Evapotranspiration (ET)-Based Irrigation System with Internet of Things (IoT) Integration for *Capsicum Annuum* Farming: A Methodology

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***Abstract*—This paper presents a methodology to develop an irrigation system that determines the amount of water to be provided based on water loss due to evapotranspiration (ET) process. The computed amount of water was based on the data gathered from an automatic weather station (AWS) sensor suites installed in the plantation plot. *Capsicum Annuum* or commonly known as Chili is the crop of interest in the conducted study due to its popularity amongst Malaysians. The system comprises microcontroller with the integration of sensors, actuator and valve modules where each node serves as an IoT device. The environmental parameters are being monitored directly over the AWS console and remotely over mobile application that helps in the controls of each node and configuration settings for irrigation. The computed amount of water for irrigation is based on CIMIS Modified Penman model for the computation of the daily reference ET, ETo. Compared to the conventional irrigation method, it is anticipated that the proposed irrigation model would help in reducing water usage without compromising its produce.**

Keywords— Evapotranspiration, IoT, Irrigation

I. INTRODUCTION

Despite the abundance of rainfall received in Malaysia, maintaining constant water supply for growing agricultural crops remains a challenge. While the annual average rainfall in Malaysia is more than 2500 mm, maintaining constant water supply can be difficult during the dry months [1] or during the higher rainfall peak [2]. Water scarcity also occurs occasionally, due to uncertainties in climate and water demand [3]. In almost anywhere in the world, agricultural sector is the largest user of fresh water. Water required for crop growth is supplied by rainfall and/or irrigation. Since rainfall is characterized by high spatial and temporal variability, agricultural producers need to use irrigation to supplement rainfall during the dry periods. Efficient water usage in agricultural sector has gained major interest due to increasing competition for water between sectors of society. By saving the use of agricultural water, the available water can be utilized for other purposes.

Alternative methods are required to know the timing and amount of irrigation water applied to supplement rain water. Since rainfall may vary depending on the seasonal factors, irrigation plays a vital part in ensuring that the crops are adequately watered at all times. Water content in soil or soil moisture is important factor for crop growth [4]. In particular, the timing and amount of irrigation water that need to be disbursed to the crops are of particular significance. Too much water will make the soil to be waterlogged, possibly leading to rotten crop roots and diseases. On the other hand, insufficient or untimely water supply will harm the growth of the crops. Thus, the moisture of the soil need to be well maintained, especially during the seed germination stage.

While the agriculture sector contributes to about 68% of total water consumption in Malaysia, their irrigation efficiency is at best at only 50% [3]. The World Bank has called for better optimization and planning of water usage efficiency, since if left as it is, the scarcity of water will reduce the GDP of countries up to 6% (-1% for Malaysia) by 2050 [5].

With the growing interest in the field of Information and Communications Technology (ICT), particularly in the area of Internet of Things (IoT) and sensor technology, a lot of studies are being done in the area of smart farming. The IoT concept and technology is integrated into an improved irrigation within the smart farming sector in order to increase the water saving aspect. Through precise irrigation, a water-saving agriculture cropping system allow farmers to conserve water without sacrificing its productivity. The integration of IoT also allows remote monitoring to be carried out anytime and anywhere. The convenient access will lead to the need of better security to avoid unnecessary intrusion.

This paper explores the methodology surrounds the implementation of an ET-based irrigation system with IoT integration that focuses on the *Capsicum Annuum* or better known as chili crop. Section II discusses related work in the area while Section III explains overall methodology involved in the project. This section involves three main phases; ET-based irrigation requirements, system requirements, and data gathering and reporting. Next, Section IV elaborates on the integration of IoT in the system and finally the paper is concluded in Section V.

II. RELATED WORK IN EVAPOTRANSPIRATION (ET)-BASED IRRIGATION FOR SMART FARMING APPLICATION

Engineers and experts have been focusing on developing ways for irrigation to be more efficient in terms of water usage and energy usage because traditional methods of irrigation use too much water and this is detrimental in countries where water is in short supply. Evapotranspiration (ET) refers to the amount of water movement from the ground to the atmosphere through both evaporation and plant transpiration processes. ET can become a good indicator of plant's water requirement as it represents the water losses of the fields due to weather conditions [6]. ET is one of the many ways that an irrigation system can be based on to make irrigation more water efficient. It is found that ET-based irrigation system can save up to 42% water over time-based water irrigation system. Smart irrigation that is based on ET is currently on the rise because saving every bit of water available becomes more crucial amidst extremely hot weather where rain is scarce. This section reviews previously reported research work on ET-based smart irrigation system.

Prabha et al. [6] implemented a smart irrigation and fertilization system that takes advantage of IoT and ET based variables to ensure that costs can be reduced and yields increased in light of an increase of suicide cases among farmers due to debt issues in India. The authors designed a user-friendly mobile application that can send crucial information to the farmers in their regional language. Their system managed to save 36% water when compared to a channels irrigation system that was already employed by a farmer. Al-Ghobari and Mohammad [7] implemented an ET based controller and compared it against a normal irrigation control system and it was found that the water saved was significant especially in drought ridden areas of Saudi Arabia. Munir et al. [8] employed an ET based smart irrigation system that is fully automated and is capable of decision making thanks to fuzzy logic.

Grabaw et al. [9] did an evaluation and a comparison between ET-based and soil-moisture-based irrigation controller for turfgrass and found that ET controller used more water than the soil moisture controller. Moreover, the turf quality of ET was found to be more superior than the soil moisture. On the other hand, Caya et al. [10] managed to saved 53.45% water in cultivating Chinese cabbage with respect to traditional irrigation system. Shahzadi et al. [11] employed IoT with ET based sensor to instead implement an Expert System (ES) where farmers can get input from experts so that crops can be continuously monitored to minimize losses due to sudden diseases and pest attacks. Villarrubia et al. [12] demonstrated a multi-agent-based system called PANGEA that can monitor various weather variables using sensors and fuzzy logic was used to decide the best needs of the crops.

Caya et al. [13] in another work based on Tomato crop used Raspberry Pi to implement their ET based automated irrigation system and managed to achieve 76.86% reduction in water consumption when compared to traditional irrigation methods in the Philippines. Rivas-Sánchez et al. [14] used Arduino and various sensors to build an ET based irrigation system for their green wall and the data collected from their system can be viewed anywhere where there is Internet connection. Abd Rahman et al. [15] implemented 3 different approaches for an automatic fertigation controller, one of which is ET based and found that ET based controller used more water than the timer based but this is due to dry atmosphere and windy condition which increases the rate of ET.

The works discussed above showcased that in certain conditions, ET based irrigation systems can save water and in other conditions can actually use more water than traditional irrigation, but this is due to poor implementation or unsuitable environments. It can also be seen that the main reason why ET based systems tend to save more water is because of the plethora of sensors used in deciding when and how much water a crop needs for proper growth and to ensure water usage efficiency. Some implementations also used IoT to collect data so that experts and farmers can work together to take suitable actions to minimize losses in farming.

It was also found that the two most preferred irrigation approaches are drip irrigation and sprinkler irrigation. Such techniques are significantly better than other approaches used conventionally. Summary of the related works as in Table I indicates that most smart irrigation systems based on just conventional sensors are not effective in saving water. For example, existing approaches considered using soil moisture sensor to measure a plant's water needs [20–23]. This is not enough to ensure maximum water saving. Other parameters need to be considered as well, such as the plant size, watering time, air humidity, light intensity, and soil quality. The current methods rely on sensor data and use simplistic methods to assess a plant's watering quantity and schedule without considering the plant type because different plant types need specific water and weather conditions [16-23]. Similarly, the amount of soil moisture for various plants varies in different weather conditions and different areas.

Apart from that, the conventional smart irrigation system has exceedingly high energy consumption due to the continuous use of sensors [16, 22]. An energy-saving smart irrigation system should be built with the ability to make smart decisions such as being able to micromanage sensors so that it is only turned ON periodically as required, being able to determine exactly the needs of each type of plants, and being user friendly so that farmers in the countryside is able to operate it comfortably, among other things. With innovative usage of IoT and sensors, a smart irrigation system would also be cost effective and is able to simplify farming as well as achieve a level of precision that makes it easier for farmers to identify problems and minimize losses.

To sum up, an ET-based smart farming is better than the traditional smart farming because it allows better yield of crops and efficient usage of water with only a small investment needed. Maintenance of the additional sensors are also fairly simple and cost efficient, taking into account the end users. Ideally, a smart irrigation system should address many problems that current farmers encounter so that water consumption can be reduced at the expense of

TABLE I. SUMMARY OF RELATED WORK ON ET-BASED SMART IRRIGATION SYSTEM

Ref	Crop, Platform and Sensors used
[6]	Chili (*Capsicum annuum*); Mobile phone; Temperature, atmospheric pressure, humidity, wind speed, solar radiation
[7]	Wheat (*Yecora Rojo)* and tomato (*Lycopersicon esculentum*); Hunter ET-system on Pro-C controller; Air wind speed, rainfall, solar radiation, air temperature, relative humidity
[8]	Green chili (*Capsicum annuum*); Mobile phone; Soil moisture, temperature and humidity, light
[9]	Turfgrass (*Cynodon dactylon*); Toro Intellisense ET Controller; Rain, soil-water sensor, weather station (WS)
[10]	Chinese cabbage (*Brassica Rapa*); Raspberry Pi; DHT22 temperature and humidity, rain gauge, pinwheel
[11]	Cotton (*Gossypium arboretum*); Expert System (ES); Temperature, humidity, leaf wetness and soil
[12]	Tomato (*Solanum lycopersicum*); PANGEA; Humidity, soil moisture, temperature, light, water and oxygen
[13]	Tomato (*Lycopersicon esculentum*); Raspberry Pi; Rain gauge, temperature, ultrasonic, water pump
[14]	Various; Arduino UNO & Raspberry Pi; Soil moisture, air temperature and moisture, light, rain, water flow
[15]	Chili pepper (*capsicum annum*); WS, wind, temperature, soil moisture
[16]	Bittergourd (*Momordica charantia*), Chili (*capsicum annum);* ONSET RG2-M model; automatic Rain Gauge and WS, Air temperature and humidity sensor
[17]	Various; WS, Temperature and calibrated FDR sensor
[18]	Sweet pepper (*capsicum annum);* meteorological station; Capacitive sensor, a linear quantum sensor
[19]	Chili pepper (*capsicum annum); WS,* Capacitance and TDR CS616 sensors
[20]	Various; A Mobile Application (APP); soil moisture , humidity, Ultraviolet (UV) Light Radiation
[21]	Various; Artificial Irrigation Controller and NI LabVIEW; soil moisture, humidity and temperature sensors
[22]	Various; hPC running LabVIEW; Soil moisture and, temperature sensors
[23]	Cucumber (*Cucumis sativus*); Humidity and temperature sensor

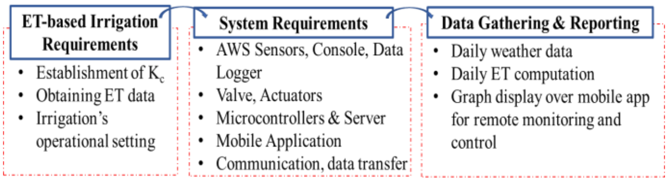


Fig. 1. Flowchat of Overall Methodology

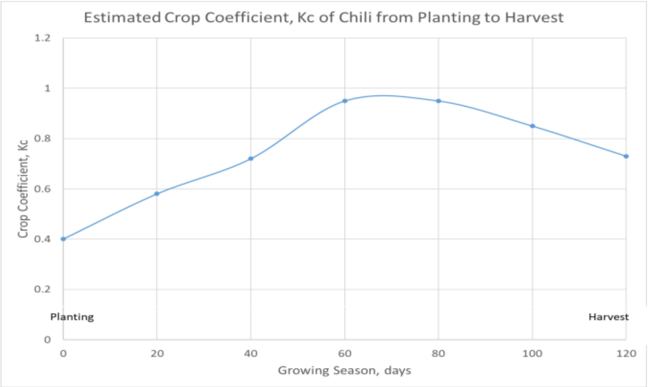


Fig. 2. Estimated Crop Coefficient, K_c of *Capsicum Annum* from Planting to Harvest

considerable energy usage, and the farmers' livelihoods are enhanced due to increased yield and better troubleshooting capability.

III. OVERALL METHODOLOGY

The flowchart of overall methodology for this project is described in the Fig. 1 which can be classified into three subsections; ET-based irrigation requirements, system requirements, and data gathering and reporting.

A. *ET-based Irrigation Requirements*

Equation (1) shows the measurement of actual ET, ET_a where ET_o is the reference ET and K_c is the crop coefficient. Here, a grass reference is used for the calculation of ET_o, meanwhile K_c coefficient depends on aspects such as the plant type, plant's growth stage, and may also include local contexts such as soil type [24]. The ET_o value can be obtained from various mathematical models where the end choice is affected by exact variables used in the input data and complexity level.

$$ET_a = ET_o * K_c \tag{1}$$

In this project, the available hourly ET_o in mm unit obtained automatically from the AWS instrument based on the CIMIS Modified Penman's equation is utilised, as depicted in (2) [24]:

$$ET_o = W * NR + (1 - W)\,VPD * F \tag{2}$$

where
W = Weighting function (based on contribution of radiation components)
F = Wind function
NR = Net radiation
VPD = Vapour deficit function

Meanwhile, since K_c is not supplied automatically by the AWS instrument, we adopt the K_c values reported by J. M. Muniandy et al. [16] due to similarity in the crop type and closely located sites. The estimated daily K_c based on this work is shown in Fig. (2), which is based on the reported K_c values of 0.58, 0.95 and 0.73 for the initial, mid and end growth stages, respectively [16].

The next step of calculating the length of irrigation time is determined based on the context of using drip irrigation method that goes directly into the polybags. The amount of water that will be applied in the soil, in terms of volume, shall be computed as:

$$V = 1 * A * d \tag{3}$$

where
V = volume of water to be applied, m^3
A = area to be irrigated, m^2
d = ET_a = net depth of water to be applied, mm

The factor 1 or 100% means that the whole polybag's area will be wetted and irrigated. The irrigation time, T shall then be determined by:

$$T = \frac{1000}{60} * (V/Q)/E \tag{4}$$

where T = irrigation time, minutes

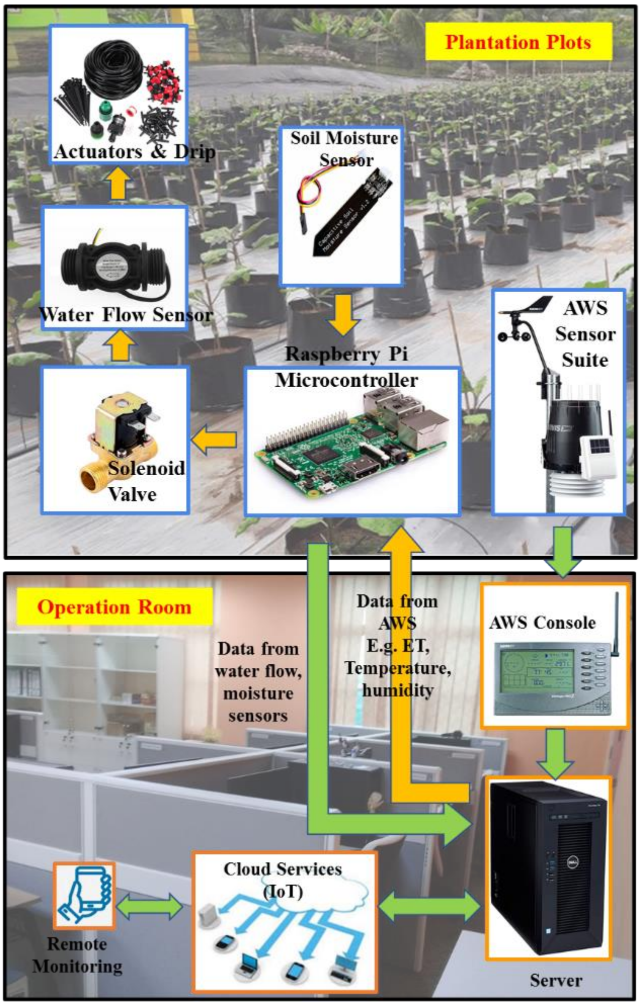
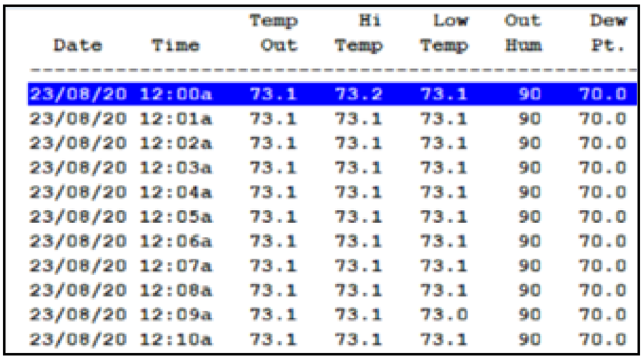


Fig. 3. System Block Diagram



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                   Temp     Hi     Low    Out    Dew
 Date      Time     Out    Temp   Temp    Hum    Pt.
------------------------------------------------------
23/08/20  12:00a   73.1   73.2   73.1     90   70.0
23/08/20  12:01a   73.1   73.1   73.1     90   70.0
23/08/20  12:02a   73.1   73.1   73.1     90   70.0
23/08/20  12:03a   73.1   73.1   73.1     90   70.0
23/08/20  12:04a   73.1   73.1   73.1     90   70.0
23/08/20  12:05a   73.1   73.1   73.1     90   70.0
23/08/20  12:06a   73.1   73.1   73.1     90   70.0
23/08/20  12:07a   73.1   73.1   73.1     90   70.0
23/08/20  12:08a   73.1   73.1   73.1     90   70.0
23/08/20  12:09a   73.1   73.1   73.0     90   70.0
23/08/20  12:10a   73.1   73.1   73.1     90   70.0
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Fig. 4. An Excerpt from AWS Output Data

V = as defined earlier in (3)
Q = pump discharge, liters/min
E = pump efficiency

The factors 1000 and 60 are used to convert the volume of water from m^3 to liters and the irrigation time from hours to minutes, respectively. In this work, the pump efficiency is at 90% and Q is in the range between 0.25 to 17 liters/min.

B. *System Requirements*

This project aims to develop an irrigation system that applies the appropriate amount of water at the appropriate time using ET_a information in a particular field. Fig. (3) illustrates the system block diagram of the proposed project. The automation of the system is the Raspberry Pi microcontroller with serves as the brain of the system. A solar-powered AWS is to be installed right in the experimental field. The daily data from the AWS shall be downloaded to a data logger attached to the console so that the daily ET_a could be computed through the Raspberry Pi microcontroller. The sensor data will then be used in the computation of water loss in the farm due to ET process. The computed water loss will then be the basis for control of the actuators through drip irrigation of the crops. Daily irrigation time will be based on Eq. (4) where T is to be further divided by f, the number of dripping occurrences within one day.

The pump should be triggered to operate based on the computed irrigation time. For example, if the computed irrigation time is 20 minutes, the system should be able to switch the pump on for 20 minutes, after which the system will also switch the pump off, and this is done every time that water is to be applied. Apart from receiving the sensor data from AWS sensor suites, the controller also accepts data from the soil moisture sensor module. Here, the installation of soil moisture is considered optional as it is carried out not to compute the required water to be irrigated but to check the validity of the applied irrigation water.

C. *Data Gathering and Reporting*

While sensor graphs from the AWS sensor suite can be directly viewed from the console, its daily raw data is also sent to the server through a data logger. In the case where different ETo models are to be used than the one supplied by the AWS, one can make necessary ET_a calculation based on the provided AWS input data e.g. temperature and humidity. Fig. (4) shows an excerpt from output of the AWS software where data can be segregated based on the required period.

The data is also to be sent to the IoT server cloud services to be made available via graphical displays in mobile application. This will also allow remote control and monitoring when instructions are allowed to be executed through the App. This decision-making part will require the function of data analytics which is an important part of IoT. The following section provides more in-depth explanation that describes the framework involved in the integration of IoT for ET-based irrigation system.

IV. INTEGRATION OF IOT SYSTEM

Fig. 5 shows a generic IoT framework for Smart Irrigation Application. The framework involves in integrating the ET-based irrigation system with IoT has been adopted from a generic framework proposed by Prabha et al [6]. This section will explain each layer based on our implementation. The system automates the water application (or the irrigation scheduling which is the determination of the "right amount" of water to be applied at the "right time"). In this section, we explain on the integration of our system which consists of AWS sensor suite, AWS console, lab server, Firebase server, Davis server, Raspberry Pi, water flow sensor, water valve, irrigation system and smart phone. Davis [24] is the provider of AWS sensor suite and AWS console, where it also has dashboard to refer the collected data, while Firebase is a cloud service by Google™.

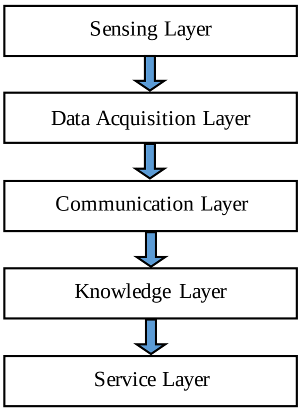

Fig. 5. Generic IoT Framework for Smart Irrigation Application

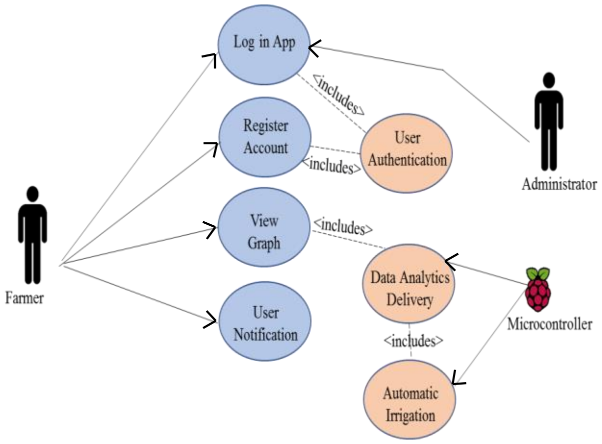

Fig. 6. Overall interaction between different functions in the mobile application

A. Sensing Layer

The sensing layer consists of AWS sensor suite and moisture sensor which feed the data into the AWS system. The data from the AWS sensor suite are radiation components, wind functions and vapour deficit function as can be found at Eq.(2). The data from all sensors is transferred to the AWS console inside our laboratory. The AWS console is attached with data logger which then send the data to the lab server. The system dashboard installed in our lab server will push the data to Davis server automatically. The data will be ready to be retrieved by data acquisition layer.

B. Data Acquisition Layer

The data acquisition layer consists of Raspberry Pi microcontroller. This layer is handling voltage power conversion, data conversion function and data filtering. Voltage power has to be converted since the devices use different voltages of 3.3V, 5V and 12V. The data conversion is needed since the data has to be changed from analog to digital and vice versa. The data filtering has to be set in terms of time for acquisition and the values to be retrieved. Raspberry Pi is retrieving the data from Davis server and push the calculated and necessary data to Firebase server. Firebase server is providing the data for smartphone/ mobile application usage.

C. Communication Layer

The communication layer handles the communication among devices which includes wired and wireless types of communication medium. The AWS system has both types of communication medium to transfer the data. The AWS sensor suite is located at the plantation plot while the AWS Console is inside our laboratory which is separated around five meters. Both devices communicate using a federal communications commission (FCC)-certified, license-free, spreadspectrum frequency-hopping (FHSS) transmitter and receiver at frequency around 900 MHz and power less than 8 mW. User-selected transmitter codes enables up to eight stations to coexist in the same geographical area where in our case we use only one code. Meanwhile, the Raspberry Pi is also connected to the server via Wi Fi. The server is using Ethernet to be connected to the cloud. While our smartphones can be connected to the cloud through either GSM or Wi Fi.

D. Knowledge Layer

The server located at our laboratory stores all the data from the sensors before being transmitted into cloud services. There are two types of cloud servers used in the system, i.e. Davis server and Firebase server. Davis server is storing all the data acquired from the AWS sensor suite as long as there is internet connection. While Firebase server is storing the important values extracted from Davis server as explained in previous sub-section. The knowledge layer stores all the required threshold values to send alert to the farmers/users when the value is out of limit. The cloud also stored the data such that users can retrieved the data anytime and anywhere with the availability of internet connection.

E. Service Layer

The service layer communicates with the end users. Our mobile application gives users the freedom of monitoring the plantation plot anywhere anytime through smartphones. The users of the mobile application have to register the application once the application is installed in their smartphone. Thus, only authenticated users can access the system. The mobile application services includes user registrations, irrigation schedule which includes the fertilization and data analysis by day, month or year. Fig. (6) shows the interactions between different functions in the mobile application that includes user authentication.

The farmer as users may turn ON or OFF the system where appropriate. However, the pre-programmed Raspberry Pi will turn ON/OFF the water valve automatically according to the threshold data set on the server. The water valve controlled the watering time to the irrigation according to the signal received from the Raspberry Pi. Besides notification in the mobile application, Farmer is also receiving the user notification through the registered email. Farmer may check all the activity through their mobile application.

Meanwhile, the data analysis consists of total water usage, temperature, soil moisture, and EC value. The data is also being secured with AES encryption. The security is spread vertically from communication layer through service layer. The Raspberry Pi, server, cloud and smartphones are devices that can adapt with the chosen security technique. The system is secured in terms of integrity, confidentiality and availability of data being transferred and data being stored.

V. CONCLUSIONS AND FUTURE WORK

In many parts of the world, the agriculture has been one of the major sources of income especially in the rural areas. Hence, improving the performance of the agricultural sector is essential for economic growth and food security. With respect to this matter, a careful understanding of water should be considered as plants need water for its survival. ET-based computation of water loss as the basis of plant irrigation is a potential alternative to the traditional method as its model that includes various weather factors leads to a more accurate estimation of water loss. Thus, it could help in reducing water usage without compromising its produce.With the help of IoT, the condition of the plantation irrigation can be easily monitored anywhere and anytime through smartphones. Farmer may check the total water usage, fertilization usage and soil condition. Whenever the data is below or over limit, the system can send the alert to the farmers. Besides that, monitoring of the plantation workers can also be added where appropriate. While the IoT gives the simplicity of monitoring at the fingertips, it also creates chaos if the data is stolen or modified. Thus, our system is embedded with security using AES encryption. In future, the system may be upgraded with information for various types of crops. Therefore, the mobile application can be easily matched the plantation crops. The plantation plot may be exchanged with other types of crops for better medium substance sustainability.

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