An Application-Driven IoT Based Rooftop Farming Model for Urban Agriculture

Arjun Paramarthalingam, Amirthasaravanan Arivunambi, Sreedhar Thapasimony

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Arjun Paramarthalingam *1[0000-0003-3998-0221], Amirthasaravanan Arivunambi 2[0000-0001-7923-4202], Sreedhar Thapasimony 3

[1, 2] Assistant Professor, CSE, [3] Associate Professor, EEE
[1, 2] University College of Engineering Villupuram, Tamilnadu, India
[3] Rohini College of Engineering and Technology, Tamilnadu, India
* arjun_ucev@ymail.com; aasaravanan777@gmail.com; sree822@gmail.com

Abstract. Presently, the urban world are switching to rooftop farming with technology support to cope with the increasing food demand and effective utilization of various resources. But the monitoring of farming in high raised building (rooftop) is little challenging. This paper presents an IoT based smart rooftop irrigation system to efficiently manage water dispersal and provides improved urban based rooftop farming productivity. The proposed model regularly monitors soil temperature and moisture level, i.e., rooftop farming are irrigated automatically without physical presence of planter and it also uses smart mobiles for irrigation control. The proposed automatic irrigation farming modal uses sensor technology, communication technology and embedded hardware technology. That is, the atmospheric weather data such as moisture level and water level are collected periodically from different part of rooftop farm area and it is analyzed, which will trigger the switching of water motor/overhead tank pump and send status updates to the planter.

Keywords: Rooftop Farming, Urban Agriculture, IoT in Agriculture, IoT, Smart Agriculture.

1 Introduction

According to the Commission on Sustainable Agriculture and Climate Change, the world's food demand and its production is progressively observed more as global population grows [1-5]. There is a very strong connection between the growth of living standards, income and wealth in a nation and the demand for food that represents this higher standard of living. This shift in preferences is associated with an increased demand for technology aided land intensive food production sources. The current situation in agriculture is privation of farming land scarcity, and traditional agricultural methods have drawbacks in essential management issues like water resources planning and monitoring, ineffective usage of man power, electrical power etc [6, 7].

One among the strength of developing countries like India is stable agriculture productivity. It is also a backbone of most of the countries. The feed requirements of the nation are satisfied up to certain level by own agriculture fields. But, the present situation is hasty urbanization of the country i.e. making all agriculture land surface to buildings and reprehensible management of water resources force to import agriculture products from other countries like China, Sri Lanka, Australia, and other Asian & European countries due to urbanization in India and lack of proper productivity management [1, 3, 5]. Due to urbanization the total agriculture land loss is rapid in India. Most of the agriculture lands are now made to concrete high raised buildings and due to which there exist scarcity of land area for irrigation. The statistical graph discussed in counterview portal for agriculture land loss in India is illustrated in Fig. 1. This graph shows the effect of urbanization and in turn confirms the pitfall of agriculture land.

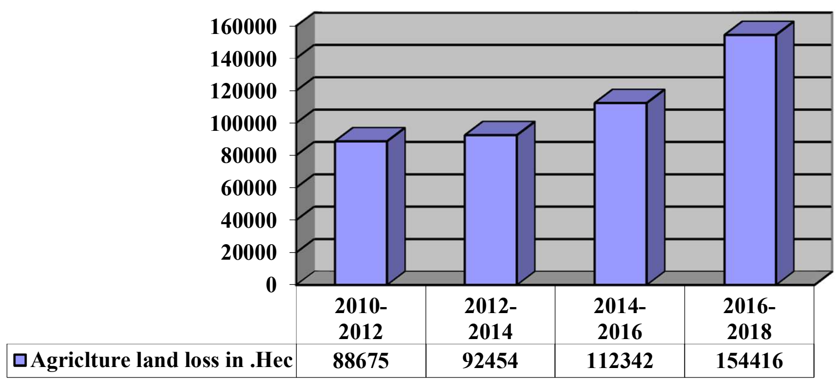


Fig. 1. Statistical graph for agriculture land loss in India (between 2010 -2018).

Another fundamental concern in traditional agriculture is water resource deployment for farm area and its related maintenance are done manually with less technological aids. As depicted earlier the urbanization also escort to ineffectual usage of water resources which also intern impact on sustainable agriculture. An effectual agriculture system demands a good irrigation surface and effective water resource stream [2, 4, 6-11]. The table. 1 shows the extent of water resources used in India as per survey for the year 2019-2020. But the effective use of these resource is possible increased by technological aid like IoT, Data analytics, Cloud computing, Machine learning etc [1, 7, 12-15].

Table 1. Major water sources for irrigation in India.

Water Source for Irrigation	% share of holdings
Tube wells	39.22%
Canals	25.17%
Wells	19.01%
Other sources	8.34%
Tanks	5.18%
Rain water	3.08%

The IoT procedure are habitually called as “smart” devices because they have sensors and intricate data scrutiny programs. IoT devices accumulate data via sensors and provide services to the users based on scrutinizes of the data and rendering to user-defined parameters [9, 10, 16]. Refined IoT devices can “learn” by diagnosing patterns in user inclinations and historical user data. An IoT device can become “smarter” as its program regulate to get better its prediction potential so as to augment user practice. The basic foundation of IoT is integration of sensors, actuators, RFID tags, and other communication objects that are connected via Internet to satisfy common goals [11, 13, 17-20]. Internet of Things (IoT) is a link of sensors and connectivity to empower application similar to agriculture ideal irrigation. The preeminent components of IoT are wireless sensor network (WSN). WSN is capable to be the solutions for a huge assortment of applications. The application instances are agriculture monitoring, health monitoring, air quality monitoring, weather observing and soil slide monitoring. WSN is syndicates several technologies such as control technology, sensor technology, networking technology, information storage and processing technology [12-14, 21].

The social and economic impact of proposed rooftop based smart agriculture is illustrated in dependency cycle shown in Figure 2. In addition with food production, implementation of rooftop farming will also provide many non-functional benefits viz. reduces the urban hotness island effect (global warming), reducing greenhouse gases emissions and reducing air pollution, systematic rainwater run-off, freshening and aesthetic surrounding farming area, air quality improvement, biodiversity etc.

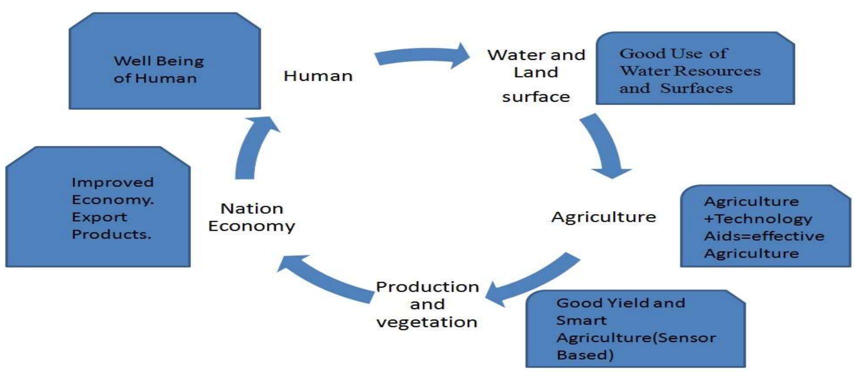


Fig. 2. The dependency cycle of effective rooftop farming system.

The proposed model is very useful to the growth of the nation economy in terms of agriculture production from building rooftops which are generally kept unexploited previously. According to the idea proposed in this paper, the general public can perform vegetation from their building’s rooftop or providing it to others in rental basis to earn money.

2 Comparative Analysis

In recent research many researchers have emerge with latest technology aid for efferent agriculture. The major design goals of an IoT system are energy efficiency of nodes, low latency, high throughput, scalability, different topology support, security, safety and privacy of nodes [12, 19, 22]. The data in Table 2 depicts a survey on such study highlights various authors contribution along with key components used in their work, but these research have several pitfalls.

Table 2. Comparative analysis of existing works on smart/ precision agriculture.

S. No	Author(s)	Year	Hardware Components Used	Outcomes
1	Vaishali et al. [1]	2017	Soil Moisture Sensor, Raspberry-Pi, Blue Term, Motor	Soil moisture level is not intimated to user. It only sends alert SMS to user.
2	Sushanth G & Sujatha S [2]	2018	Arduino, Moisture Sensor, Humidity sensor, Temperature sensor, Motion sensor, Relay, GSM module, Motor	User can't able to know whether the water is flown to every corner of the land or not.
3	Pushkar Singh & Saikia [3]	2016	Arduino, Temperature sensor, Soil Moisture Sensor, ESP8266 Wifi module, Motor	Website communication is needed to intimating information to user.
4	Shweta B et al. [4]	2017	Zigbee, GPRS/3g/4g modules, Wi-Max, Wi-Fi, Bluetooth, soil moisture & temperature sensor.	Increases the cost, scalability has to be improved.
5	Nageswara Rao & Sridhar B [5]	2018	Raspberry pi 3 – model,LM 358, Temperature sensor, Soil Moisture Sensor, Relay, Buzzer, Motor	It is high in cost and maintenance cost of components is high.
6	Kiranmai Pernapati [7]	2018	ESP8266, Moisture Sensor, Humidity sensor, Ultrasonic sensor, Relay, Motor	Sensor information and Water level are not intimated to user.
7	Kizito Masaba et al. [10]	2016	ESP8266, Moisture sensor, Temperature sensor, Bluetooth, Motor	It works on Bluetooth technology so it covers only limited region
8	Hamami Loubna & Nassereddine Bouchaib [22]	2018	Zigbee ,EC-5 Soil Moisture Sensor and DS18B20 temperature sensor	Prototype of a smart irrigation system using WSN and ZigBee is developed but accuracy is minimum

9	Le D.N. et al. [20]	2019	Intelligent Data Processing sensors, IoT based SMS, Cloud services	It assesses business model canvas for IoT based startups.
10	Ledesma G. et al [21]	2020	City Maps, Buildings information, IoT Farming Technology	Sustainability Assessment of rooftop farming with respect to technical, economic, environmental, legal and urban factors

Apart from the study performed in Table 2, the present revolutionary irrigation is rooftop farming. But the existing rooftop irrigation system is a manual system which is purely human based, and it requires more labor for its operation. The drawbacks in existing approach are it requires more time, money, labor and it leads to erroneous water management [6, 17]. These drawbacks are overcome by automating the irrigation system using currently available technological advancements.

This proposed work inculcates IoT ideas in smart farming to monitor & automate the tasks involved in the rooftop irrigation system in land and water scarcity vicinity like urban condition. The environmental conditions related to the selected rooftop agricultural area are regularly sensed using different sensors/actuators. The collected data are feed to a cloud server with a decision making system, which directs various components present in the system to work as per the predefined instructions given by the farmer/user.

3 Proposed Work Methodology & Design Model

In the proposed IoT based smart rooftop farming, the farming area is created with the help of sensors/actuators, IoT infrastructure and data analytics capability. The sensors used in for the model includes humidity (DTH11), soil moisture (REES52) sensors. In the system, moisture sensors is submerged into the soil with different locations, which would alert the system about quantity of water content in the soil. Sensors acquire the environmental conditions of the selected area on rooftop and send the collected data to cloud server. If the moisture level is not as much of the amount of water desirable by the plant, the system automate or mechanize the flow of water from an overhead tank unless a threshold value is reached. This make certain that plant has been supplied optimum quantity of water without any physical labor or consumption. The IoT infrastructure provides the environment for the whole system to work, which includes sensors/actuators for data acquisition, wireless technologies like wireless sensor Networks, Wi-Fi/Mobile network etc for data communication, cloud server for storing and processing of sensed data. The input data are processed according to set of predefined rules and the water level threshold given in Table. 3 to handle the working of smart rooftop irrigation system.

In order to make a precise model of the proposed system, the components used in this work are, sensors/actuators (humidity and soil moisture), Raspberry Pi kit, server, smart phone, electrical motor, automatic starter, etc. This proposed work simplifies the risks in irrigation farming system, further it promotes effective water management in rooftop farming area. The detailed architecture diagram is shown in the figure 3.

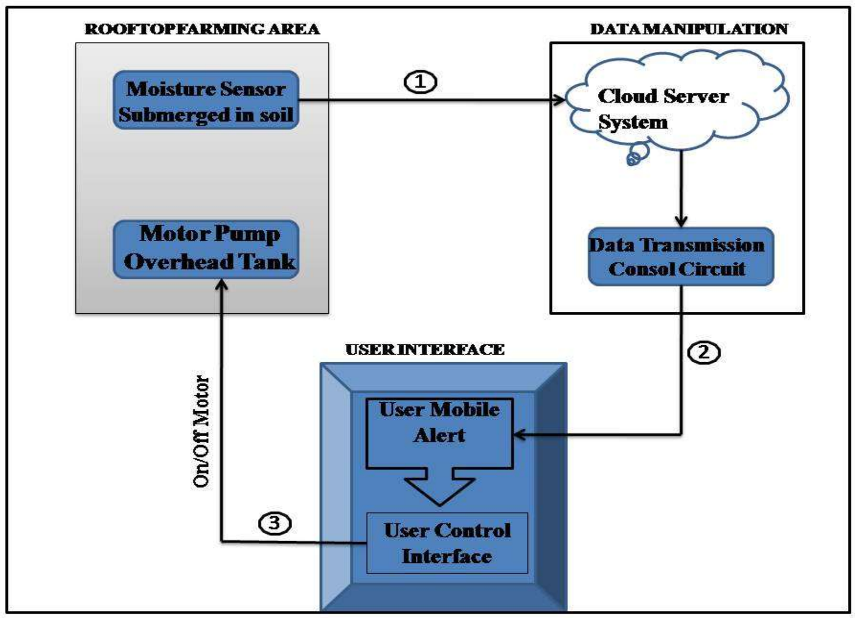


Fig. 3. Schematic diagram of proposed rooftop farming model.

The architecture diagram shown in Fig. 3 explain the working of proposed approach, the entire system is split into three modules viz. rooftop farming area (Sensors/actuators, Overhead tank), Data manipulation (Cloud Server for data handling and processing), User console (Smart phone for regular monitoring and alerts). The soil moisture sensor will sense the moisture range in the soil at regular time interval. The readings from the sensor are regularly monitored and processed to the server. In general, the moisture content in the soil is formulated by the weight of the soil with adequate wetness content in the soil to that of low wetness in the soil.

Calculate the moisture content on a wet-weight basis using the following equation 1,

$$\text{Moisture content } (\%) = \frac{W2 - W3}{W2 - W1} * 100 \quad (1)$$

Where,

W1 = initial weight of soil;

W2 = weight of soil and vegetation before drying; and

W3 = weight of soil and vegetation after drying

The readings from the sensor are handled by the server. The server system makes pronouncement on data and process the data to the user mobile system as an alert. The decision making process is done based on regular monitoring the data from the sensor to the server system which is connected through Wi-Fi modules [15-17, 22]. For the proposed model, the decision making on soil wetness is valuated as given in Table 3.

Table 3. Decision making on soil wetness by the server system.

Wetness Level	Decision	User Insinuation
0 to 15 %	Dry	Need Watering
16 to 60 %	Wet	Water Content is Ok
61 and above	Excess	Stop Watering

Based on the decision an alert message is send to the user mobile. The Android based automation interface will guide the user to automate the water resource by simply turning ON and OFF the motor/tank on a single touch for the farming. Raspberry Pi and ESP8266 Wi-Fi microchip which are circuited to the overhead tank will automate the water resources to the farming and the sensor in the soil will have close reading of the moisture levels.

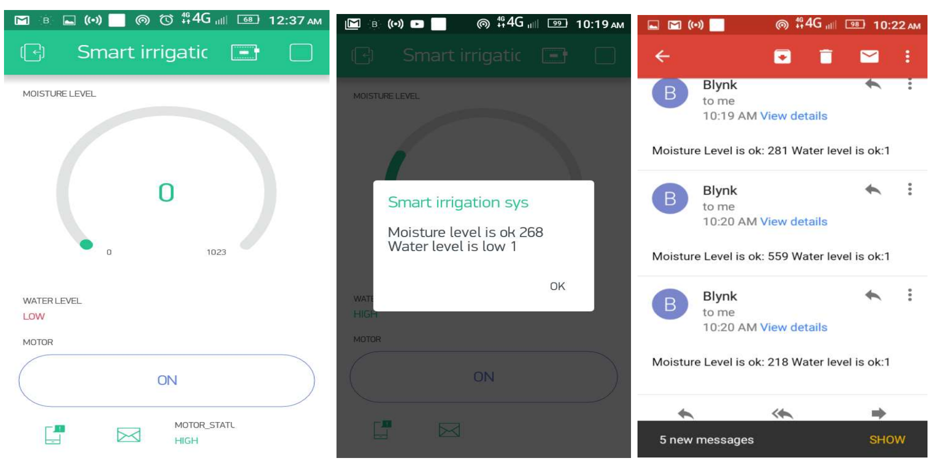
4 Experimental Setup & Implementation

The proposed work used humidity (DTH11) sensor, soil moisture (REES52) sensor, Raspberry Pi and ESP8266 Wi-Fi microchip. The moisture sensor immersed in soil reads moisture level of the soil regularly. This sensor plays major role in this work to notify the level of water content existing in the soil. The core part of processing is performed at server which takes necessary actions based on the pre-defined decision logic. The networking capabilities between different components in the system are established by Raspberry Pi and ESP8266 Wi-Fi microchip kits. The overall functioning of the system is monitored and controlled remotely using android based smart phone. Relay is connected to motor for controlling operation of the motor. The traditional rooftop farming and rooftop farming with technological aid are shown in Fig.4(a-b).

a b

Fig. 4. The urban rooftop farming. a. Traditional method[1] and b. With technology aid[2]. (Source: [1]www.thehindu.com, [2]economictimes.indiatimes.com)

As shown in Fig4, the existing system needs manual monitoring for farming and water sources management. But the proposed approach, employs IoT technology for Rooftop Farming and water management. The working model of proposed IoT based Rooftop Farming along with user notification module are shown in Fig.5. The Table 4 lists out different functional benefits of using IoT technology in rooftop farming.



a b c

Fig. 5. Notification screenshots of proposed IoT based rooftop farming. a) IoT based mobile monitoring b) Low moisture indication through mobile c) Mailing system for consistent monitoring.

Table 4. Functional benefits of rooftop farming with IoT aid.

EFFECTS CATEGORY	FUNCTIONAL BENEFITS	
	EFFECTS	FACTORS WHICH INFLUENCE EFFECTS
Rooftop mitigation impacts and Water resource utilization through IoT adaptation impacts	Reducing the Urban Heat Island Effect	- Plant leaf area index - Green surface coverage
	Reducing Greenhouse gases emissions	- Green surface coverage (insulation) - Plant yield (volumes of food produced locally)
	Carbon storage and sequestration	-Soil coverage and depth , plant species used, degree of permanent cover and harvest
	If it rains then reducing rainwater run-off	- Soil depth - Plant leaf area index - Green surface coverage
	Biodiversity improvement	- Input of organic matter - Depth and composition of the soil -Variety of plant species and degree of permanent cover
Developmental benefits	Reducing air pollution	- Plant leaf area index -Degree of permanent cover
	Reducing food insecurity	-Intensity of growing -Plant yield
	Improved living environment	-Degree of plant cover

5 Outcome of Proposed System

The principle objectives of the developed automated irrigation system are to accomplish operational intelligence, automation and independence thereby easing the stress often related with conformist irrigation performs. The innovations of this work lies in the point that the ease of operation of the developed automated system comes with its various modes of operation, which gives the user convenient choices of operation [18]. The modes comprise the full automation mode whereby the system operates autonomously using the states of the timing system and the soil feedback sensor to take intelligent decisions on appropriate time and extent of irrigation activities to be implemented. In addition, a user could send a command remotely via mobile phone to the field system to start or stop irrigation. Furthermore, users have the privilege of querying the system remotely to acquire response on the soil tangible time settings. Upon receiving such command via the Short Message Service (SMS), the system queries the soil feedback sensor and sends the soil moisture readings to the authorized user(s). The system can also be made to operate in the manual mode relying on human control during certain periods such as the start up or shut down based on the environment and nature of irrigation activities to be carried out. For the purpose of proposed work, only two moisture sensors are been used in the experiments. The features of the soil moisture sensor include: current 3.5 mA, input voltage power supply (3.3 V–3.5 V), output voltage power supply (0–4.2 V)), size (60 × 20 × 5 mm).

The soil moisture sensor comprises of two probes which conduct current into the soil and thereafter reads the electrical resistance so as to regulate the moisture level. Extraordinary moisture content in the soil often triggers high conductivity of current by the soil and vice-versa. The output voltage from the moisture sensor which is immersed in soil is then amplified and sent to the micro controller where it is transformed to digital format using Analog to Digital Converter (ADC). On the controller, the voltage is linked to the threshold value pre-set on it, if the voltage measured is less than the threshold value, the micro controller activates the relay which turns ON the pump for irrigation activities. On the other hand, if the measured value exceeds or equal to the threshold, it implies there is no need for irrigation hence system remains in the idle state. Since the system is automated, manpower is also reduced. Such type of farming (IoT based rooftop farming) have dependency cycle for every human, where such farming will not only improve the vegetation system in urban sector but, it also improves the single-to -nation's revenue. The details about experimental setup and specifications of the components used in the proposed work are given in Table 5.

Table 5. Experimental setup and specifications of proposed model.

Experimental Setup		
Month and Year	April 2018 to December 2018	Duration - Nine months
Farming Model	Roof Top	With Green Agro Net
Farming Area	3600 sq.ft	60X60 sq.ft
Farming Kit	Organic Potting Soil Mix Fertilizer, Red and regional soil mix, Grow Bags	Grow Bags Size :16X16X30Cm
Vegetation	Tomato, green chili, better gourd and ladyfinger	Seasonal Vegetation's
Climate	Summer –Rainy - Winter	Summer –4 months Rainy-3 months, Winter-2 months
Sensors used	1. Raspberry pi 4	Model Number: BE-000030
	2.Soil Moisture Meter Soil Humidity Sensor Water Sensor UNO	Model B
	3.NodeMCU ESP8266 CH340 WIFI Node	CH340 WIFI Starter Kit
Output of yield	Vegetation by seasonal conditions (Near approx. in Kilo grams)	8KG. of Tomato
		5KG.of green Chilli
		6KG (3+3) of Bitter gourd and Ladyfinger

Experimental tryout were executed from April 2018 to December 2019 on the rooftop of a public lodging building in the city of Villupuram (TamilNadu, India). TamilNadu is a representative state were year-round open-air rooftop farming practices can be accomplished due to promising climatic conditions. The trial crops were grownup in a communal garden executed on the 334-m^2 terrace of the 3rd floor of the building. This current rooftop farming and their latent to be low-cost choices for self-managed rooftop gardens. Soil production was also prepared on wooden ampules where plants were grownup on commercial soil with manure and fertilizers. IoT based tank water was used for irrigation in all the systems meanwhile design does not consider any rainwater harvesting system. The crops like tomato, green chili, better gourd and ladyfinger were selected for vegetation since they are all seasonal and throughout year available crops.

6 Conclusion

The research work presented in this paper provides IoT based smart agriculture solution for irrigation of rooftop vegetation in different climates. This automatic irrigation system uses sensor technology with micro controller to create smart switching mechanism and this model displays simple switching tool of water motor/pump using sensor from any part of ground or soil by sensing moisture existing in the soil. This work used humidity, soil moisture sensors, Raspberry Pi and ESP8266 Wi-Fi microchip to make smart switching of various components to ensure automatic water dispersal in rooftop farming area. The main advantages of proposed work are optimum use of water resources, minimum use of human labor, energy saving, cost saving, automation etc than traditional irrigation techniques. The applications of rooftop farming will up-rise the creative green roofs conglomerate food production with natural sustainability, such as abridged rainwater run-off, temperature aids such as latent reduction of heating and cooling necessities, biodiversity, enhanced aesthetic significance and also air quality in urban vicinity.

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