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An IoT Platform for Urban Farming

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***Abstract*—Technologies such as Internet of Things (IoT) and big data have been widely adopted to improve quality of life. In this paper, an IoT platform is proposed to automate urban farming process by embodiment of IoT, big data and cloud computing. The IoT platform is designed so that users especially farmers can monitor the growing environment and the nutrient can be adjusted automatically without human intervention. The platform utilises pH, total dissolved solids (TDS), oxidation reduction potential (ORP) and temperature data to regulate the optimum concentration of the nutrient solutions. The growth rate of the plant is monitored continuously using camera. The proposed system uses a WiFi-based network and Message Queuing Telemetry Transport (MQTT) protocol to send sensor data from IoT device to server hosted in the cloud. Web and mobile based user application is included in the platform to allow users to monitor the urban farm anytime, anywhere.**

Keywords—Internet of Things (IoT), precision agriculture, urban farming, wireless sensor network, cloud computing

I. INTRODUCTION

Globally, food deprivation is becoming an issue primary driven by an increase in world population. Climate changes and scarcity of arable land makes it more challenging to achieve the food production to meet the demand of world's population. According to United Nation (UN), the current world population of 7.6 billion is anticipated to reach 9.8billion populations by year 2050 [1]. In order to achieve sustainable development goals (SDG) of zero hunger, traditional farming need to be transformed into knowledge-based agriculture using modern technologies.

Precision agriculture is an application of information technology that allow farm management to observe and manage crops efficiently. This innovative approach is proven to be beneficial to farmers because of the positive impacts e.g. water conservation, productivity boost through shorter cultivation period and lower carbon footprint, as compared to a traditional farm management. Although standalone precision agricultures has shown promising results, the adoption rate is very low due to high cost in the system. Automating sensor data collection in traditional farm land requires stable network connection to these sensors as data need to be sent to a database for further processing. This situation is worsened by the fact that traditional farm land are prone to climate change, causing challenges in deploying long lasting sensors in open field.

Urban farming using hydroponic technique has gained popularity in recent years. This is due to the growing needs of a constantly evolving urban life [2]. Hydroponic system allow urban farmers to utilize nutrients-rich solution to nourish the plant. Since hydroponic system is soil-less, urban farmers can save space and it is less prone to soil-borne diseases. Nevertheless, in order for urban farming to be successful, proper maintenance of nutrient solution concentration is needed to optimise the yield. Imbalance nutrient will affect the growth of the crops in hydroponic system.

As such, integration of IoT in urban farming can minimize human intervention in tending the crops. A system that automatically regulate the nutrients, temperature, humidity and carbon dioxide can increase the productivity as compared to regular method [3]. The organization of this paper is as follows. Section II presents related works on precision agriculture in agriculture. Section III describes the design of the proposed system. Section IV discuss the experimental results. Conclusion and future work are presented in Section V.

II. RELATED WORKS

In recent years, many researchers have applied precision agriculture in hydroponic farming to increase the yield. Kularbphettong [3] integrated IoT in hydroponics system by measuring temperature and humidity, light, pH and water level information. The system regulated these parameters by pre-defined specific thresholds. Similarly,

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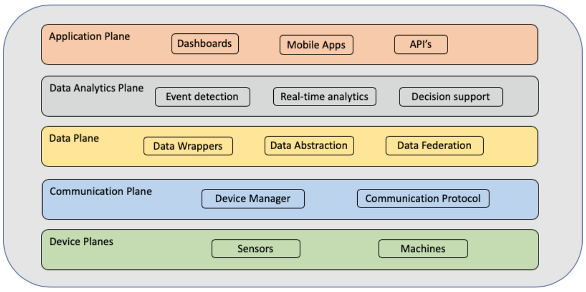


Fig. 1. Overview of IoT Platform

Helmy et. al. [4] implemented a web-based monitoring applications of hydroponic farming to evaluate the correlation between pH, TDS and temperature. However, the system does not contain notification support to the users whenever the sensor parameters are below or above pre-defined threshold. Changmai et. al. [5] utilised pH, EC and air temperature to evaluate the quality of the produces. The system was tested in lettuce farm. One of the drawback of the system is the system has been pre-defined with parameters for lettuce farming. Users are not allowed to control the system, thus unable to use the system for different crops. Van et. al. [6] developed an IoT-based intelligent hydroponic plant factory solution. PlantTalk allows users to configure the connections of various plant sensors and actuators through arbitrary smartphone. Al-though these systems are capable to automate the environment changes, it still lacking the capability to remotely observe the plant growth, such as recording plant growth periodically using a camera. Vasisht et. al. [7] proposed a low-cost IoT platform that support television white space (TVWS). FarmBeats is used in for large scale land farming and incorporated drone technologies for farm monitoring and mapping. Although FarmBeats provide comprehensive end-to-end platform, it is not suitable for urban farming.

III. SYSTEM DESIGN

There are several criteria that need to be considered when designing IoT platform for urban farming:

- Availability: The IoT platform should be able to collect data and automate the system even when there is down-time.
- Compatibility: The platform can support wide variety of devices such as sensors and indoor robots.
- Scalability: It is expected to grow tremendously since urban farms utilize less space.

To achieve the above criteria, an IoT platform is proposed as shown in Fig. 1. There are five (5) layers in the IoT platform namely device plane, communication plane, data plane, data analytics plane, and application plane. The platform is supported by both hardware and software.

A. Hardware

The IoT platform is tested on Nutrient Film Technique (NFT)-based hydroponic system, that allow nutrient-rich solution to be consistently flowing and circulates in the hydroponic system. In order to monitor the concentration of the nutrient solution, sensor nodes comprising pH sensor, Total Dissolve Solids (TDS) sensor, ORP sensor and temperature sensor are installed at the hydroponic rack as shown in Fig. 2.

Off-the-shelf sensors are used to measure specific parameters of the nutrient solution and the data captured are sent to cloud server over WiFi connection. TDS sensor is added to the sensor node to determine the amount of minerals that dissolved in the solution. Too much nutrients may cause the plant to experience nutrient burn whereas too little nutrient may stunt the growth. As such, a suitable TDS value is needed to ensure sufficient nutrient for the plant. pH that measures acidity or alkalinity indicates the suitability of the nutrient for the root to absorb nutrient. If the roots are exposed to nutrient that is too acidic or too alkaline e.g. pH between 2 to 3, the root will be damaged. Since different crops have different nutrient and pH requirements, the IoT platform allows user to set the threshold value depending on the crops that they grow. Table I shows recommended values of pH and TDS value for different crops [8].

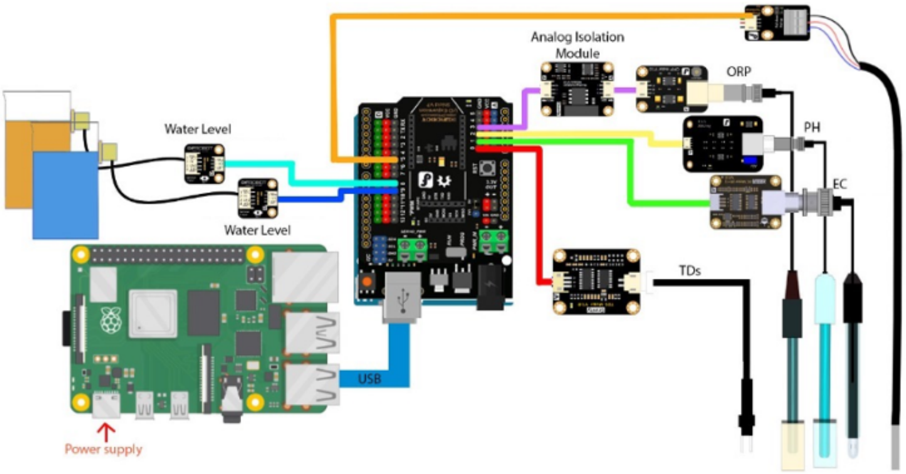


Fig. 2. Sensor Node

TABLE I. RECOMMENDED VALUES OF PH AND TDS FOR DIFFERENT CROPS [8]

Crops	pH	TDS (ppm)
Lettuce	6.5 - 7.0	560-840
Bok Choy	7.0	1050-1400
Tomato	5.5 – 6.5	1400-3500
Broccoli	6.0 – 6.5	1960-2450

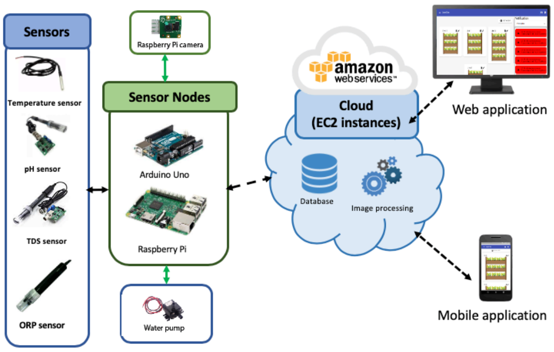


Fig. 3. Software design

Besides pH and TDS, temperature of the nutrient solution is monitored as well. The benefit of monitoring the temperature is two-folded. Firstly, temperature plays and important role to ensure ideal setting for healthy roots and optimal nutrient absorption. Nxawe et. al. [9] showed that controlled temperature setting can increase the yield of the crops. Roots that are submerged in nutrient with temperature between 20-25°C can increase the chlorophyll level. As such the nutrient solution and water solvent must be kept at proper temperature to keep plants thriving. Secondly, the results of TDS and pH are directly influenced by temperature. The sensor nodes measure and automatically compensates variations in temperature using mathematical models [10].

ORP is a measurement of oxidisation power in the solution. It measures fungal and bacteria content in nutrient rich solution for crop growth in hydroponics. Unlike soil-based farming that naturally contain bacteria, it is important to keep the nutrient solution of hydroponic farms free from fungal or bacteria [11]. This is because the presence of fungus and bacteria may alters the nutrient status of the solution.

These sensors are connected to Raspberry Pi 4 and Arduino UNO, which are used as microcontroller to collect and pre-process the data before sending to the cloud server via WiFi. Based on the sensor data, Raspberry Pi 4 will perform decision support by automating the discharging of water, hydroponic fertilizer A and fertilizer B and hydrogen peroxide that control the ORP level. The water pump are setup externally to pump nutrient solution into the system based on the data obtained from the sensor nodes. The IoT sensor nodes also supports cameras for remote farm monitoring. To accommodate multiple camera views, Arducam is used to connect multiple cameras into one Raspberry Pi 4.

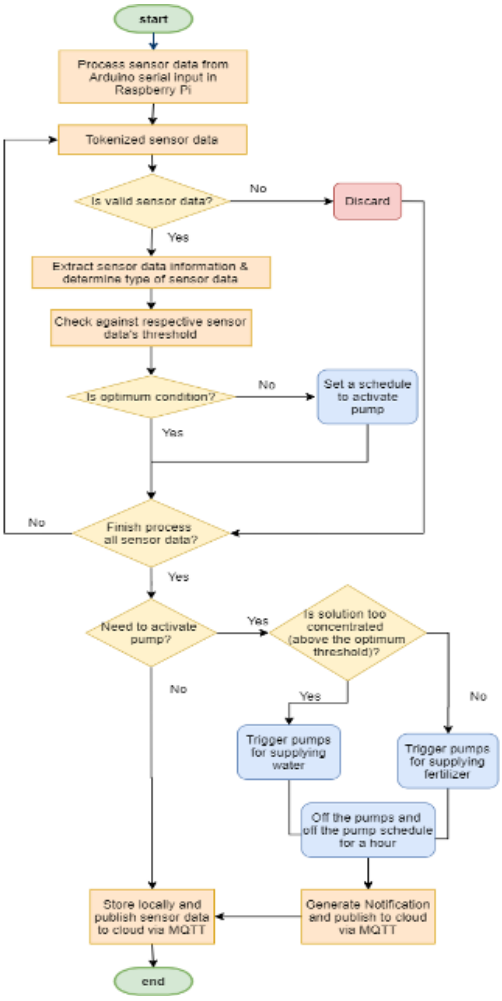


Fig. 4. Flow diagram to automate the fertigation

B. *Software*

The IoT platform uses Message Queuing Telemetry Transport (MQTT) protocol as communication protocol to send data from sensor nodes to the server since it is designed to be used in constrained environment. Moreover, it is optimized for unreliable and low-bandwidth networks. The sensor nodes publish sensor data on a topic and clients subscribe to the topic of interest from specific sensor nodes. In this IoT platform, the subscribe topic at IoT sensor node is defined by using MQTT wildcard. This is to provide a larger and scalable scope for the IoT MQTT broker to manage multiple sensor nodes labelled with different serial number.

MongoDB, a NoSQL database, is setup at the cloud server to store the sensor data and images captured as shown in Fig. 3. No SQL database provides flexibility for further expansion since it is not necessary to predefine the database schema. NodeJS application is running to handle incoming API request from the web and mobile application. Both MQTT and MongoDB are secured with authentication configuration to prevent unauthorized access from malicious users. Besides, firewalls are setup at the cloud server to prevent Denial-of-Service (DoS) attack. Only selected ports are opened for application usage, the rest are closed by default. The web application is hosted using HTTPS protocol that secure all the web traffics.

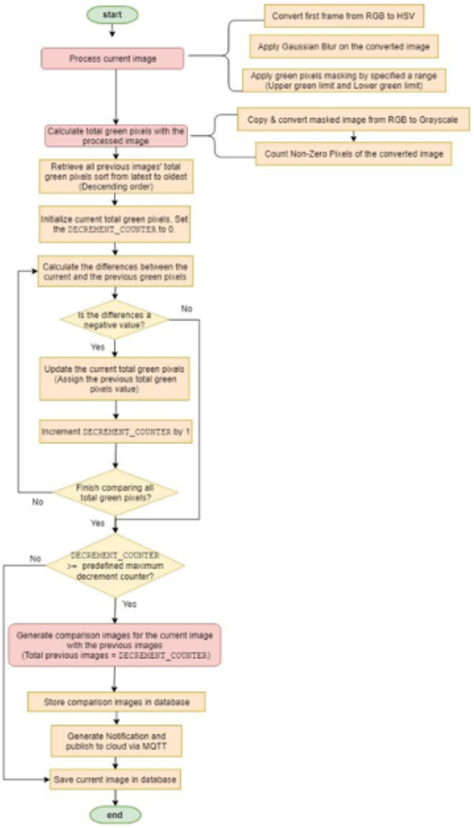


Fig. 5. Flow diagram for image processing algorithm

In Raspberry Pi 4, sensors data are collected and processed locally to automate the fertigation process. In addition, image frames are captured and sent to the server using socket.io library. Socket.io supports bidirectional, real-time and event-based communication between the client and server [12]. Another major benefit of socket.io is auto-reconnection and disconnection detection support. Image streaming is an essential feature implemented to monitor the growth of the crops remotely. The Raspberry Pi utilized socket.io client library whereas Node.js server application is deployed at cloud server by implementing a listening socket to handle incoming socket.io client request.

The image frames are processed using python and OpenCV. The cloud server utilizes green pixels of the processed image as reference to determine the growth rate. Firstly, the image is converted from RGB to HSV. This provides a better contrast between the background and the foreground. Next, Gaussian Blur is applied, and the green pixels is masked by specifying a range of lower green colour and upper green colour. Currently, the current lower limit and upper limits applied for the H (Hue), S (Saturation) and V (Value) is (30, 0, 0) and (90, 100, 100) respectively. Based on the processed image, total green pixel is calculated. Current pixel is compared with previous pixel to analyse the growth rate. This is done by querying the total green pixel of the previous image from MongoDB as shown in Fig. 5.

Data virtualization and analytic are performed in the cloud server. Events such as abnormal nutrient is analysed and users are notified. The cloud server also allows users to manage sensor nodes and set the threshold for individual sensors. Web and mobile application are built for users to view the sensor data in the dashboard, either current or historical data. Users can also view the camera feeds that are captured periodically in three (3) hours interval to observe the growth rate.

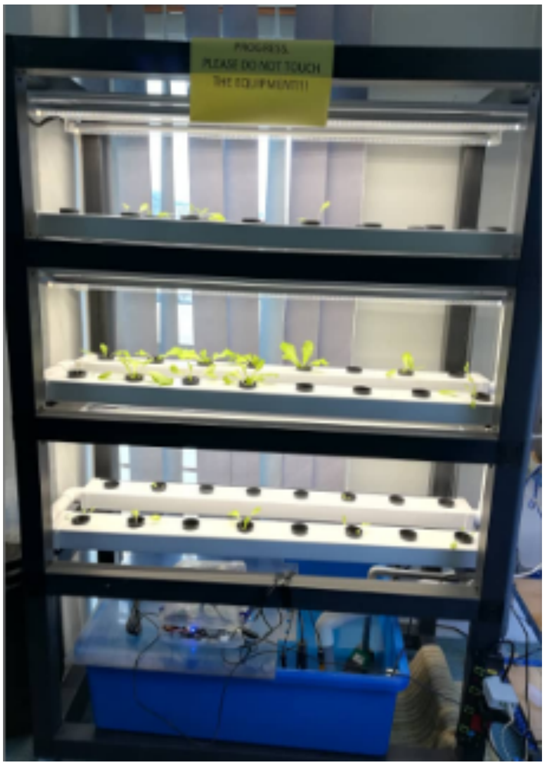


Fig. 6. Testbed in hydroponic farm

IV. FUNCTIONAL TESTING

The platform is evaluated on a 130 cm (L) x 65 cm (W) x 175 cm (H) hydroponic farm as shown in Fig. 6. System functional testing is performed to make sure that it can function as expected. The test results are shown in Table II.

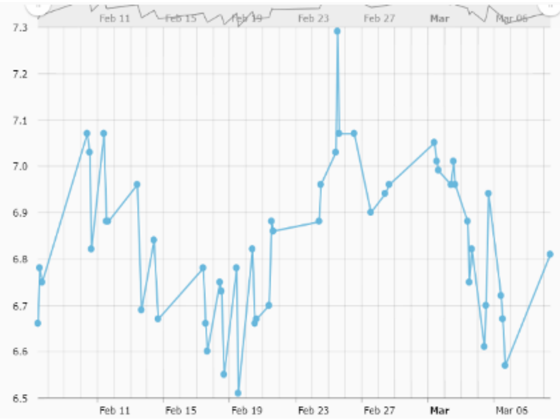
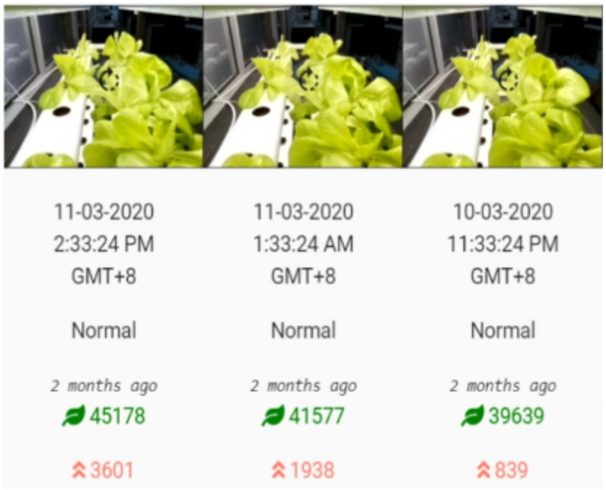


Fig. 7. pH throughout the plant growth

TABLE II. FUNCTIONAL TEST

Functional Test	**Results**
Users can manage devices (sensor and camera)	Passed
Obtain data from sensor nodes	Passed
Regulate nutrient based on sensor data	Passed
Send notification to users if abnormal value is detected	Passed
Process image to detect growth rate	Passed



11-03-2020 2:33:24 PM GMT+8	11-03-2020 1:33:24 AM GMT+8	10-03-2020 11:33:24 PM GMT+8
Normal	Normal	Normal
2 months ago	2 months ago	2 months ago
45178	41577	39639
3601	1938	839

Fig. 8. Processed image to monitoring plant growth

The result for monitoring the plant growth is recorded. Nutrient supplied has been regulated according to the sensor data. Fig. 7 shows pH value that has been regulated to the optimum range of lettuce, which is 6.5 – 7.0. Starting from seedling until full plant growth, images are captured. Fig. 8 shows screenshot of the plant images that have been captured. Fig. 9 shows graph of the growth rate from the images over time.

V. CONCLUSION AND FUTURE WORK

Data-driven IoT platform can help urban farmers to monitor and automate the nutrient solutions. Formers is able to set the threshold and regulate the nutrient based on the crops that they would like to grow. As future work, the IoT platform will be expanded to create prediction model for quality of crops, growth and yield. In addition, image processing algorithm will be enhanced to process images for non-green crops such as red spinach.

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Fig. 9. Growth rate

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