Drip Irrigation Scheduling System Using Sensor Network

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Abstract– *The agriculture is vulnerable and sensitive to climate changes. These changes reduce the production while encouraging the growth of bush, which lead to water consumption extravagantly. In this paper, we proposed an automatic drip irrigation system based on calculating the required crop water and irrigation depth. The aim of the proposed system is to automatically compute irrigation scheduling of certain crop according to a crop type and climatological conditions. This system includes two parts: hardware and control center. The sensors send their real-time readings of the soil moisture and climatic information to the monitoring part of the system wirelessly and then save them in database server. The hardware part consists of a main unit represented by ARDUINO Uno and sensors of soil moisture and DHT11. The wireless communication link between the hardware and control center parts are covered using Bluetooth HC-06. In the control center, the database is built using SQL server 2015 and the related Graphical User Interface (GUI) frames is designed using Visual Studio C#. The proposed system has been presented in a prototype to represent the case study and the obtained results show a clear reduction of power and water consumption.*

Index Terms*— Irrigation, water consumption, embedded systems, sensors, Microsoft Visual Studio C#, SQL Server, Bluetooth HC-06.*

I. INTRODUCTION

Recently, the advance of electronics makes our life more flexible. As a result of this advancement, we have implemented an automatic irrigation system that seeks to make farmers' work more flexible and reduces their stress. The automated irrigation system tries to give water to a crop when needed with net irrigation requirement only. The system result in water saving compared to traditional irrigation system which gives water to a crop without known whether it needs watering or not. The irrigation of a plant performed is based on obtaining readings from sensors used to monitor soil water content and climatological conditions to schedule the irrigation for a plant. The irrigation scheduling can be administrated accurately to achieve plant demands, holding the guarantee of expanded quality [3]. The development in the irrigation system can result in time saving, reducing manual work and increasing a crop yield. The benefit of using sensors is to monitor all related arguments for best irrigation administration [8]. Checking parameters for soil moisture, temperature and humidity are a significant means for getting high-quality medium. Remote observation will be a successful method so as to avoid obstruction nature's domain and enhance effectiveness. [9]. In this paper, automated irrigation system is designed to minimize water consuming and human involvement, while a plant gets all needed water.

II. RELATED WORKS

The system in [4], suggested agricultural climate management system for obtaining information about external agricultural output environment using sensor network. The proposed agricultural management system aggregated parameters about climate and soil on the outside out of sensors. This

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system supplied the environmental controlling utilities and simplifies monitoring utilities, to increase the crop yield in an efficient way. In addition, this system upgraded the suitability and productivity of users. It did not monitor irrigation process, only monitor environment, and soil parameters. In [5], described a use of a wireless sensor system for minimal effort remote controlled watering system arrangement and ongoing checking of water substance of soil. The outlined framework has 3 units in particular: Base Station Unit (BSU), Valve Unit (VU), and Sensor Unit (SU). The created watering system framework has a few focal points, for example, averting moisture anxiety of trees, reducing of over the top water utilization, guaranteeing of fast developing weeds and disparaging calcification. In [10], proposing an arrangement of programmed dribble watering system by utilizing wireless sensor system to quantify the dampness of soil. This system based on soil identification which comprises of ZigBee module for interchanges reason. The goal of the system is to a) preserve vitality and water assets b) handles the framework physically and consequently c) distinguishes the level of water d) constructs such framework which upgrades crop efficiency e) learns determination techniques for watering system taking into account distinctive parameter. In [2], authors discussed various observing frameworks and proposed a programmed checking framework model utilizing Wireless Sensor Network (WSN) which helps the rancher to enhance the yield. The proposed framework comprises of various sorts of detecting unit, for example, Soil Dampness Sensor to quantify water substance of soil, Temperature Sensor recognizes the temperature, Mugginess Sensor to gauge the nearness of water in air, Weight Controller Sensor to be chosen for keeping up the suggested weight, Atomic Sensor chose for better harvest development. In [14], a smart irrigation system based WSNs is actualized. This framework comprises of the primary unit that spoke to by an Arduino Uno board which incorporate an ATmega328 microcontroller, diverse sensors as moisture temperature sensors, humidity sensors, XBee modules and solenoid valve. In [1], suggested a generic algorithm for irrigation scheduling management for micro-irrigation technique which were: sprinkler and drip. This method provided estimation of needed plant water, irrigation frequency, irrigation frequency time duration required to estimated irrigation scheduling for a crop.

III. SYSTEM DESIGN

Figure (1) shows the designed architecture of the hardware part of the proposed automation irrigation system. It contains soil moisture and DHT11 sensors to monitor real-time information of soil water and temperature and humidity in the atmosphere. These information is collected and controlled by Arduino and then it is sent to control center for making an irrigation decistion and storing in database.

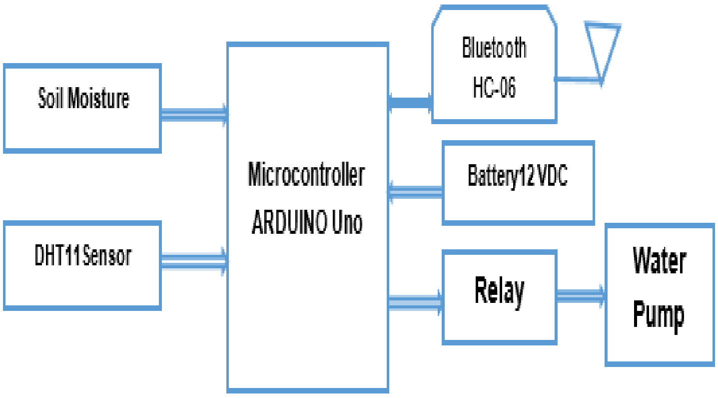

FIG. 1: THE IRRIGATION SYSTEM SCHEMATIC DIAGRAM.

The hardware components utilized in this work can be described briefly:

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A. Arduino Uno

The Arduino Uno is an open-source microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started [6]. Figure (2) shows description of the Arduino Uno.

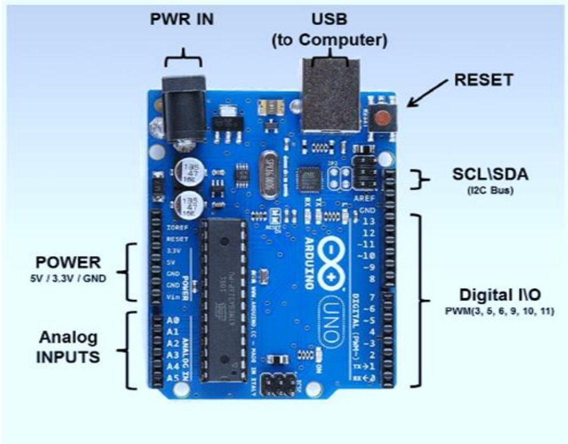

FIG. 2: ARDUINO UNO BOARD.

B. Soil Moisture Sensor

The soil moisture sensor is capacitive kind. It gives simple yield of zero volts when there is 100% moisture and 5V for 0% moisture [2]. This sensor is used for detecting the water amount of the soil in the field. The soil sensor has two tests and uses them to gauge soil moisture in the soil by telling how well an electrical current is passed between the two tests [16]. Figure (3) (a): Shows the soil moisture sensor and (b): the soil moisture sensor is interfaced with Arduino.

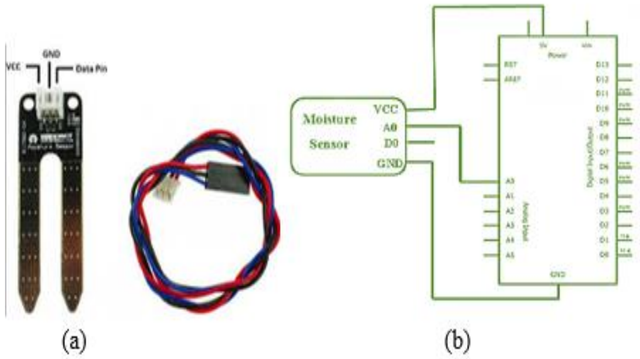

FIG. 3: (A) THE SOIL MOISTURE SENSOR (B) THE SCHEME OF INTERFACING A SOIL MOISTURE SENSOR WITH ARDUINO.

C. DHT11 Temperature and Humidity Sensor

DHT11 digital is a combination sensor used to sensing humidity of environment temperature and humidity. This sensor includes capacitive humidity sensing of wet component and a NTC temperature deterministic tools [11]. Figure (4) shows interfaced block diagram of DHT11 sensor with Arduino.

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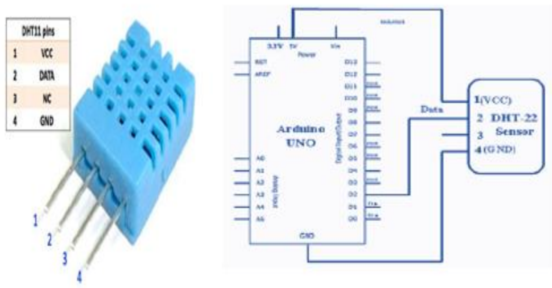

(a) (b)

FIG. 4: (A) THE SENSOR (B) THE SCHEME OF INTERFACING A DHT11 SENSOR WITH ARDUINO.

D. Bluetooth HC-06

HC-06 module is a simple to utilize Bluetooth SPP (Serial Port Protocol) module, intended for straightforward wireless serial communication setup [7]. Bluetooth serial module is utilized for changing over serial port to Bluetooth [11]. Figure (5) shows the Bluetooth of HC-06.

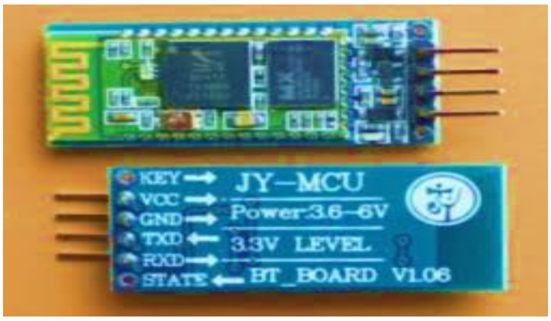

FIG. 5: BLUETOOTH HC-06

At the other hand, the control center includes the core of the proposed system that involves the database and the GUI as well as the server. The received readings of the sensors from the hardware part are used for scheduling the irrigation periodic cycle for a specific type of crop. In addition, these readings are saved in the database server.

The proposed application is designed by the researcher and the data recorded in the database are the actual sensor readings that were used in calculating the irrigation table and are stored in the built-up database to be analyzed statistically for soil moisture, air temperature and humidity in the planting area to determine the evaporation rate Water from the surface of the soil and plant and also the knowledge of the plant's need for water.

IV. DATABASE BUILDING

In this work, we build database by using SQL Server [15] and [13]. The underlying database called IRRIGATION Database has been built using local SQL server with three tables which are: ***Reading Table, Crop Water Requirement Table*** and ***Irrigation Scheduling Table***. Each table includes different elements and each of which is represented by an individual column in the table.

Figure (6) shows ***Reading Table*** which is involves the collected data readings from the assumed sensors fixed at the farm represented in ***Moisture1, Moisture2 Temperature*** *and* ***Humidity*** as there are just two considered sensor types in addition time stamp.

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ZENA.Irrigation_Sc...dbo.Reading_Table1

Date	Period	Moisture1	Moisture2	Temperature	Humidity
2016-12-04	14:48:00	0	0	20	20
2016-12-04	14:48:00	0	0	20	20
2016-12-04	14:48:00	14	0	20	19
2016-12-04	14:48:00	14	0	20	19
2016-12-04	14:48:00	14	0	20	19
2016-12-04	14:48:00	14	0	20	19
2016-12-04	14:48:00	78	0	21	20
2016-12-04	14:48:00	78	0	21	20
2016-12-04	14:48:00	22	0	20	20
2016-12-04	14:48:00	22	0	20	20
2016-12-04	14:48:00	96	1	36	26
2016-12-04	14:48:00	96	1	36	26
2016-12-04	14:48:00	0	0	34	25
2016-12-04	14:48:00	0	0	34	25
2016-12-04	14:48:00	0	0	35	25
2016-12-04	14:48:00	0	0	35	25
2016-12-04	14:48:00	0	0	36	24
2016-12-04	14:48:00	0	0	36	24
2016-12-04	14:48:00	0	0	35	25
2016-12-04	14:48:00	0	0	35	25

FIG. 6: READING TABLE.

Figure (7) shows ***Crop Water Requirement Table*** that includes ***Crop Name*** for save crop type, ***Total growth period*** represent total growth period of a specify crop, ***planting date*** is the date of planting a plant, ***Stage name*** represents the name of any four stages of growth a plant. In addition, ***Stage duration*** represents the duration of a specified stage of growth a plant, ***ETref*** is the evapotranspiration resulting from climatological parameters, ***Kc*** is the crop factor and ***ETcrop* is the** crop water requirement resulting from ***ETref*** product by ***Kc*.**

Figure (8) expresses the **t**able of ***Irrigation Scheduling*** that contains ***ETcrop*** from ***Crop Water Requirement Table, Depletion*** is the allowable depletion of a plant, ***dnet*** is the net irrigation requirement for a plant, ***dgross*** is the total water requirement include water losses through evapotranspiration, ***Irrigation Frequency*** represent the number of irrigation, ***Irrigation Interval*** represent the period between two successive irrigation, ***Start Time*** is the starting time of an irrigation, ***Duration*** is the duration of one irrigation, ***Pipe1*** *and* ***Pipe2*** columns represent which Pipe is turned on at specified time.

ZENA.Irrigation_Sc...ng - dbo.CWR_Table

Crop_Name	Total_growth_...	Planting_date	Stage_name	Stage_duration	ETref	Kc	ETcrop
Green Maize	150	24/9	Initial	25	0.4	0.7	2.8
	0		Dev	50	1.1	0.8	0.88
	0		Mid	40	0.8	1.2	0.96
	0		Late	35	0.4	0.65	0.26
Cabbage	140	1/12	initial	30	4.2	2.1	8.9
	0		Dev	40	5.4	3.17	17.14
	0		Mid	35	5.11	3.14	16.07
	0		Late	35	3.97	2.97	11.81
Tomato	132	1/2	initial	30	5	0.45	2.3
	0		Dev	40	5.8	0.75	4.1
	0		Mid	40	6.3	1.15	6
	0		Late	25	6.8	0.8	7.8

FIG.7: CROP WATER REQUIREMENT TABLE.

Irrigation_Sc..._Scheduling_Table1 ZENA.Irrigation_Sc...n_Scheduling_Table

Date	ETcrop	Depletion_1	dnet_1	dgross_1	Irrigation_Freq...	Irrigation_Inter...
2016-02-11	2.8	52	51.9	52.198	2	6.5

FIG. 8: IRRIGATION SCHEDULING TABLE FOR TOMATO.

V. GUI DESIGN

The system interfaces are designed using Visual Studio C#. Figure (9) shows irrigation scheduling system page with five buttons: *Irrigation Table*, *Delete*, *Update*, *Statistical Information* and *Arduino Connection*.

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A. Irrigation Table

This is the creation of a new Irrigation Schedule. By clicking this button, the page of Figure (9) is shown. The add operation starts with the first of three stages by entering *add a crop type, planting date, location of planting a crop, total growth stage of a plant, and a stage of growth a plant these variables are entered manually as described in* Table1. According to selected a stage, the related section of this stage is enabled to enter the data about Duration of the selected stage, *ETref* and K_C values. The ***Upload*** button below will take value of *ETref* product by K_C value and resulting value is *ETcrop*, which estimated according to Equation (1), then store all data into ***CWR Table*** into SQL Database. The Clear button below used to clear all data contain in field. The ***Next*** button is used to transfer next stage of adding new Irrigation Schedule.

$$ET_C = K_C * ET_\circ \tag{1}$$

Where ET_C the crop water requirements [mm/ day], $ET_\circ$ the reference evapotranspiration [mm/day], K_C the crop coefficient.

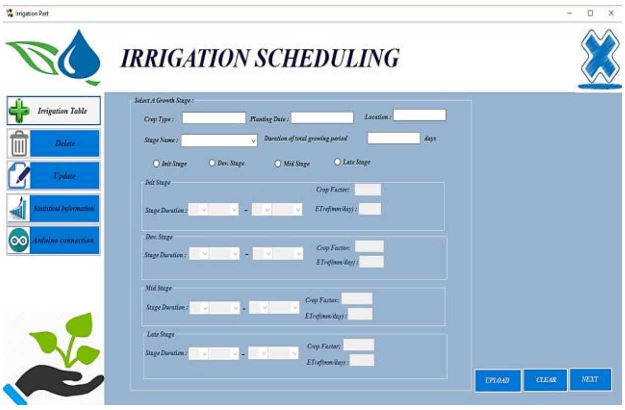

FIG. 9: IRRIGATION TABLE INSERTION.

Figure (10) shows the second stage that deals with entering initial information of: *date, day of growth a plant moisture1, moisture2* retrieved from ***Reading Table***, ***ETcrop*** retrieved from ***Crop Water Requirement Table*** and *Field capacity and Wilting point of a soil, Root Zone of a plant, discharge of a pipe, Number of Nozzle in a pipe, start time to irrigate variables* entered manually.

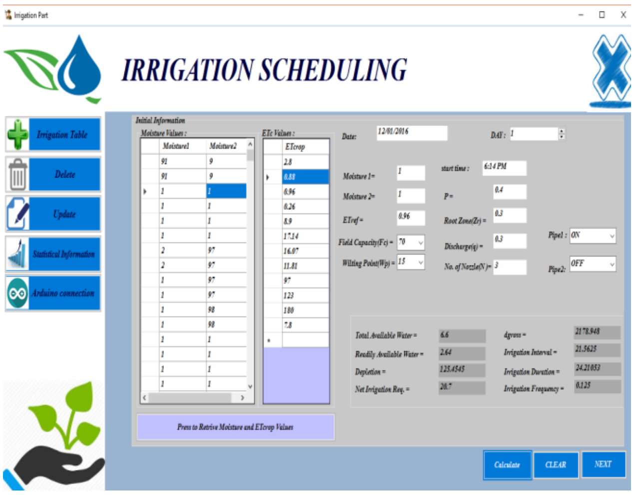

FIG. 10: THE CALCULATION PROCESS OF IRRIGATION SCHEDULING.

The calculate button below is used to produce Total Available Water (TAW) as:

$$TAW = 1000(F_c - W_p) \times Z_r \tag{2}$$

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Where *TAW* is the total available soil water in the root zone [mm], F_c is the water content at field capacity [m^3 / m^3], W_p is the water content at wilting point [m^3 / m^3], Z_r is the rooting depth [m].

The readily Available Water (RAW) which is percentage of TAW can be estimated as:

$$RAW = P \times TAW \tag{3}$$

Where *RAW* is the readily available soil water in the root zone [mm], *p* represents average fraction of Total Available Soil Water (*TAW*) that can be depleted from the root zone before moisture stress (reduction in ET) occurs.

In addition, depletion is estimated as:

$$d\% = [\frac{(F_c - S_m)}{(F_c - W_p)}] \times 100\% \tag{4}$$

where d is the percentage soil moisture depletion ratio, F_c is the water content at field capacity [m^3 / m^3], W_p is the water content at wilting point [m^3 / m^3], S_m is current soil moisture [m^3 / m^3].

Moreover, the net water requirement (dnet) is evaluated as:

$$d_{net} = (F_c - S_m) \times Z_r \tag{5}$$

where d_{net} is current net irrigation amount [mm], S_m is current soil moisture [m^3 / m^3], Z_r is root depth [m].

While gross water (dgross) is computed according to:

$$d_{gross} = (100 \times d_{net})/ET_\circ \tag{6}$$

Whered_{gross} *is total water applied [mm],* d_{net} *is percentage of* d_{gross} *and is really needs by a plant[mm],* $ET_\circ$ *is reference evapotranspiration [mm/day].*

The irrigation frequency (which is the number of irrigation) is calculated as:

$$IF = S_m/d_{net} \tag{7}$$

Where IF is irrigation frequency, S_m is soil moisture [m^3 / m^3], d_{net} is net irrigation requirement [mm],

Additionally, irrigation interval (that is the period between two successive irrigations) in days which is calculated as:

$$II = d_{net}/ET_c \tag{8}$$

where *II* is irrigation interval (day), d_{net} is net irrigation [mm], ET_c crop water requirements [mm/day].

Finally, duration of one irrigation in minutes was estimated according to:

$$T = d_{net}/(q \times N \times E) \tag{9}$$

Where *T* is irrigation time [minute], d_{net} is net irrigation [mm], *E* is system efficiency %, *q* is nozzle discharge rate [l/s], *N* is number of nozzles. The clear button below is used to clear all data. While, the Next button is used to go for the last stage, which is showing the irrigation scheduling table.

B. Irrigation Table Delete

This is button is utilized to delete irrigation scheduling table completely. By clicking on the button will appear attention message for ensuring the deleting the table.

C. Irrigation Table Update

The button is used for the updating operation. When click on this button, all fields of the above frames are available for updating.

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D. Statistical Information

This button contains statistical analysis of all data related to irrigation scheduling process. Figure (11) shows statistical information of irrigation operation. The statistical information includes graphs to express the development in the readings of soil moisture data, temperature, humidity, crop water requirement, ***ETcrop,*** weather data, etc. These graphs can be drawn for specific dates and time.

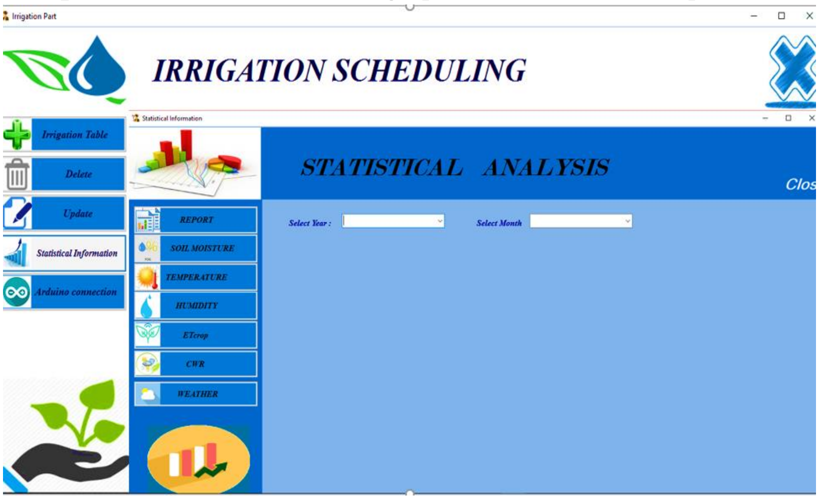

FIG.11: STATISTICAL ANALYSIS OF IRRIGATION OPERATION.

E. Arduino connection

This is button to configure communication between GUI Page and Arduino. When click on this button, the communication between Arduino and server is setup, then Arduino send sensor reading to server for storing in SQL database. Figure (12) shows Arduino connection button.

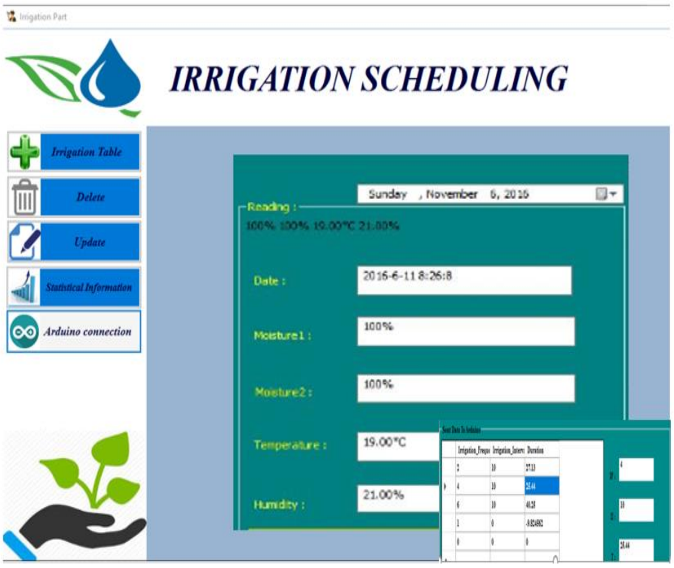

FIG. 12: ARDUINO CONNECTION BUTTON.

VI. PROPOSED ALGORITHM

The adopted algorithm of the proposed system can be represented as a flowchart shown in Figure (13). After power up the system, the Arduino begins sending the readings of the considered sensors to server at the control center.

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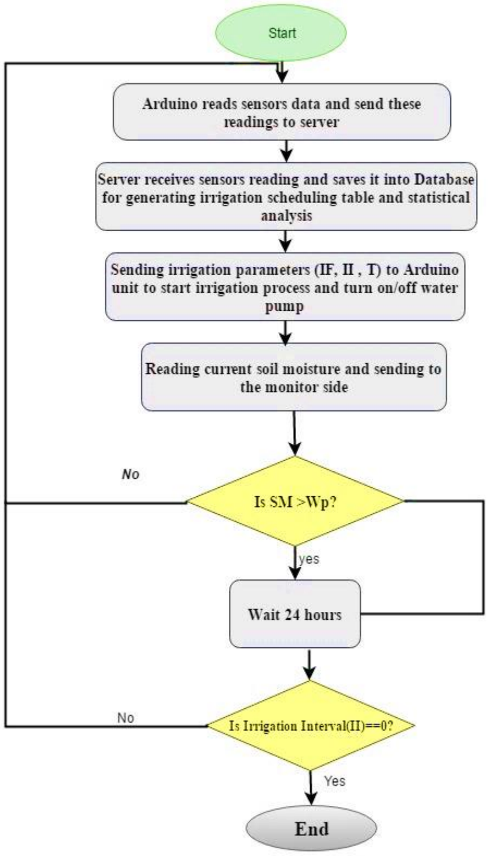

FIG. 13: IRRIGATION PROCESS FLOWCHART.

The control sensor analyses the received data and performing the calculation of producing irrigation scheduling table for a plant. During irrigation operation, the sensors is keeping check the soil water content daily and if sensor reading value is decreases under the expectation in which the is a risk of depletion of a plant, the irrigation process is rescheduled automatically.

As in figure above shown (24 hours) because it is monitored the soil moisture at real time during irrigation process and this duration is between irrigation interval which it may be one day, two day or more depend on irrigation interval obtained from irrigation scheduling calculation process.

VII. EXPERIMENTAL RESULTS

The designed system is tested. The hardware part of the proposed system is shown in Figure (14), where the involved components are installed with the required connections. At the server side, based on the received sensors' readings from Arduino, the calculation operation to produce irrigation scheduling table for a plant is performed. Depending on the produced irrigation table, the watering process is started automatically. During the irrigation operation, the sensors are keeping reading and checking the soil water content daily. In case of detecting a sensor reading value below the allowable depletion of a plant, the irrigation process is rescheduled automatically as shown in Figure (15). In Figure (16), the irrigation process stops, as well as water pump turn off when soil water content above depletion value of a plant.

As shown in figure below the sensor is placed near the root of the plant and at various depths ranging from 30 cm to 50 cm from the root of the plant to the maximum extent because the application of drip irrigation is used for plants that grow on the surface of the soil in the ranks and bushes are not high and also roots are not deep in the soil such as tomatoes. The location of the plant and the extent of its effect on climatic conditions according to its position in the area of the planting is predicted by the

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use of temperature and humidity sensors, as well as determine the type of soil and its suitability to the plant type and the extent of retention of water quantity and provision of plant to prevent the occurrence of pests and plant injury diseases.

FIG. 14: IRRIGATION SYSTEM ARDUINO PROTOTYPE.

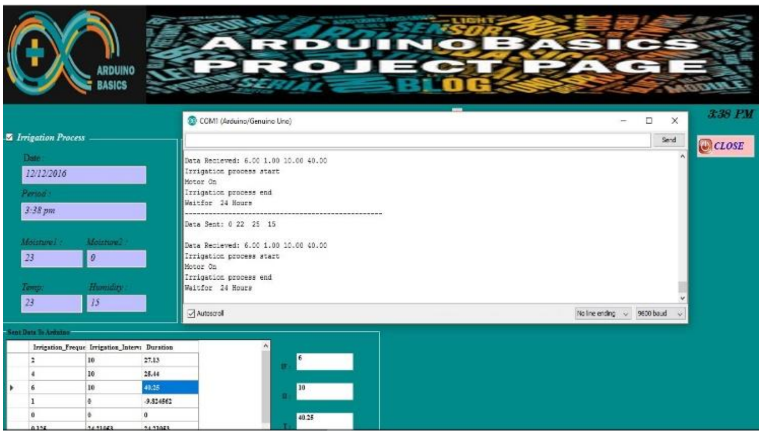

FIG. 15: IRRIGATION PROCESS STARTING.

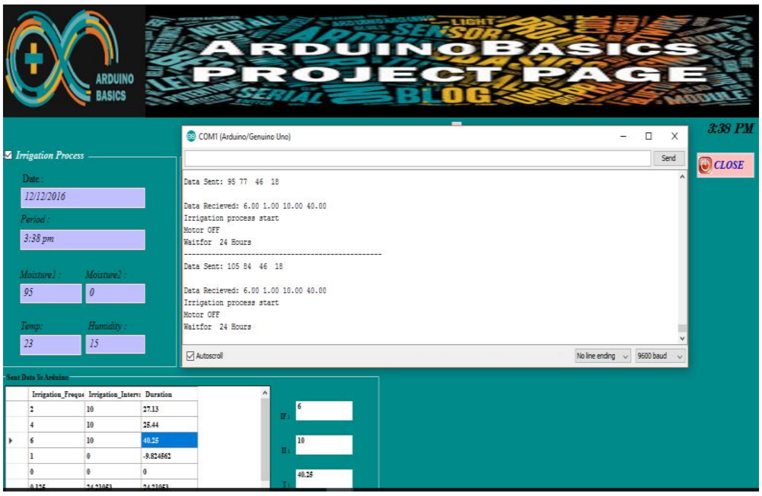

FIG. 16: IRRIGATION PROCESS STOPPED.

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In Table 1, the required initial information has been considered. These information is used to calculate the needed crop water (ET_C) for Tomato crop at the initial stage of growth. It is important to note that the Tomato crop has been chosen as a case study in testing the proposed system. In Table 2, the initial information required for evaluating the irrigation scheduling table has been adopted. The values in the table are taken from a real case study.

TABLE 1: INITIAL INFORMATION OF A CROP

Name	Variable	Units
Crop Name	Tomato	-
Planting date	February	-
Total growth period	135	days
Stage Name	Initial /Dev/Mid/Late season	-
Stage Duration	30/40/40/25	days
ETc	ETref=(5, 5.8, 6.3, 6.8)	mm day−1
Crop factor	Kc=(0.6, 1.15, 0.8)	-

TABLE 2: INITIAL INFORMATION TO CALCULATE IRRIGATION SCHEDULING PROCESS.

Name	Variable	Units
Field Capacity	Fc=90	m3 m-3
Wilting Point	Wc=(0-25)	m3 m-3
Allowable depletion level	P=0.5 or 50%	(%)
Root zone depth	Zr=(0.4,.05)	m
discharge of a pipe	Q=0.3	l/s
Number of Nozzle in a pipe	N=3	None
start time to irrigate	Start Time: 07:00 AM	Minutes

According to the proposed algorithm of Figure (13) and the irrigation scheduling building steps explained in Figures (9-10), the irrigation scheduling table shown in Figure (17) has been calculated.

The statistical reporting of the proposed system has been tested as well as shown in Figures (18, 19, 20 and 21). These figures show statistical analysis of a temperature, soil moisture, plant water needs and water applying to a plant for year 2016 in February month.

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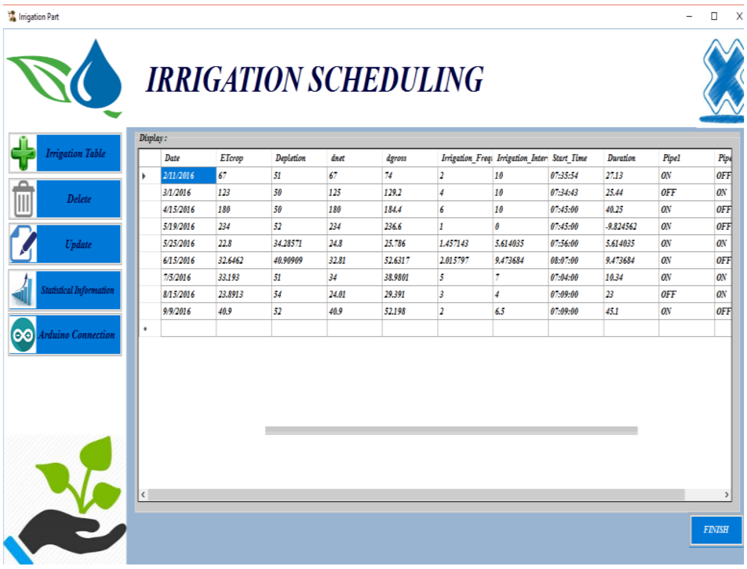

FIG. 17: THE IRRIGATION SCHEDULING TABLE.

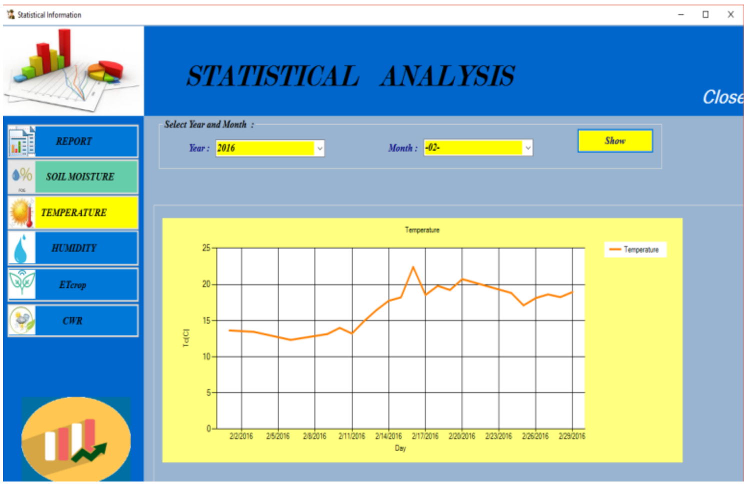

FIG. 18: STATISTICAL ANALYSIS OF TEMPERATURE (TC).

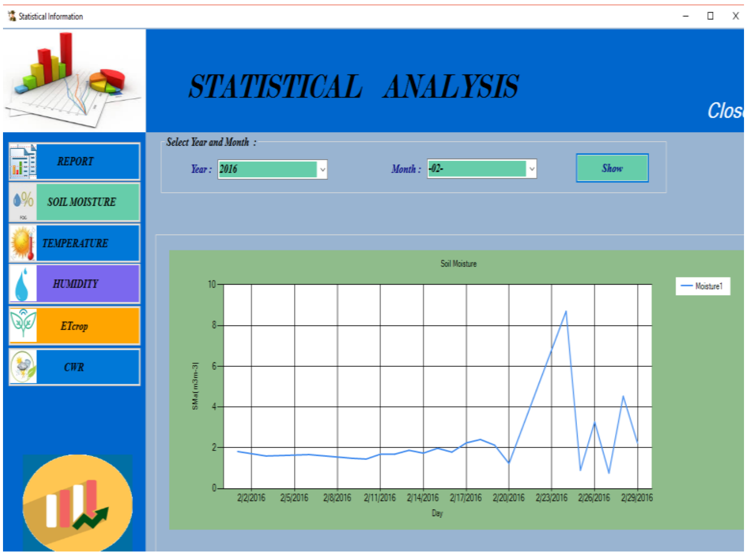

FIG. 19: STATISTICAL ANALYSIS OF SOIL MOISTURE (SM).

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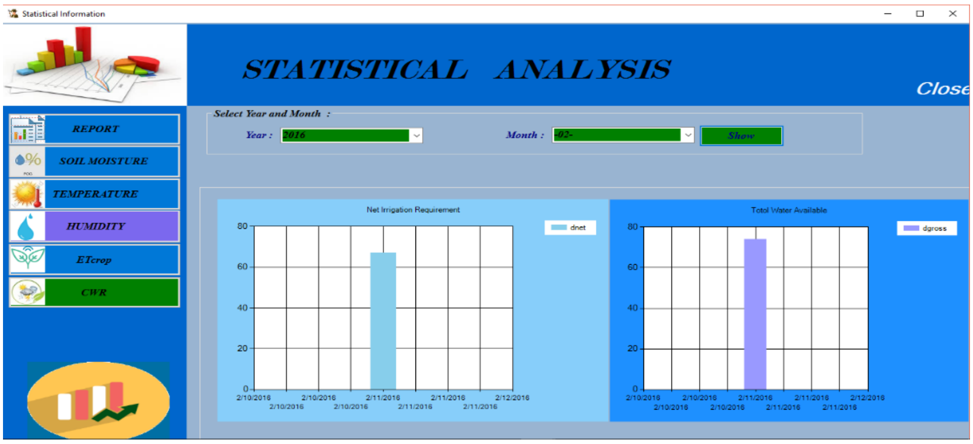

FIG. 20: STATISTICAL ANALYSIS OF WATER AVAILABLE (DENT, DGROSS)

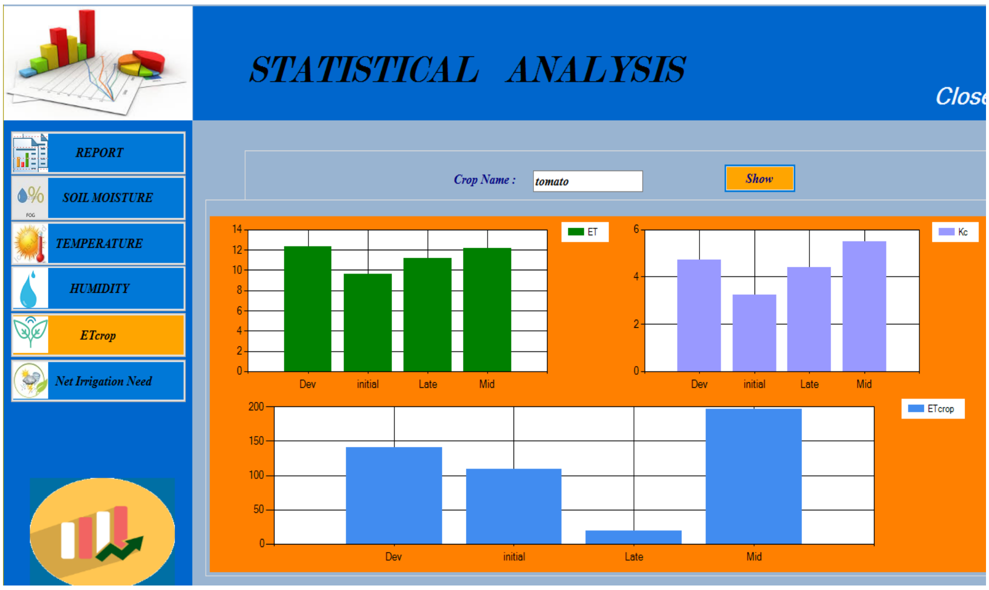

FIG. 21: STATISTICAL ANALYSIS OF CROP WATER REQUIREMENT DURING ALL GROWTH STAGE OF TOMATO PLANT.

VIII. CONCLUSIONS

A Drip auto-irrigation system based on sensor network has been introduced. This system changed the hard irrigation process to more flexible and result in water and time conserving. The farmer can begin irrigation process based on received sensor data without the need to visually see plant and based on its appearance decide whether it needs to irrigate. Physically, the proposed system consists of two main parts: Hardware equipment and control center. Hardware part is composed of Arduino Uno, soil moisture, temperature and humidity (DHT11) sensors, Bluetooth HC-06 and water pump which are located in the farm.

Control center included the server that involved the database structure and the GUI design. The main objective of the proposed system was producing the irrigation scheduling table for a specific plant with full control mission on the pumps of water used in drip method. Additionally, the real-time monitoring of the irrigation was continued all the time to tackle any accident problem. The used software consisted of Microsoft VS C# that is used for designing the GUI of the system and SQL server 2015 for database building. The presented system was tested by taking a prototype hardware model with the information of Tomato crop. The obtained results showed increased accuracy and efficiency of the system.

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