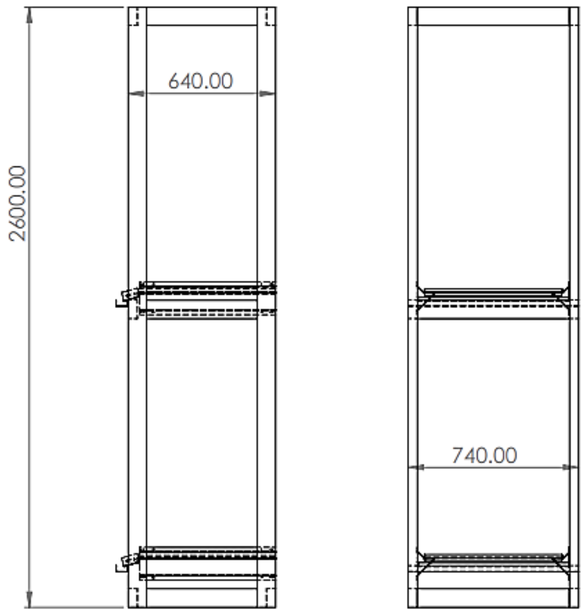

Figure 2. Front and side view of vertical rack

The size of the rack is decided based on the operating limitation of the AGV and space required by the plant to grow healthily while receiving enough sunlight from all possible directions. Figure 3 shows design of PVC water drainage system, where the aim is to minimize fertilizer mixed liquid come into contact to the aluminum frame.

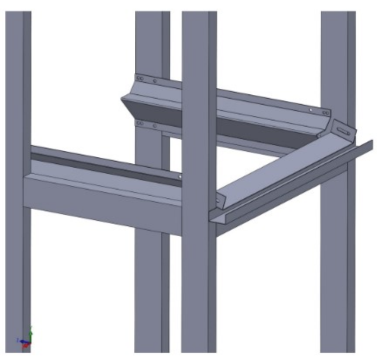

Figure 3. Water drainage system design

The water drainage is placed at the back of the rack, as the AGV will retrieve and place plants from the front. Stainless steel plates are used as tray to place the plant sack, which placed at 3° of inclination in order to direct any excessive water to drip out at the back to the PVC drain. Fig. 4 shows the completed rack.

Figure 4. Completed rack with operational AGV in position

By the time of writing this paper, there are no ginger plants were planted yet due to Covid-19 Pandemic restrictions. The total cost breakdown for the vertical rack (excluding the AGV) is shown in Table I. All the prices shown are in Malaysian Ringgit currency (RM).

TABLE I. VERTICAL RACK CONSTRUCTION COST BREAKDOWN

Items	Quantity	Price (RM)	Amount (RM)
Aluminium profile racking, - L60 X W70 X H270, -2 layers, 4 stainless steel pallet supports, -profile 40mm X 80mm, - mounting brackets to the floor.	48	450	21,600
Stainless steel pallet 60cm X 60cm	96	60	5760
Drainage system for all racking	1	5000	5000
Labour	1	4500	4500
Food grade PE tube 6.3mm X 100mm	1	100	100
Food grade PE tube 9.5mm X 150mm	1	300	300
Solenoid valve 24Vdc 6.3mm/9.5mm	100	45	4500
Ball valve 6.3mm connecting hole	110	5	550
6.3mm T join	110	3.50	385
9.5mm T join	90	6	540
Overhead power supply rail system for 20m	1	5000	5000
Testing and Commissioning fee	1	1765	1765
		TOTAL	**50,000**

IV. RESULTS AND DISCUSSIONS

After The whole rack system can hold 96 plants, consists of two 19 m rows. Each row has two stacks of plants. 64 units of plants will receive LED treatment, where else the balance 32 unit of plants will not have LED installed for experiment purposes. The rack is built using aluminum profile, to ensure lightweight, flexibility in future modifications, easy maintenance and cheaper. However, it is known that aluminum does not hold up against corrosion caused by fertilizers, hence few parts of the racks that have direct contact with plants and fertilizers to be designed in stainless steel (e.g., pallet and pallet support brackets). Rack will be equipped with protrusions to assist robot with its position sensor. Also, each plant containment will be equipped with required LED lights and watering system, complete with waste water drainage path. The whole rack system will be fabricated by Greenamics Technology Sdn. Bhd. according to the specification detailed by our team.

Further research on LED placement is still pending is it outside of the scope of this research. Also, different research team is handling the task where they are well equipped with biotechnology knowledge and knows the exact wavelength of the lights required for specific species of plants to grow healthily. Detailed analysis regarding corrosion of fertilizer fluids against rack structure had taken place once all racks being installed. Use of new materials were introduced at places which (or potentially) have direct contact with fertilizer fluids in order to lengthen the service life of the racks. For example, PVC wire conduit is used as drainage water channel, fixed alongside of the rack. This is to ensure budget friendly maintenance good resistance against chemical corrosion by the fertilizer.

The AGV is able to navigate through the rack and retrieve the plant from any slot as specified in the programing. The AGV is programmed using PLC and can be controlled via online through standard web browser from anywhere, enabling remote observation of each plant in specific schedule or by request anytime. However, the AGV was not designed to be water proof, as this is just a prototype, and was originally planned to work under covered area. Since the covering plastics over the ginger plantation area is starting to tear open (due to weather), some concerns have been raised regarding safety and durability of the AGV. The water / irrigation line to the rack is under construction; as it was originally planned to be post-graduates' students' project work. But due to Covid-19 pandemic restrictions, no students were able to enter the campus and carry out said research. Hence, the budget and expenses for this installation is handled as separate maintenance work with special arrangement between college and supplier.

CONCLUSION

As a conclusion, it can be said that by employing vertical farming technique, massive land occupancy can be saved, reduced waiting time for natural mineral in soil to recover and increased production of ginger, which contributes to local economic growth. Also, with current high price for this particular type of Bentong ginger, it is assumed that the price of the ginger can be lowered down if production costs reduced significantly. On the other hand, Agriculture 4.0 opens up opportunity to farmers to manage their massive farms more efficiently, without relying in massive labor force. Furthermore, this automated farming is planned to be extended beyond the harvesting process. Current ongoing research is focusing on automated processing plant of the ginger, which the ginger extract will be bottled and shipped out with zero human interaction as ordered received via online platforms.

REFERENCES

[1] Aitken C. J., Kozai T., Smith M. A. L. (1995): *Automation and environmental control in plant tissue culture*. Springer, Dordrecht.

[2] Chan A. (2017): '*Minister: Relying on food imports affects ringgit's value*', The Star Online. 14th February, viewed on 2 March 2020, <https://www.thestar.com.my/news/nation/2017/02/14/minister-relying-on-food-imports-affects-ringgits-value/>

[3] Husni M. (2017): Food Security in Malaysia, Faculty of Agriculture, 2nd May, Accessed on 10th June 2018 < http://www.agri.upm.edu.my/article/food_security_in_malaysia-30913 >

[4] Pandit M., Paudel K. P. and Hinson R. (2013): *Irrigation water sources and irrigation application methods used by U.S. plant nursery producers*, Southern Agricultural Economics Association (SAEA) Annual Meeting, Orlando, Florida, 3-5 February.

[5] Nikhil J. R. (1998): *Design of Water Distirbution System*. South Gujarat University, Surat.

[6] Sankar, K.S. & Selvaraj, Senthil Kumaran. (2015). *Optimization of piping expansion loop in process plant.* 10. 574-578.

[7] Despommier, D. (2011): *The vertical farm: controlled environment agriculture carried out in tall buildings would create greater food safety and security for large urban populations*, J. Verbr. Lebensm. 6, 233–236.

[8] Lee Z. Hall. (1965). *Cantilewer Rack.* US3913498A

[9] Baker H. C. & Leh Man E. G. (1920): *Boltless Rack Shelving*. US1411260A

[10] Robert E. & Charles R. (1981): Pallet Shuttle System, US4278381A