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SMART TERRACE GARDENING WITH INTELLIGENT ROOF CONTROL ALGORITHM FOR WATER CONSERVATION

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In conventional agriculture, agricultural lands are located far away from residential areas. Farmers use excess of fertilizers and pesticides in their field, which produces poisonous vegetables. Also most of the people do not have their own agriculture land. Organic vegetables in the market may not be always genuine as they may be produced using chemical components. Terrace gardening is a booming technology which solves all the above said problems of conventional agriculture and produces healthy vegetables in home. A novel intelligent approach is proposed in this paper by using fuzzy rules to cultivate the vegetables in terrace. The proposed method dynamically measures the atmospheric temperature, humidity and soil moisture in the stipulated time intervals and adjusts the terrace temperature automatically. Terrace temperature is controlled with the help of smart roofs, where smart roof plats are automatically tilted with the help of motors. With the controlled terrace temperature, the proposed fuzzy rule based intelligent system irrigates the crops with exact quantity of water which conserves water, electricity, avoids excess irrigation and produces good yield.
Keywords: Smart gardening, terrace crops, terrace temperature, soil moisture, smart roofs, fuzzy rules.

INTRODUCTION

Organic terrace gardening provides an opportunity for all people in cities to cultivate quality vegetables, fruits, flowers in home. This considerably increases human health as adding fertilizers and pesticides are totally in the hands of one who cultivates. Green terrace tops with plants and flowers grant green and cool spaces, energy conservation, best quality air for breath, healthy life, good biodiversity (Jose, 2014). Also rooftop and terrace gardens give pleasure to city residents and provide an opportunity for improving creativity as well psychological benefits. As an added advantage, balcony gardens change the visual appearance of the building, screening from neighbors and hide unwanted pipeline.

One can easily build the terrace garden with reasonably priced materials like metal and plastic drums, plastic sacks, grow bags, plastic and earthen pots, basins, bricks, etc. By nature, most of these building materials have adequate pores for the aeration and free flow of water during irrigation. Bricks can be placed one above another to desired height and later filled soil and biomass. A tarpaulin sheet may be used at the base of the drum or bed to avoid the problem of algae. (Rao, 2016) provides a case study, which highlights the benefits of terrace garden and its significant role in sustainability and environment.

Green roofs have become an ecological solution in most of the cities, which are used as aesthetic elements for the city and urban environment. (Eski and Uznun, 2013) analyses the thermal properties of a typical extensive green roof in comparison with a bituminous membrane roof and found that impacts of the extreme temperature fluctuations on the surface of the green roof. This shows that the green roofs are a sustainable choice for various climate conditions. Plants including fruits, decorative plants and vegetables can be selected for terrace gardening. Criteria for the selection of plants depend on the interest of the users, visual appearances, plant characteristics, longer span, disease and pest resistance. The plants should also posses easy propagation, rapid establishment, high ground cover density and tolerant to extreme climatic conditions. Availability of water is a threatening constraint in terrace gardening as most of the urban areas seriously suffocates for proper water distributions. Lack of technical knowledge among farmers leads to waste the water in irrigation (Nisar *et al.,* 2015). The soil and plant parameters were significantly influenced by good water harvesting techniques during both growing seasons through improving the structure, infiltrability and water storage capacity of the soil (Abubaker *et al.,* 2014). The fuzzy rule base approach used to increase the system performance significantly (Ganapathy *et al.,* 2014). The main objective of this research paper is to control the soil moisture in the soil beds located in terrace gardening thereby conserving water and electricity significantly.

MATERIALS AND METHODS

Climate over a land surface is a complex balance of many processes coupled together (Betts, 2007). There is a strong coupling exists between soil moisture and atmospheric temperature. The contribution of soil moisture and atmosphere interactions to surface temperature investigated (Berg *et al.,* 2014). Soil moisture is an important parameter that couples the land and atmosphere as it controls the partitioning of available energy between sensible and latent heat flux at the surface. As a result, soil moisture variability controlled by the atmosphere feedbacks on to the near surface temperature.

Soil moisture-climate interactions are found to have considerable effects on temperature (Jaeger and Seneviratne, 2011). Relationship between temperature and soil moisture content is a function of water evaporation factor. The amount of water evaporated from the soil bed is directly proportional to the amount of heat absorbed by the soil bed. The water evaporation causes soil moisture content loss in the soil bed, which affects the growth of the crops and increases the quantity of water required. Water is a limiting factor in the production of dry land agriculture. Improved soil cover and terracing is one of the techniques of water conservation in dry land. (Prijono and Bana, 2015) proposed a technique to know the ability of soil profile to retain water for coffee plantation in relation to the condition of rainfall. (Suman *et al.,* 2010) proposed a method for monitoring the soil moisture using a wireless network sensors by dynamically scheduling the sensor measurements to reduce the energy consumption. (Virma *et al.,* 2016) developed an autonomous gardening robotic vehicle which automatically identifies and classifies the plant species using feature extraction algorithms and measures the key parameters like temperature, humidity, heat level, wind speed, wind direction and soil moisture. These data acquired from the on-board sensors of the gardening rover are sent to the data processing centre in a regular interval and the predictions are made to maintain the garden more effectively and efficiently.

The proposed research work is implemented and experimented in two different sites called site I and site II, where site I is Conventional Terrace Gardening (CTG) and site II is Smart Terrace Gardening (STG). The proposed smart terrace gardening consists of smart roof, which is built over the soil bed area with the help of supporting frames. Heat stop is an advanced development in polycarbonate based sheets, which effectively eliminates 60% of the radiated heat of the sun. The proposed approach uses polycarbonate sheets with different thickness to make the smart roof. The smart roof consists of three layers where each layer is built with multiple segments. The individual segments in each layer of the smart roof are rotatable with the help of motors. In STG, an outer sensor unit is used to measure the temperature and humidity of the region above smart roof with the help of temperature sensor (TS_{out}) and humidity sensor (HS_{out}). Similarly, an inner sensor unit consists of temperature sensor (TS_{in}) and humidity sensor (HS_{in}) is used to measure the temperature and humidity in the region below the smart roof. The soil moisture of the soil bed is frequently measured with soil moisture sensor (SMS_{sb}). The smart roof motors, outer sensor unit, inner sensor unit and soil moisture sensors are controlled by the Smart Gardening Control Unit (SGCU). Based on the need, the SGCU can automatically operate the sprinkler to water the plants.

Any crop needs certain soil moisture content in the soil bed in its crop period. Some crops need less soil moisture content in the beginning, whereas some crops need very high soil moisture at all time of their crop period. Based on these requirements, water supply is usually given to the soil bed for the healthy growth of the crops. In the proposed research work, the soil moisture content to be maintained in the soil bed on each day of the crop period is defined in prior. Every day, the inner sensor unit measures the temperature under the smart roof and the soil moisture sensors measure the soil moisture content in the soil bed. They are monitored and values are adjusted by applying fuzzy rules for intelligent decision making. Based on the measurements taken, the SGCU system rotates the smart roof and controls the temperature in the soil bed to conserve the water and electricity. The next section gives the results and discussions about the proposed research work.

RESULTS AND DISCUSSIONS

In this experiment, the soil bed in both site I and site II were watered in every morning around 6.30 AM on 22-09-2015, 23-09-2015, 24-09-2015, 25-09-2015, 26-09-2015, 27-09-2015, 28-09-2015 with the soil moisture values 0.045%, 0.044%, 0.041%, 0.042%, 0.045%, 0.051% and 0.049% respectively. The temperature and humidity values measured by the outer sensor units and inner sensor units on 22-09-2015, 23-09-2015, 24-09-2015, 25-09-2015, 26-09-2015, 27-09-2015, 28-09-2015 in both site I and site II are given in Table 1 and Table 2.

Since the conventional terrace gardening in site I is not covered by the smart roof, the soil moisture content in the soil bed was drained significantly as shown in the Table 3. But the soil moisture content in the soil bed of site II is covered and protected by smart roof, the soil moisture content loss is significantly controlled as shown in the Table 4.

Since the proposed research work significantly control the soil moisture loss in soil bed, the quantity of water required to maintain the necessary soil moisture is also reduced, which leads to the conservation of water unlike the conventional terrace gardening.

From Table 1 and Table 2, it is observed that the conventional terrace gardening method had the average temperature of 28.67^{0}C on 22-09-2015, 29^{0}C on 23-09-2015, 29.33^{0}C on 24-09-2015, 29.67^{0}C on 25-09-2015, 30.67^{0}C on 26-09-2015, 30.67^{0}C on 27-09-2015, 29.33^{0}C on 28-09-2015 in the site I between 7 AM to 10 PM. But the proposed STG method had maintained an average temperature of 26^{0}C on 22-09-2015, 25.33^{0}C on 23-09-2015, 26.33^{0}C on 24-09-2015, 26^{0}C on 25-09-2015, 27.5^{0}C on 26-09-2015, 27.33^{0}C on 27-09-2015, 27.17^{0}C on 28-09-2015 in site II between 7 AM to 10 PM.

From Table 3 and Table 4, it is observed that the conventional terrace gardening method had maintained an average soil moisture of 0.18% on 22-09-2015, 0.168% on 23-09-2015, 0.56% on 24-09-2015, 0.174% on 25-09-2015, 0.185% on 26-09-2015, 0.21% on 27-09-2015, 0.194% on 28-09-2015 in the site I between 7 AM to 10 PM. But the proposed STG method had maintained an average soil moisture of 0.256% on 22-09-2015, 0.252% on 23-09-2015, 0.239% on 24-09-2015, 0.245% on 25-09-2015, 0.257% on 26-09-2015, 0.295% on 27-09-2015, 0.266% on 28-09-2015 in the site II between 7 AM to 10 PM. From the experiments conducted for terrace gardening with and without the application of fuzzy rules, It is observed that the application

Table 1. Temperature and Humidity Measurements in Conventional Terrace Gardening (CTG)

TOM	22-09-2015		23-09-2015		24-09-2015		25-09-2015		26-09-2015		27-09-2015		28-09-2015	
	T (ºC)	H (%)	T (ºC)	H (%)	T (ºC)	H (%)	T (ºC)	H (%)	T (ºC)	H (%)	T (ºC)	H (%)	T (ºC)	H (%)
7 AM	26	86	26	83	26	73	26	74	27	70	27	70	26	75
10 AM	29	85	29	78	29	73	29	74	30	69	31	70	29	73
1 PM	31	83	31	70	31	72	32	72	33	68	33	68	32	71
4 PM	31	84	31	71	32	72	32	72	34	68	33	69	32	71
7 PM	28	84	29	72	30	74	30	73	31	72	31	71	29	72
10 PM	27	87	28	73	28	75	29	74	29	73	29	74	28	73

Table 2. Temperature and Humidity Measurements in Smart Terrace Gardening using Fuzzy Rules (STG)

	22-09-2015		23-09-2015		24-09-2015		25-09-2015		26-09-2015		27-09-2015		28-09-2015	
TOM	T (ºC)	H (%)	T (ºC)	H (%)	T (ºC)	H (%)	T (ºC)	H (%)	T (ºC)	H (%)	T (ºC)	H (%)	T (ºC)	H (%)
7 AM	26	86	25	85	26	80	26	82	27	79	27	81	26	82
10 AM	26	86	25	82	26	80	26	80	28	79	27	80	27	80
1 PM	27	85	26	80	27	79	28	79	28	76	28	79	28	79
4 PM	26	85	26	80	27	79	26	91	28	76	28	81	28	80
7 PM	26	85	25	82	26	81	25	82	27	78	27	81	27	81
10 PM	25	86	25	83	26	83	25	83	27	79	27	83	27	82

Table 3. Soil Moisture Measurements in Conventional Terrace Gardening (CTG)

TOM	22-09-2015 (SM %)	23-09-2015 (SM %)	24-09-2015 (SM %)	25-09-2015 (SM %)	26-09-2015 (SM %)	27-09-2015 (SM %)	28-09-2015 (SM %)
7 AM	0.045	0.044	0.041	0.042	0.045	0.051	0.049
10 AM	0.039	0.036	0.035	0.037	0.038	0.047	0.045
1 PM	0.029	0.025	0.024	0.029	0.029	0.032	0.029
4 PM	0.024	0.022	0.020	0.024	0.026	0.029	0.025
7 PM	0.022	0.021	0.019	0.022	0.024	0.026	0.024
10 PM	0.021	0.020	0.017	0.020	0.023	0.025	0.022

Table 4. Soil Moisture Measurements in Smart Terrace Gardening using Fuzzy Rules (STG)

TOM	22-09-2015 (SM %)	23-09-2015 (SM %)	24-09-2015 (SM %)	25-09-2015 (SM %)	26-09-2015 (SM %)	27-09-2015 (SM %)	28-09-2015 (SM %)
7 AM	0.045	0.044	0.041	0.042	0.045	0.051	0.049
10 AM	0.044	0.043	0.041	0.042	0.044	0.051	0.045
1 PM	0.043	0.042	0.040	0.041	0.043	0.049	0.044
4 PM	0.042	0.041	0.040	0.041	0.042	0.049	0.043
7 PM	0.041	0.041	0.039	0.040	0.042	0.048	0.043
10 PM	0.041	0.041	0.038	0.039	0.041	0.047	0.042

of fuzzy rules enhance the quantity of output more significantly. Figure 1 and Figure 2 gives the measured soil moisture values of conventional terrace gardening and smart terrace gardening respectively.

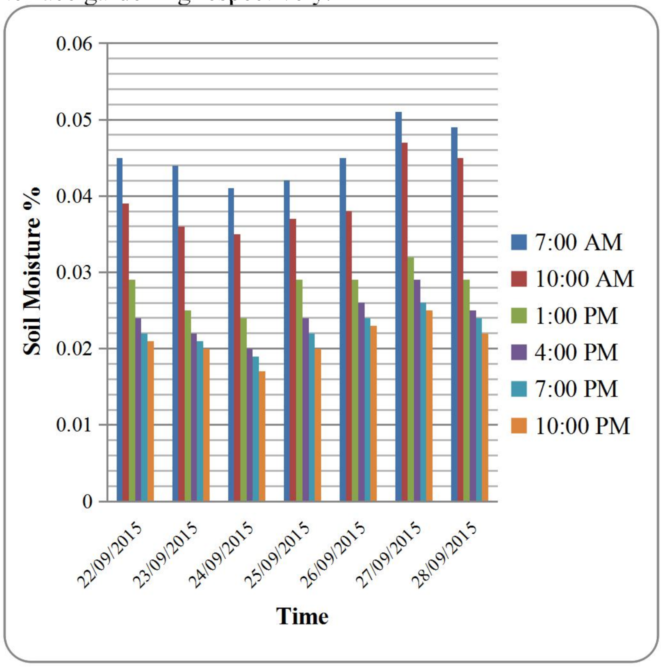

Figure 1. Soil Moisture Measurements in Conventional Terrace Gardening (CTG)

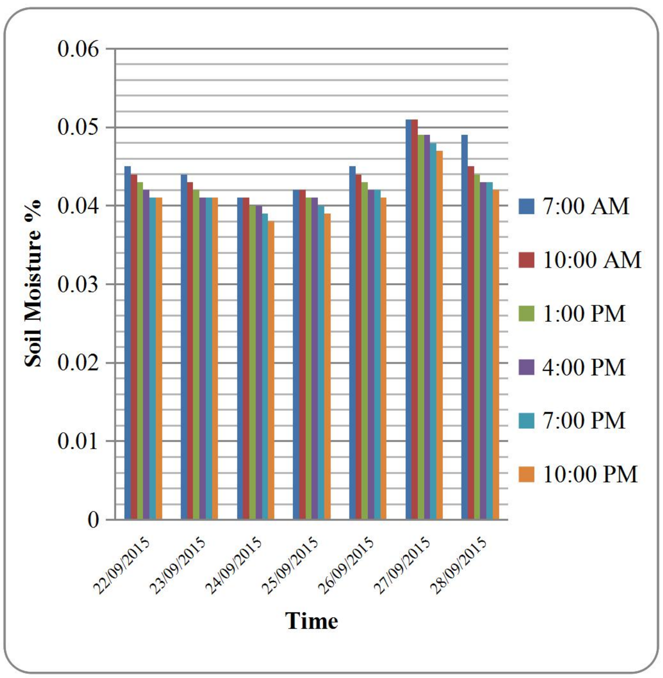

Figure 2. Soil Moisture Measurements in Smart Terrace Gardening using Fuzzy Rules (STG)

Based on the temperature, humidity and soil moisture values measured using the proposed smart terrace gardening system, the fuzzy based intelligent rule set is formed and tabulated in Table 5.

Table 5. Fuzzy Rules for Measuring the Soil moisture

Rule	Fuzzy Rules
1	**IF Temperature** is *below* **26^{0}c** and **Humidity** is *below* **85.5% THEN** Rotate the smart roof to vertical position to reduce the sunlight radiation heat and supply water till the **temperature** reaches **26^{0}c** and **Humidity** reaches 85.5% .
2	**IF Temperature** is equal to 2**6^{0}c** and **Humidity** is equal to **85.5%** and **THEN** Maintain the smart roof in current position and no supply required = NULL.
3	**IF Temperature** is *above* **26^{0}c** and **Humidity** is *above* **85.5% THEN** Rotate the smart roof to vertical position to reduce the sunlight radiation heat and supply water till the **temperature** reaches **26^{0}c** and **Humidity** reaches 85.5%.
4	**IF Soil moisture** is *below* 0.043% **THEN** Increase the water supply till the **soil moisture** reaches **0.043%**
5	**IF Soil moisture** is equal to 0.043% **THEN** No water supply is required = NULL
6	**IF Soil moisture** is *above* 0.043% **THEN** Decrease the water supply till the **soil moisture** reaches **0.043%**

***Conclusion*:** The proposed research work significantly controls the soil moisture in the soil bed deployed in terrace gardening using the smart roof technology. Depending on the current condition of the atmospheric temperature and humidity, the proposed system automatically adjusts the position of the smart roof and controls the soil moisture in the soil bed. From the serious of experiments conducted, it is observed that the proposed STG method reduces the temperature with an average value of *2.67^{0}C on 22-09-2015, 3.67^{0}C on 23-09-2015, 3^{0}C on 24-09-2015, 3.67^{0}C on 25-09-2015, 3.17^{0}C on 26-09-2015, 3.33^{0}C on 27-09-2015, 2.17 ^{0}C on 28-09-2015* in site II than the site I between 7 AM to 10 PM due to the use of fuzzy rules, moreover the STG maintains better soil moisture in the soil bed of site II than the site I with the average value of 0.076% on 22-09-2015, 0.084% on 23-09-2015, 0.083% on 24-09-2015, 0.071% on 25-09-2015, 0.072% on 26-09-2015, 0.085% on 27-09-2015, 0.072% on 28-09-2015 between 7 AM to 10 PM. Since it applies fuzzy decision on the maintenance of soil moisture. This approach considerably reduces water conservation and saves electricity. Finally the proposed approach also helps the plants to grow with accurate soil moisture conditions and increases the yield. As a whole, the proposed research strongly enables every person in the city area to build their own terrace garden to produce homemade healthy vegetables, fruits with water and electricity conservation due to the use of intelligent rules.

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