IoT in Agriculture: An overview

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***Abstract*— Food production has gone through a variety of revolutions, from growing vegetation and raising animals for consumption in hundreds of years ago to many methodological processes of crop rotations and the utilisation of artificial fertilizers in the last decades. The agriculture industry is presently undergoing another revolution impacted by the growing usage of information technology in the industry as part of the new era of digitisation.**

The world population is growing exponentially thus the demand for food production skyrockets in effect. Smart systems such as the Internet of Things (IoT) are introduced as a new way of managing agricultural businesses aiming for optimal production whilst keeping sustainability in the overall food chain value process. The agro owners can check the farm's vitality from any location, thus, will be able to make business decisions quickly and efficiently. However, despite IoT technology's positive potentials, it also has its drawbacks.

Keywords – Internet of Things, Smart Farming, Precision Agriculture

I. INTRODUCTION

The agro-industry has been considered a significant sector in the global economy as it sources the primary needs for human consumption such as food and wealth [1]. According to a report from McKinsey in 2015, crop and meat growing business generates a "$5 trillion global industry" and this emerging sector is expected to further increase in the next 5 decades. It has been estimated that the rate of meat intake will rise by 70% while fruit and vegetable demand will gain by around 100%. International investments for this industry alone have expanded to further $100 billion in the year 2013 alone [2]. In the recent years, the so called new technology - smart farms have emerged as a product of innovation in the agro industry with the goal to support global demands of productivity while effectively manage food security and value chain.

These smart farms uses internet of things infrastructure in the agriculture setting and provides farms a new way of collecting information while having the capability to automate processes. IOT offers promising benefits to farm business owners including real-time farm environment updates, automation, precision on monitoring of livestock, irrigation systems monitoring and better farm security. By utilizing this technology, it further improves the processes involved in crop and cattle growth, thus also reduces manual labor costs, and provides big data for performance optimization [3]. However, to compare with other industries, farm owners have been a little slow in integrating these innovations to their businesses due to the underlying issues involving setup cost and technical service fees in such as way where farmers perceive it as something that does not give an immediate value in the first few years of setup.

This paper aims to review literatures about how internet of things work, various existing IOT systems and applications in the farm sector and the software and hardware technologies utilized by organizations. This paper will also discuss the technology's underlying issues and future opportunities.

II. REVIEW OF LITERATURE

A. Analysis of IoT Technologies Utilised in Agriculture

In recent years, internet of things has changed the game of various industries including agriculture. In 2019, a study has published saying that the value of the smart farm market is at USD 1.84 billion and is expected to increase to approximately 7.22 billion in the year 2026 [4]. This means that in the next few years, the utilisation of smart devices in farms will dramatically increase, thus the demand for skills in data and internet of things will also rise.

In the field of farm technology, a variety of innovations has been made available and a few of which are affordable for farm owners to integrate to their farm systems. The IoT technology in a farm is segmented into a few common application categories. These include precision farming, precision livestock monitoring, smart technology in greenhouses, fish agriculture, and other food chain value process [5].

Precision Agronomics

The term called precision farming is an agriculture management approach in which it utilises information technology and hardware systems such as GPS, sensors,

agriculture robots, drones, and autonomous machines with the integration of low-cost setup materials and mobile accessibility to achieve an efficiency of farm yield. Below are some of the applications that are already in the market.

1. *Soil Monitoring System*

Soil is a critical element in keeping land farms producing high-quality vegetation. There have been innovations done in tracking soil health and one of which is the soil monitoring system. This application is composed of various sensors which track the soil characteristics such as temperature, soil moisture and acidity level. The data is captured through each of the sensors and sent into a micro-controller e.g. Arduino, then passed to communication (transmitting) devices before it goes to the internet server or cloud platform.

From the server, it will then provide a visual insight into the conditions of the soil elements to the end-users through a mobile application. Few examples of transmitting devices are ZigBee and RF Link. They are mostly used as an alternative to wi-fi or Bluetooth in a wide range area due it can send data with low power consumption on the soil monitoring system itself. In the farm field, where there is limited access to electricity and internet signal due to its rural location, the use of low power devices and renewable energy sources are the most beneficial solution [6].

This system is set up through the model illustrated below.

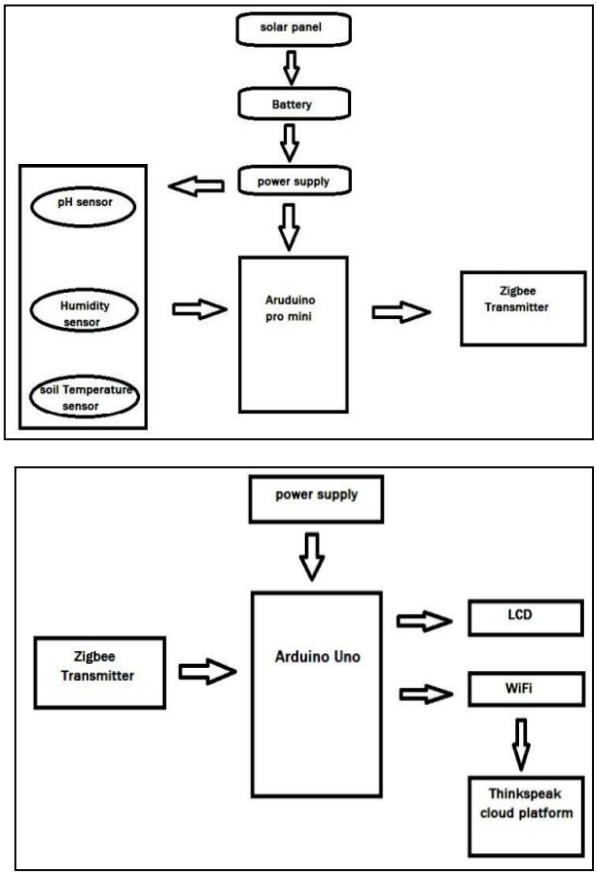

Figure 1: Soil monitoring system transmitter and Receiver
Source: Adapted from [6]

2. *Irrigation Management*

Irrigation is a crucial aspect of any agriculture environment. Many farm owners invest in innovations that involve in this field. In smart farms, there have been applications that have developed in recent years specific for irrigation management. One of these systems is an IoT-based automatic irrigation system. It monitors the soil moisture and drips water if the level is below the limit allocation and water source when soil is fully irrigated. It uses a soil moisture detector device (similar to above) and temperature sensors connected to the microcontroller (Arduino Uno) then to the water pump instrument.

The sensors are sending data to the micro-controller e.g. Arduino Uno then it will relay the data to the Wi-Fi module to be transmitted to the cloud server. Meanwhile, the micro-controller also manages the motor driver connected to the water pump when it is ready to drip the water to the soil [7].

The image below shows the flow of the system.

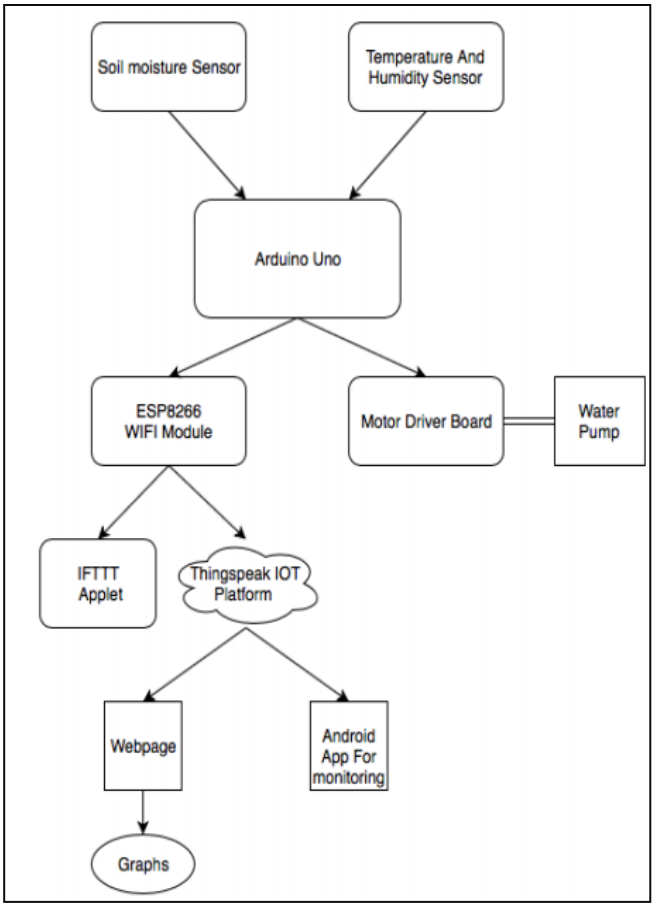

Figure 3: IoT Automated irrigation system
Source: Adapted from [7]

3. Weather Monitoring Application

Another essential aspect of the agriculture industry is weather monitoring. Recently, there have been technological developments done on this and one of which is called IoT-based weather monitoring system. This system can transmit data from the sensors that (checks) tests the weather conditions like air temperature, environmental humidity, the amount of carbon dioxide present and lightning presence. The data is captured through each of the sensors and directed into a server over the internet through communication devices such as Wi-Fi module.

This system is composed of sensors such as temperature sensor for a specific location; a sensor to check moisture output; light sensors to check the existence of light, and finally the CO2 quality sensor.

With regards to the communication machine, it has been preferred to use the ESP8266 Wi-Fi module device as opposed to other low powered communication devices such as ZigBee. This is (due to the fact) since that the entire architecture requires bigger amount and real-time data to transmit that will then provide a visual insight of the conditions to the end-users. Additionally, the ESP8266 Wi-Fi module utilizes low power consumption to as low as 3.3v.

With regards to the micro-controller, instead of using Arduino, LPC2148 is being used because it also using a super low voltage to be manipulated [8]. The illustration below is a graphical representation of the system architecture for the weather monitoring device.

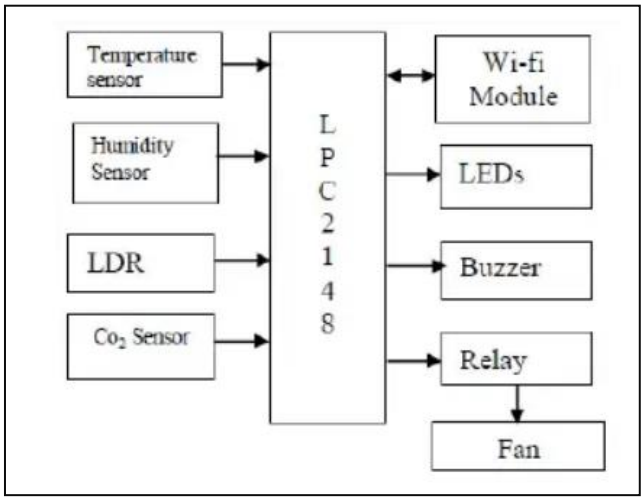

Figure 4: IOT Weather Monitoring System
Source: Adapted from [8]

4. Agricultural Drones

Unmanned aerial vehicle technology has become a popular innovation that transformed human lives differently. In agriculture, the industry has leaped to use flying drones to transform the way of doing things on the farm. As part of the precision agriculture, these high tech UAVs improved the efficiency of the process involving planting, crop health monitoring, plant height monitoring, livestock control, pest and spray management, mapping of irrigation systems and plantation mapping to name a few.

Drones are customised depending on what purpose it is being used. However, it is usually made with light materials so that it will be low weight and can go on high speed without consuming so much power. Additional components are added such as recording cameras, up-to-date navigational devices, light-weight sensors, vision equipment and other variety of controllers that can be programmed to automate flights, perform a specific robotic task and transmit information in real-time. These flying vehicles are controlled by a human that specialises in areal systems with the use of radio communication.

With regards to the agro AUV's architecture, it is usually composed of any type of drone with typically a few numbers of propellers which they call quadcopters, hex-copters and octocopters [9]. For example, a pesticide drone has additional equipment attached to the AUV such as spray system. It operates through petrol fuel as its purpose is to lift a few heavy materials such as the liquid spray and fly in a large range of area. These machines are controlled through a flight mainboard system where it is also embedding a few other parts such as the microcontroller (e.g. Arduino) and other motors (BLDC in the diagram). There is also a radio transmitter and receiver device present in the system to accept and transmit data from the copter to the pilot and vice versa.

Other parts that come together in the drone are multispectral imaging camera, laser scanners, video recording camera, barometer, humidity device, spray coverage sensors, movement sensors and anemometer to name a few [9].

The illustration below represents the graphical representation of the architecture.

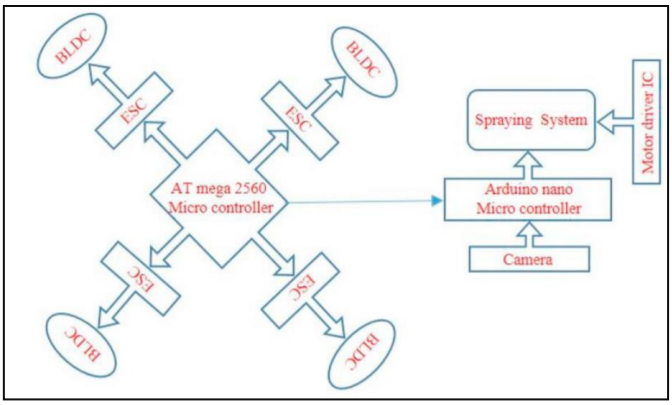

Figure 5: Architecture of Drone Spraying System
Source: Adapted from [9]

Crop monitoring AUVs also have a slightly different set of components compare to the spray drones but mostly sharing

similar features. It also uses multispectral capture system attached below the centre of the vehicle in which it can to take clear images up to 1 second per image [9].

Meanwhile, irrigation drones are created for another purpose but use similar components as the other AUVs mentioned above. It only has an additional component in the flying vehicle that holds the water for sprinkling and motor pump to release liquid through the nozzle [10].

One of the few commercial agricultural drones is a DJI Agras MG-1 octocopter below.

Figure 6: DJI Agras MG-1 octocopter
Source: Adapted from [10]

5. *Precision Livestock Farming*

Farm animals are also a massive market in the agricultural industry in which many innovators have invested time and effort to improve the efficiency of the process in managing the herd. The introduction of IoT technology in this sector has revolutionized the way of tracking the livestock.

The IoT technology uses livestock biometrics (tags) system to record movements of the animals on the farm [11]. Data collected is being transmitted to the cloud server for analysis as well as providing alerts if animals get out of range. The system is usually composed of components such as GPS tracking and radio frequency identification or BLE sensor attached to the animal's ear or neck. In terms of data communication, it utilizes a so-called technology low power wide area (LPWA) network in which acts as a central network station that transmits data with the livestock sensors.

An LPWA is a wireless device in which it uses low power connectivity to IoT machines in a wide geographical location. It has gained popularity in recent years because it solves the problem of inability of connectivity of Wi-Fi in many rural areas. Aside from LPWA's cost-benefit and can communicate with sensors at a wide distance, it also processes signals fast in a form of small data packets and uses low power as well as require lesser equipment for building its infrastructure [12]. Thus, this translates to higher cost savings to farm owners.

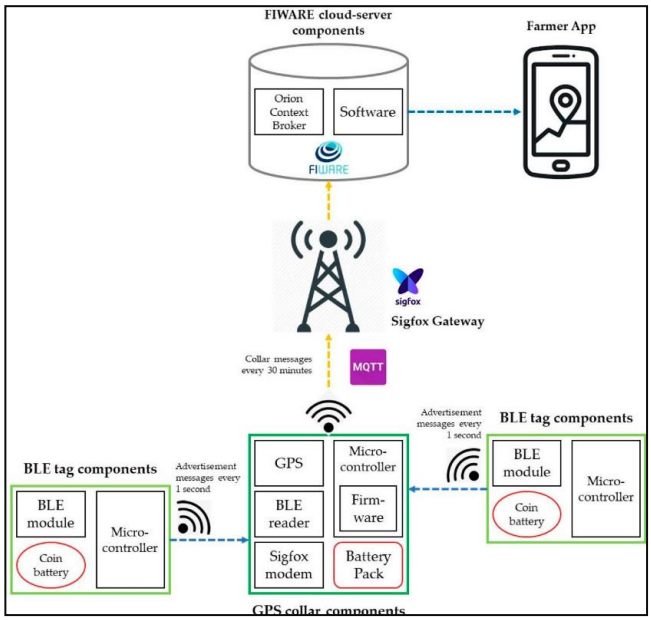

Figure 7: Livestock Monitoring System
Source: Adapted from [12]

Meanwhile, there is another improved animal monitoring system called Animal Health Monitoring System. It is composed of parts such as temperature sensor, micro-controller, server and the end-user. The sensor is attached to the body part of the animal to where it tracks the temperature regularly and sends signals to the micro-controller which then transmits to the cloud server through the Wi-Fi module. It generates insights about the health of the animal and will be sent to the end-user [13].

6. *Agricultural Robots*

Aside from static sensors that only gather data from any agricultural environments, there is also an increase of popularity of high tech robotic applications in the agro sector. These motorized machines are built to automate a time-consuming repetitive process in farming. With this technology, it provides farm owners more time to deal with other aspects of agriculture production improvements. A few in the list of the most used robots in farming include:

- *Vegetable and fruit harvesting*

An example of the robotic harvester is a cherry tomato picker in China. The device is composed of 4 peripherals which include the image processing sensor, robotic motors, the micro-controller and the transmission equipment. The camera or the vision sensor performs the recognition and inspection of the fruit thus checks if it is ready for harvest. The robotic motor is activated to pick the ripe fruits.

The controller is the brain of the system in which it identify

between unripe and ripe cherry tomatoes with the use of image recognition technologies. Meanwhile, the micro-controller manages all signals from the vision system and the motor, in which it collects and receives data to the transmission devices then to the server [13].

- *Autonomous Agri-bot Cultivator, Sower and Sprayer*

Another great innovation that has been done in the IoT for agriculture is the prototype robot that can plough soil, sow, plant seeds and spread insecticide autonomously. The parts of the system are composed of rotary electrical and servo motor for ploughing, sowing the seeds, and pesticide distribution; a Wi-Fi module and Arduino as the main controller [14].

The micro-controller manages the robot motors through L292D driver control which operates the machines for movement such as ploughing and sowing [14]. The system then gathers data from the sensor to be analysed and provide insights to the end-user. The illustration below represents the graphical representation of the workflow of the system.

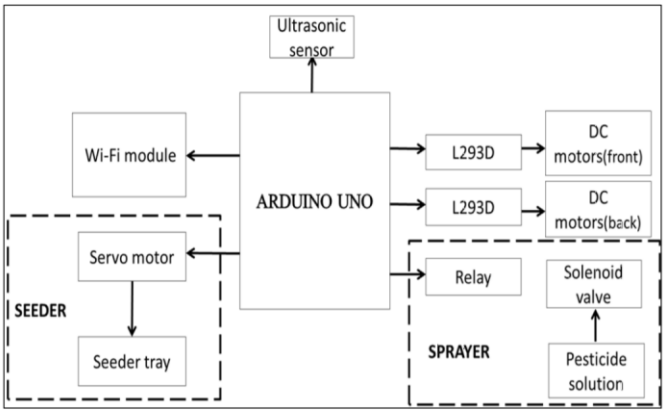

Figure 9: Animal Temperature monitoring IoT system
Source: Adapted from [14]

Robots can provide a positive impact on the farm production, however, it may not be feasible to most farms due to its underlying investment cost and available human resources who knows how to manipulate these new technologies.

Smart Greenhouse

A greenhouse is a structure in which plants are grown in a controlled environment such as temperature, humidity, exposure to sunlight to mention a few in such a way to suit optimized plant growth. Recent innovations have to change the way how greenhouses are managed particularly when the internet of things has penetrated this specific industry. It is so-called the Smart Greenhouse which uses sensors that are integrated into various applications whilst automating the processes involved.

According to a publication done in 2018, this industry will grow to 1.31 billion USD business worldwide. Many IOT-based greenhouse applications have been proposed and developed which includes temperature and humidity control through the wireless and control plant fungi infections; GSM - global system for mobile communication machine for remote monitoring of various sensor data from light, garden temperature and air humidity in a greenhouse; soil monitoring sensors that track–various minerals present in the soil; smart spraying systems for greenhouses and many more.

A typical IoT-based greenhouse is composed of a variety of sensors, a motor control device, a tracking system and a microcontroller. With regards to its connectivity, previous years have used ZigBee however they have failed due to its limitation of the bandwidth data transfer. New proposed communication devices include GSM and Wi-Fi as mentioned above for its computing power. With regards to new features, the data is sent to a cloud server in real-time in which is processed to communicate other sensors to make decisions autonomously. In addition to this, the system also utilizes a mobile app messaging platform to transmit data directly to the end-user through a mobile phone [15].

Internet of Things in Aquaculture

While land farming has always been the highlight of many technological innovations and researches, this paper would like to include some other aspects of agriculture that is emerging in terms of adopting the high-technology capability and that is the aquaculture. Aquaculture is the process of growing and breeding of water animals suitable to be consumed [17]. Thus, the processes involved in cultivating these products is similar to livestock but in an aquatic manner. Different species of fish have different methods of growing before they can be transported to the processing plant for packing. There have been challenges of going through the entire lifecycle of growing fish products particularly those involved in water preparation and monitoring the quality of water regularly.

Aqua farmers usually observe the elements found in the water including air volumes such as oxygen and CO2, water temperature, salt levels, and other minerals in the water such as ammonia and PH levels. In the past years, the monitoring of these processes are done manually, however, with the emerging innovations of IoT, smart equipment is being introduced which made monitoring automated and end-users can see real-time updates from their mobile phones. Thus, the farm owners can make quick and better decisions with regards to the insights they found from the IoT application.

There are a few proposed research and recent projects being done to optimize aquaculture processes and one example is the IOT-based water health monitoring system. This smart aquaculture system is composed of sensors component, micro-controller, power source component, Wi-Fi module and the mobile app module [16]. The sensor component is where the

different types of sensing capability that will be used for the water health monitoring such as dissolved oxygen, carbonates, salt levels, and acidity levels to name a few.

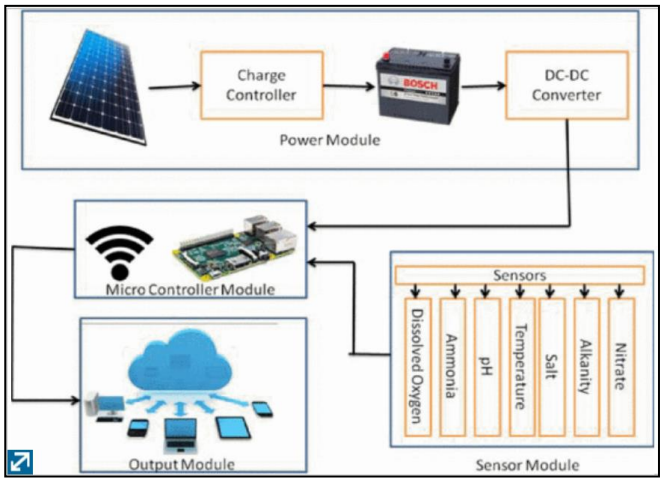

Figure 10: Water Health Monitoring IoT system
Source: Adapted from [16]

The sensors are then connected to the micro-controller (Raspberry Pi) that sends and receive signals to the Wi-Fi module then to the mobile app. The power source section is where the electricity is generated and stored but through the solar panel and the charging station controller. The figure below shows the illustrative representation of the workflow.

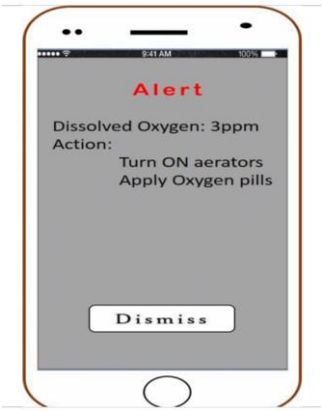

Figure 11: Mobile alert for Water Health Monitoring system
Source: Adapted from [16]

This system has many benefits brought to the farmers as it tracks water characteristics in details and in real-time, thus, reducing time spent for manual labour for farm owners and will be able to make plans ahead prior any issue becomes big on the aquafarm may face. It also saves cost on energy usage as IoT-devices are low powered, thus the farm owner can focus its other investments on scaling the aquafarming business. In addition to that, farms have the data that are stored in analytics systems which can be used if they wanted to do some research and development on their farms. Although not all innovations have positive aspects and the only disadvantage of this approach is it will have a high start-up cost, however other than that, there is no maintenance cost on the equipment [16].

IoT and Food Source Chain Monitoring

Latest food supply approaches are transforming into a more complex process. After the agro products have been harvested, it will be now ready for the other processes before it will be hand over for consumption. Going through that entire journey, many agricultural organizations are heavily faced with risks concerning food safety. These risk can be involving crops or horticulture end products exposure to the unsuitable environmental situation, food theft, storage and delivery mishandling. The food chain can be local, national or global which uses routes by land, air or sea which can develop potential risk points to maintain product quality [19].

The IoT-based technology has many solutions to provide in such a way that will help optimize the processes involved in the food supply chain particularly tracking the items as it goes along in the chain. One great example of a smart food chain approach is by incorporating tags with Radio Frequency ID capability to food items. These tags are working together with other sensors during the food supply chain process, thus providing more insightful information about the end-users. The information flows from RFID to sensors then to micro-controllers and then to the cloud servers, thus forming a big data architecture.

Internet of Things has been a game-changer in the food chain processes as it has developed various applications that help automate the process of transporting and keeping of agricultural goods from the source which is the farmer to the middleman which is the wholesale and retail reseller to the end of the chain which is the consumer.

Different innovations have been done including harvesting facilities monitoring, after-harvest IOT systems, warehouse tracking and management, shipping containers monitoring, delivery drones, and autonomous vehicles such as trucks and big boats. With these, farm owners, suppliers, wholesales, and logistics service owner, etc. crucial have access to accurate and real-time information, thus making better decisions for the business [18].

B. Internet of Things Benefits, Challenges and Success stories in the Agricultural Sector

IoT technology has significantly transformed the agricultural industry and will continue to do so in the next coming years. As mentioned in the paragraphs above, it is clear that the smart and connected farm is more efficient because it can connect globally through a mobile app; requires less human labour in the farm; provides real-time and efficient data access to farm owners, and can automate processes. Thus,

it can save time and money to businesses. However, despite the promising idea of its innovation, in reality, there have been challenges that the farm industry has been facing.

1. Setup & Maintenance Cost

In the farmer's point of view, integrating an IoT system in a farm could be overwhelming in a way the idea of this technology involves many technical aspects for a farm business owner to understand. Additionally, the expenses involved in the entire process of integrating to the new technology would also be intimidating.

According to a report in 2018 from an Agtech research company called Alpha Brown, they have estimated around 10% to 15% of farm business owners in the United States are utilizing internet of things solutions on a 3.1 billion acre with 250,000 farms that collectively spending around USD 960 million. Despite the challenge of the farmer's perception about the underlying cost of the IoT integration setup, the research has found out that it is the awareness of the value of the IoT technology to growers that are on the top of the issue. Despite many agribusinesses are aware of how the technology works, their view of the return of investment is quite not clear versus the cost involve to set up and maintain the IoT system [20].

On the other hand, some organisations have thrived in seeing the real value of this new technology. For example in Australia, Data61 has developed a Vertebrate Pest Detect-and-Deter (VPDaD) technology which uses motion sensors and high tech thermal cameras to deter pests. The company does data and engineering research and the problem that they were intending to solve an Australian pest problem on crops causing AU $1 billion loss a year in 2017. The firm has been successful with the research and is now progressing to test on other types of crop pests [21].

Meanwhile, some government bodies are supporting the digitization of farm businesses by providing funding investments to farm owners such as Australia's Victoria On-Farm Internet of Things (IoT) Trial program. It aims to help growers invest in technology that will impact their farm business. They offer about AUD $20,000 – AU $30,000 investment grant to eligible farmers [22].

2. Communication Infrastructure

Many farms are based in rural areas where the access to internet signal has been a huge issue. Having an IoT system implemented in a farm would require reliable connectivity to work efficiently otherwise, the new technology will be no use. In 2019, several Australian farmers have signed up to test IoT solutions however, this has resulted in issues concerning the connectivity.

According to Meat and Livestock Australia's (MLA's), the farmers faced a significant struggle of IOT despite the buzz around low power and consistent connection devices. This means that moving forward, to get the expected promise from IoT, farmer-owners will be forced to invest for a signal infrastructure to get a reliable connection. On the other hand, a few Australian agricultural companies who had the fund to invest in the internet infrastructure, have gained positive impact overall [22].

3. Data Security Concerns

Sensors and other IoT devices collect data from agricultural systems and will turn into an enormous amount going forward. The exposure to risks in data security will also arise. Common types of security issues on IoT devices are segmented into categories:

- **Sensing** segment is where the attacks happen in the sensors where hackers can inject an infected node that will be able to perform fraudulent activities. In such a way, hackers can also put codes that expose critical data or may put false data in the nodes that can cause harm to the system.
- **Network** segment is where the attack is happening on the network such as during the transmission of data from a sensor to microprocessors or Wi-Fi modules. A few security threats can be part of this layer such phishing in which the attacker uses proxies to be able to penetrate access without getting noticed.
- **Middleware** segment is where the threat is exposed between the network and application layer. This can be a database server or cloud server. Some attacks can be in a form of server virus-like malware in which if it can in the system, it can send or request data as well as input faulty information.
- **Gateway** segment is where the vulnerability lies on the translation of protocol between sensors and other communication modules of an IoT system. A threat can be on the encryption in which not all gateways support end to end.
- **Application** segment refers to the end-user apps that have vulnerabilities. These include commercial smart devices at home or offices, smart components found in connected cities as well as smart fences. Data theft is one of the most common attacks for this layer [23].

The cyber risks mentioned above will vary on the type of the IoT system has been integrated into the farm. An example is where in 2015, an attacker has changed the setting of the temperature sensors in a chicken farm which cause USD 1.7 million worth of loss to the business [24]. Although some of the data security issues are being addressed, the risks would always be an open concern.

Meanwhile, on real scenario point of view, a report in February 2020 has said that, although farms would want to try integrating IOT in their farm, however, the issue is that many

farm owners are not comfortable of the idea that third party companies are handling their big data considering it passes through their own private devices [25].

III. Discussion/Conclusion

Processes in the agricultural production sector have a wide range of distinct segments such as soil and weather condition observation, water and waste management, livestock monitoring, theft prevention, farm asset management, food storage and delivery optimization, and many others. As a result of technological advancement connected devices such as IoT were developed for agricultural purposes which include sensors, autonomous vehicles, robots and automated decision systems that can provide farmers management advice at the tip of their mobile device.

Putting these together, the technical advancement encompasses changes that disrupt the standard farming procedures. Such dramatic shifts will bring so many opportunities however as a result it also initiates new challenges.

One of the few shifts will be the rise of the demand of technology specialists including ICT professionals specializing in smart devices, system & network administration, cloud computing, big data and the most crucial one – cybersecurity.

This will also put pressure on farm owners to learn about technology. Meanwhile, robots will automate farm processes that may cut off manual physical labour jobs such as fruit pickers, machinery operators, baggers etc. There can also be an issue regarding technology companies to monopolize tech services in which leaving farm business owners have no choice but to make them dependent on these organisations [26 – 27].

With regards to the current issue of farm owners slowly adopting the new technology, private and government organizations must work together to build awareness to let farmers educate about the real value of IoT technology and the general idea about the risks of cybersecurity. This is to let agriculture business owners understand more about the long term return of investment is not just on profitability but also for the sustainability of the industry.

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