Experimental Investigation Of Remote Control Via Android Smart Phone Of Arduino-Based Automated Irrigation System Using Moisture Sensor

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***Abstract*—Climate change because of the greenhouse effect has been authenticated. Fallouts like the 2015 Chennai floods suggest techniques like precision agriculture that includes automation in the irrigation system are important. This paper suggests an economical and easy-to-use arduino-based automated irrigation system that utilizes the Android smart phone for remote control. The system design includes a soil moisture sensor that provides a voltage signal proportional to the moisture content in the soil which is compared with a predetermined threshold value obtained by sampling of various soils and specific crops. The outcome of the comparison is that appropriate data are fed to the arduino uno processor. The arduino is linked wirelessly via the HC-05 module to an Android smart phone. The data received by the Android smart phone from the arduino is displayed on the User Interface (UI) (S2 terminal application). The UI in the Android smart phone allows the user easy remote control of the irrigation drive system that involves switching, on and off, of the drive motor by the arduino, wired to its controller, based on commands from the android smart phone. Studies conducted on a laboratory prototype suggest that the design is viable and can be easily adopted for real time application.**

***Keywords—** android smart phone; arduino; bluetooth; climate change; precision agriculture; sensor; soil moisture sensor*

I. Importance Of Eco-Friendly Technologies

The deterioration of the earth's environment may be attributed to either overexploitation of the natural resources and adoption of technologies that produce non-biodegradable waste or release toxic material. The former includes indiscriminate combustion of fossil fuels including coal and petroleum products which releases greenhouse gases at a rate that is beyond the replenishable ability of the planet while the latter includes use of plastics, emission of radioactive radiation, embedding of metal in the earth's surface due to minelaying that cause irreversible pollution.

The contamination of air, water and other fundamental component elements of the earth's ecosystem has the potential to alter the balance of nature in a negative manner. For instance, the atmosphere comprises in terms of percentage by volume, approximately 78.08% nitrogen, 21% oxygen, 0.036% carbon dioxide and other gas components account for less than 1%. The most important life sustaining chemical reaction is photosynthesis that not only is the provider at the base of the food chain but also plays a pivotal role in the upkeep of the carbon dioxide content in the atmosphere.

The process by which the radiatively active gases in a planet's atmosphere, referred to as greenhouse gases, that have the characteristic to absorb and emit radiation within the infrared range, warm a planet's surface beyond the temperature that would have been existent in the complete absence of its atmosphere is known as the greenhouse effect [1]. The greenhouse gases predominant in the Earth's atmosphere include methane, nitrous oxide, ozone, water vapour and carbon dioxide. The last two are an offshoot of the water and carbon cycles respectively. The Earth reflects about 30% of the incoming solar radiation and the greenhouse gases trap this reflected radiation and dissipate it in all directions and the portion of it directed towards the Earth's surface contributes to its warming. The Earth's natural greenhouse effect is critical for maintaining a balanced heating cycle that is essential for survival of life. The intensity of the Earth's natural greenhouse effect is increased because of the tampering with the carbon cycle on account of human activity that not only enhance the carbon dioxide levels by burning fossil fuels but also lowering of the natural sinks by deforestation and rapid urbanisation. Anthropogenic activities have caused a 40% increase in the atmospheric concentration of carbondioxide since the industrial revolution in 1750. The concentration was 400ppm in 2015 compared to the 280ppm in 1750 [2]. There is a definite correlation that has been irrefutably established between increasing levels of greenhouse gases particularly carbon dioxide and rise in global temperatures. Global warming is thus, related to excessive carbon emissivity that disrupts the carbon cycle as corresponding sinks are not created. It impacts the water cycle too. These imbalances in the carbon and water cycles cause global warming and climate change.

II. Global Warming: The Indian Perspective

In 2014, India was the third largest carbon dioxide injecting country, accounting for 7% of the total global greenhouse emissions behind China and USA who accounted for 25% and 15% respectively. The current carbon dioxide emission by

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India, in Billion Tonnes (BT), is 1.5 BT which is expected to rise to 5.5 BT in 2020 with a projected cut of 13% to 18% in emissions.

A. *Torrential Rains in Chennai, Tamilnadu, India*

Chennai is the fourth largest metropolitan city of India and is the capital of Tamilnadu, one of the four states located in peninsular India. The city gets almost all its rainfall from the north-east monsoon in the months of November and December. As per the meteorological records, the wettest month ever endured by Chennai was in November 1918 when it received 1088.4 mm of rainfall and other substantial downpours were of 970 mm in November 1985 and 1077.1 mm in October 1985. In 2015, Chennai was lashed by torrential rains that were marked by uncharacteristic sporadic spells of very high intensity. The weather station in Meenambakkam, where the Chennai international airport is located had already recorded 1144.8 mm by 24th November 2015. A single day's torrential rain, on 23rd November 2015, was recorded to be 93 mm in the city. However, Chennai actually recorded 1049.3 mm rainfall in November 2015, thus making it one of the wettest months in a century for the pounded city and its beleaguered inhabitants whose only solace was that the unprecedented deluge had belied the expectations of meteorologists who speculated that it might surpass its all-time record of rainfall.

Heavy rains continued to batter the coastal districts of Tamilnadu in early December 2015 and Chennai specifically on the 1st and 2nd. The rainfalls were attributed by the Regional Meteorological Centre to two low weather systems comprising two low pressure troughs over Bay of Bengal near South Andaman Sea and Sri Lanka coast that moved and lay over southwest Bay of Bengal. The earlier maximum rain fall recorded on a single day in Chennai in December was in 1901. This was exceeded in the 24 hour period from 8.30 a.m. on 1st December 2015 when rainfalls of 294 mm in the city and 490 mm in Tambaram, one of its prominent localities, were recorded. The intense rains that lashed the catchment areas of the Chembarambakkam lake, a major water storage facility for the city, had an unparalleled ferocity of 250 mm between 8.30 a.m. and 5.30 a.m. on 1st December 2015.

B. *Fallout of the Chennai Rains*

The record rainfalls in November-December 2015 that assaulted Chennai resulted in virtual paralysis of large areas in the city. Several areas were heavily water-logged, roads were flooded, streets and highways became rapidly flowing rivulets and all forms of transportation including road, rail, and air were indefinitely suspended. At many places in the vicinity and within the city the inter-city and the suburban train services respectively were suspended for days because floods washed away the ballast below the tracks. For the first time, since its establishment, the Chennai international airport was closed to commercial flights from 2nd December 2015 till 8 December 2015. Not only was the city's landscape turned to an macabre spectacle marked by tree falls, waterlogging, sewage overflow, overflowing of its waterways etc. but also its infrastructural amenities snapped that manifested as inundation of hundreds of thousands of homes, submersion and, hence, shutdown of bridges across rivers in spate, sustained electricity interruptions for several hours and even days in many areas, disruption of telephone networks, non-deliverance of essential supplies including milk, liquefied petroleum gas (LPG) cylinders, vegetables and fruits. Water from Chembarambakkam reservoir was discharged at the rate of 20,000 cubic feet per second into the Adyar river resulting in the shutdown of the Kotturpuram bridge near Adyar and Maraimalai Adigal bridge at Saidapet because of inundation. On the railway bridge across the Adyar river, shifting of girders between Guindy and Saidapet, caused disruption in rail service. For the first time in its 137 year old history, The Hindu – founded in 1878, the third most circulated English newspaper in India, with a readership of 2.2 million people as per the Indian Readership Survey in 2012, which has its headquarters in Chennai, could not publish a print edition on 2nd December 2015 as employees were unable to reach its printing facility. In fact, all the statistics pertaining to the rains, information regarding damage and disruption, and the condition of people in Chennai and its suburbs, in this section, are based on reportings in The Hindu [3]. After the record downpour in November 2015, i.e. the first cycle of the monsoon rains, the Tamilnadu state government had assessed the loss as Rs.8,481 crore. The Associated Chambers of Commerce and Industry of India (Assocham) estimated the total financial loss due to the floods to be above Rs. 15,000 crore. Hundreds of thousands of marooned people were subjected to the rigours of the sudden, unexpected extreme monsoon weather conditions that included inaccessibility to fresh water, food, sanitation and medical facilities and any form of media apart from the frustration in not being able to even solicit emotional support from their family members, friends and well-wishers. In residential suburbs like Velachery, Tambaram and Mudichur in the south and Anna Nagar in the west people rescued fellow citizens from buildings with submerged ground floors and water rising to the first floors.

It is noteworthy that amidst the infrastructure devastation and personnel bedlam internet based social media viz. whatsapp, twitter, and facebook were the sole means of communication for the people of Chennai via smart phones until the batteries were active. In some limited areas the Government of India administered Bharat Sanchar Nigam Limited (BSNL), a telephone service providing company could provide connectivity via its wired network.

C. *Causes of the Chennai Rains/Floods*

The Environment Ministry of India, citing evaluation methodology used in India and the Inter-Governmental Panel on Climate Change (IPCC), has suggested, in the aftermath of the Chennai rains that in the later portion of the 21st century, the probability of severe rainfall based happenings occurring more often is rather high. It also categorically stated, whether it was global warming or local the state government was unprepared for the deluge, and the water bodies including reservoirs, lakes, ponds and rivers were not desilted and all governments including the present and the preceding ones allowed infringement on the banks and beds of the waterways which diminished their volume. The Ministry further noted that floods occur due to the hydrological response of heavy

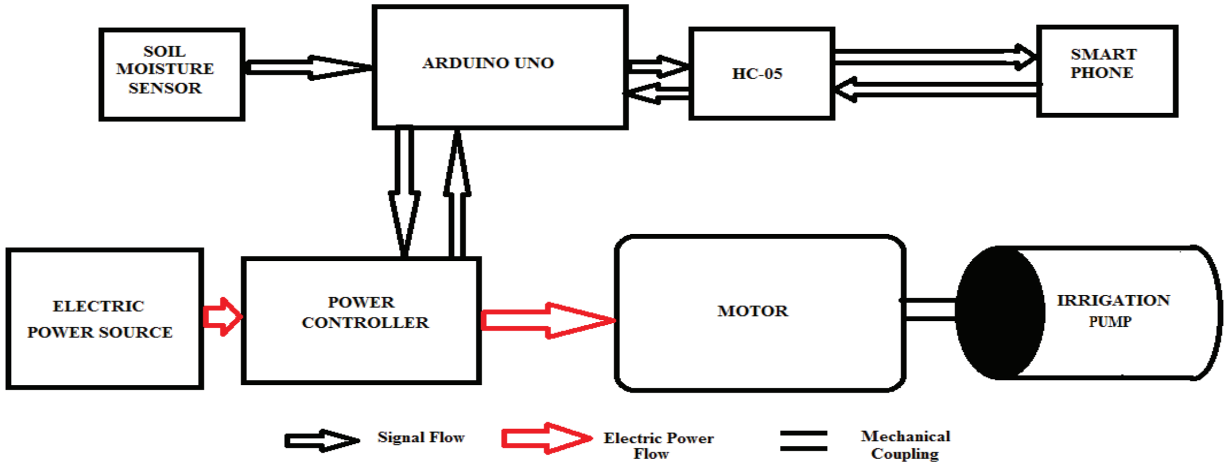


Fig. 1. Signal and power flow schematic of the automatic irrigation system.

rainfall and referred to "non-climatic reasons" for flooding in cities and industries located in high risk locations, particularly coastal and riverine areas. These reasons include lack of proper urban planning, demographic pressures, improper sewage disposal and drainage systems, and encroachment of land. It also stated, as per some reports, the rains and the excess water released from the dam at Chembarambakkam resulted in the flooding of the Adyar river, its banks and inundated its floodplain.

D. *Chennai Deluge at the UNCC 2015*

The 2015 United Nations Climate Change Conference, (UNCCC 2015) also referred to as 21st annual Conference of the Parties (COP 21) to the United Nations Framework Convention on Climate Change (UNFCCC), 1992 and the 11th Meeting of the Parties (CMP 11) to the Kyoto Protocol, 1997 was held in Paris, France, from 30 November to 12 December 2015 [4]. The record rainfalls and floods in Chennai during November- December 2015 were alluded to at the UNCCC 2015. Al Gore, Nobel laureate and former Vice President of the United State, US Secretary of State and the French foreign minister were among many world leaders who citing the Chennai floods urged for a global climate agreement to protect the world from such inclement weather conditions in future. While experts agreed that it is not possible to correlate discrete weather happenings to climate change, they also emphasized, disassociation of severe weather happenings like the one in Chennai from climate change is incorrect. According to the International Policy Manager for climate change at Action Aid based in New Delhi, India - "Climate change may not be directly responsible for flooding in Chennai but it has definitely contributed to it,"

III. PRECISION AGRICULTURE AND CLIMATE CHANGE

Agriculture when confined to raising of crops systematically combines the advantages of not only adopting an eco-friendly strategy to obtain food but also of seasonal afforestation. With quality and quantity of the various natural inputs including water, air, and soil, and; human intervention based ones like fertilizers, pesticides, weeding, digging etc. deteriorating because of pollution, limited availability, imprecision etc. the yield from a farmland could be well below its potential output. This not only results in wastage, losses and commercial viability but also loss of much required green cover needed desperately to combat global warming. It is important to recognize, the strategic management of the input resources involves their judicious use in terms of magnitude and timing to obtain optimum yields despite the vagaries of uncontrollable constraints such as weather conditions.

IV. AUTOMATED IRRIGATION SYSTEM

A key input to ensure optimum yield of a crop is the regulation of water at the various stages of its life cycle, referred to as irrigation. Precision agriculture [5]–[11] requires an irrigation mechanism that accurately regulates water commensurate with the specific growth stage of the crop and various concomitant parameters including soil moisture, ambient temperature, sunlight, humidity, etc. If such a mechanism has the ability to operate automatically, based on sensing of one or more parameters, with incorporation of remote control as well, then, it would be most useful, particularly when confronted with extreme weather conditions, for the agrarian community. During extreme weather conditions and natural calamities accessibility of the farms is an important issue and an automated irrigation system [12]-[15] capable of being remote controlled management can be very useful in disaster management and devastation control. The irrigation pumps in conjunction with the valve systems can be used to regulate water flow and the direction of flow. While the quantity of water is controlled by switching the irrigation pump motors the change in the directions of flow can be used for letting in water and draining the farm of flooding.

In this paper an arduino-based [16]-[19] irrigation system that operates automatically via signals provided by a soil moisture sensor and subject to remote control by an android [20]-[23] smart phone is proposed. The schematic of the system is shown in Fig. 1. The feasibility and performance of the proposed system is investigated experimentally on a prototype fabricated in the laboratory. The objective is to provide an implementable design of a relatively economical, simple and easy-to-use automated irrigation system that also

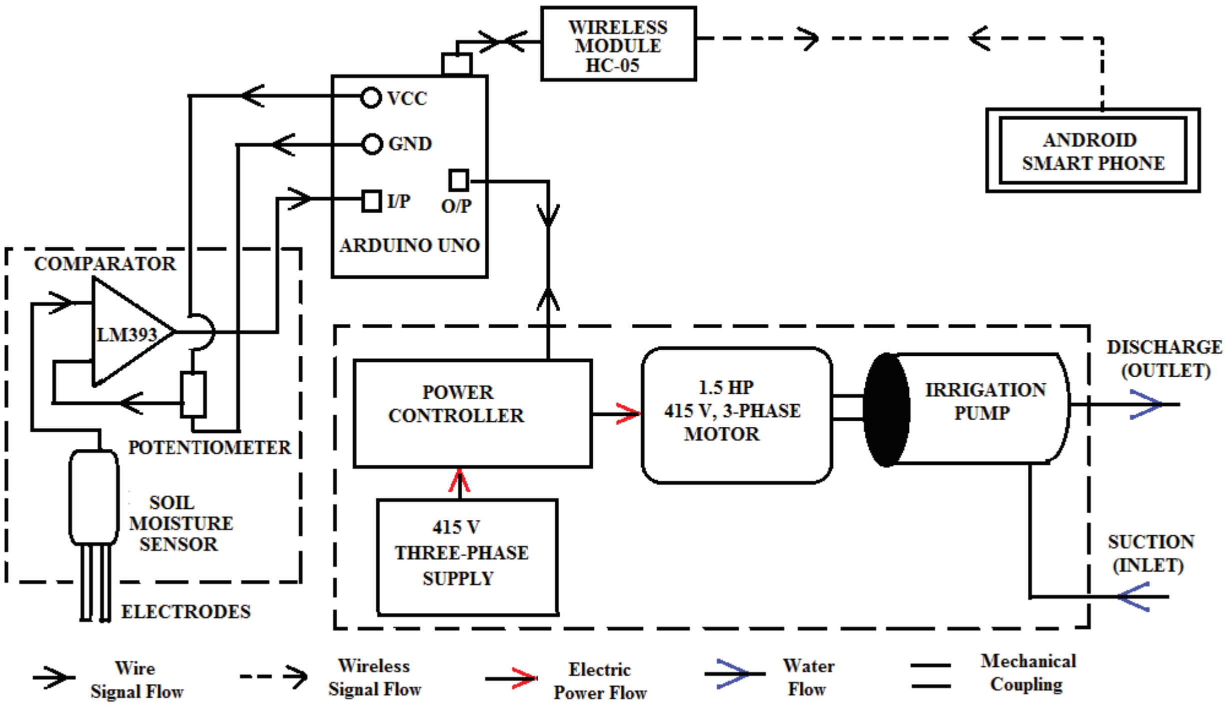


Fig. 2. Block diagram of the proposed automatic irrigation system depicting the communication, control, power and water systems.

has remote control.

With advancement in technology associated with sensors [24]-[27], sensor networking and wireless sensor networks (WSNs) [28]-[32] the routine activities are increasingly being taken over by automated systems [33]. This trend has made inroads in agriculture as well wherein several automated systems for irrigation purposes have been proposed. However, a majority of the existing systems are either expensive and require the user to be within the precincts of the farm to control the irrigation pumps or merely give an indication of water requirement. The proposed automatic irrigation system deploys the well-established combination of the android operating system and the Arduino Uno [34]-[40] that are compatible in terms of providing a wireless remote control. Fig. 2 depicts the various sub-systems and their interconnection that constitutes the automatic irrigation system. From the Fig. it is clear, the subsystems include the soil moisture sensor, Arduino Uno processor board, drive system that includes power controller, motor and irrigation pump, the bluetooth module HC-05 and Android smart phone.

A. *Automatic Arduino Uno Control System: Functioning*

The soil moisture sensor has a pair of probes that when inserted in the soil provide a voltage proportional to the soil moisture. This voltage is compared with an appropriate pre-set reference voltage, corresponding to the soil moisture threshold value, by an LM393 comparator inbuilt in the sensor. The reference voltage is precisely adjustable as per the requirement pertaining to a specific crop using a potentiometer that is ingrained in the sensor signal processing circuit. The analog output of the comparator is connected to one of the analog input ports of the Arduino Uno board that has an analog to digital converter (ADC) which converts this to a digital value in the 0 – 1024 range.

The Arduino Uno board is loaded with a program using the Arduino Integrated Development Environment (IDE) software that reads the input value and compares it with the threshold moisture level value corresponding to the crop. The threshold moisture level required for each crop should be obtained experimentally. If the value lies above the threshold value, it implies that the soil is dry and the motor has to be switched ON to activate the irrigation pump and hence, water the soil. Alternatively, for values below the threshold value, the moisture content of the soil is sufficient and need not be watered. Corresponding to the above logic, the Arduino Uno will output a “1” (HIGH) or a “0” (LOW) value respectively at the output pin.

The output pin of the Arduino board [5-6] is connected wirelessly to the smart phone via the HC-05 bluetooth chip. There is an application called S2 Terminal on the smart phone that displays the readings obtained from the HC-05. As soon as the communicate button on the Serial Terminal is pressed, the user (farmer) will be able to see 1’s or 0’s appearing on the screen at regular intervals, depending upon the time period specified in the code. These values indicate if the motor has to be switched ON or not. The farmer will be presented with the option of either turning the motor ON or not and the farmer has to respond by sending a “y” (yes) or “n” (no) response respectively. This response is then fed back to the Arduino board via the HC-05. The code loaded in the Arduino board then checks the response received from the smart phone. If the response is y (yes), it sends a HIGH (1) to an output pin that is connected to the power controller of the motor. On the other hand, if the input response is n (no) it sends a LOW (0) to the

TABLE I. MOISTURE CONTENT FOR VARIOUS CROPS

S.No	Crop	Moisture level (in %) For every 150g of soil sample
1	Sunflower	9.5%
2	Wheat	12%
3	Soybean	13%
4	Milo	13%
5	Rice	13.6%
6	Corn	15.5%
7	Maize	18-24%

output pin wired to the power controller. The power controller turns ON/OFF the motor based on the reading to water the plants.

The moisture content data required for optimum productivity for various crops for every 150g of soil sample level that have been obtained by experimental observation are shown in Table I. Similar experimental observation should be made and the potentiometer in the soil moisture sensor must be calibrated appropriately to set the threshold value for each crop. The threshold values must also be included in the code that is loaded into the Arduino board. The flowchart corresponding to the code loaded in the Arduino Uno board for comparison of the sensed and threshold values and initiates switching decisions is illustrated in Fig. 3.

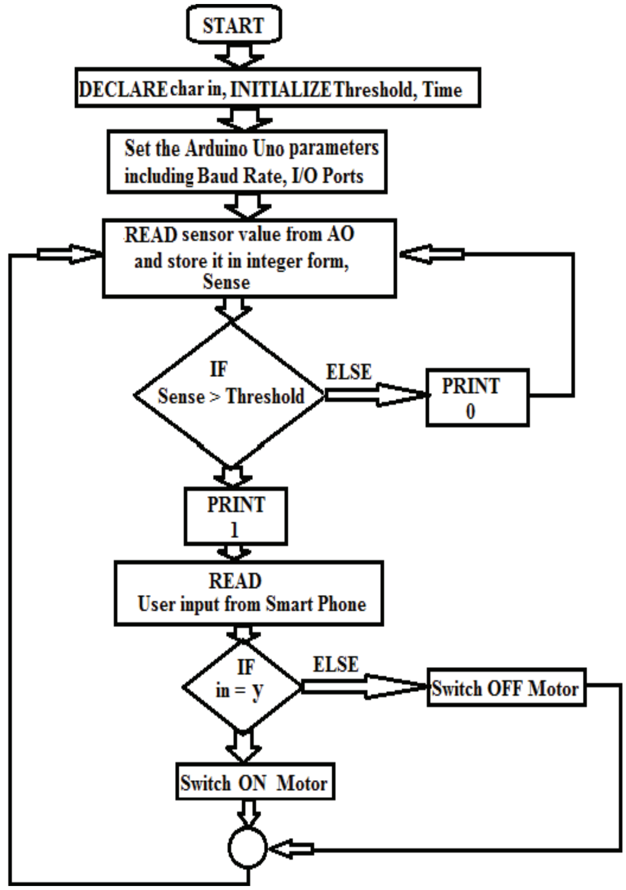


Fig. 3. Flowchart of arduino code.

B. Soil Moisture Sensor

The soil moisture sensor shown in Fig. 4 comprises sensing signal processing and display units. The sensing unit (SU) has two electrode probes S1 and S2 that provide an analog voltage proportional to the moisture content in the soil when inserted into the soil. The voltage delivered by the electrodes is the differential voltage between them that is related to the conductivity of the soil. The principle involved is simple, the conductivity of the soil is directly proportional to its moisture content. The differential voltage between the electrodes is the output of the sensing unit that is compared with the reference voltage, derived from an aptly calibrated potentiometer (R2), corresponding to the soil moisture threshold voltage. The comparison is done in the signal processing unit that includes the potentiometer (R2) and a LM393 chip. The chip is a package that comprises dual independent precision voltage comparators. The comparison of the voltages is done using one comparator (A) while the other (B) is kept as a backup in case of any contingency. The supply voltage (Vcc) and the ground for the sensor are obtained from the Arduino Uno board. The output of the sensing unit is is given to the non-

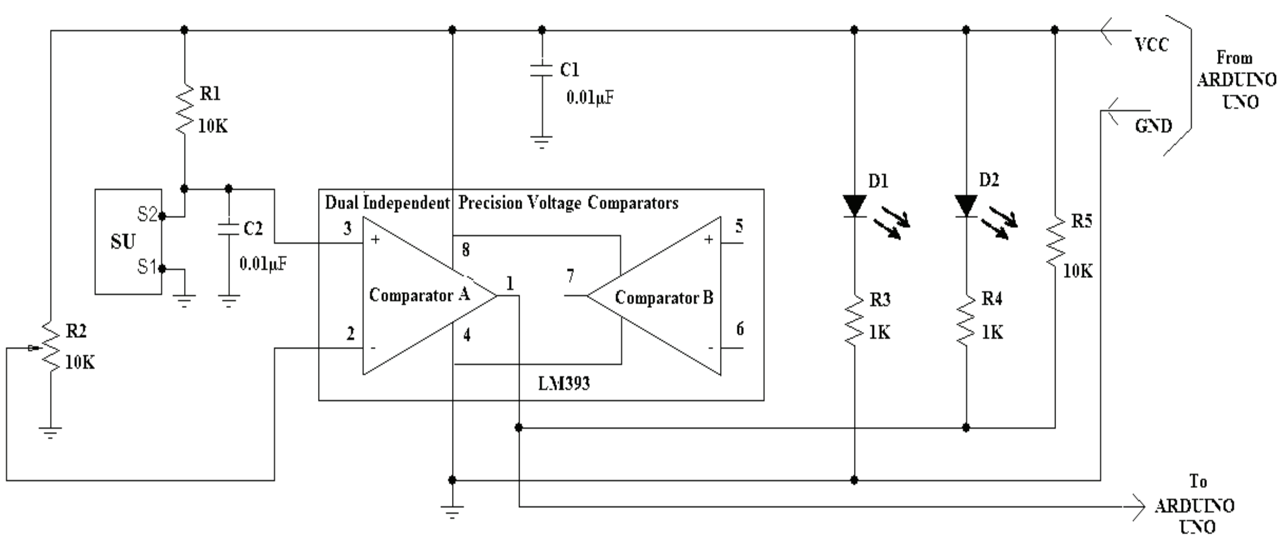


Fig. 4. Circuit diagram of the soil moisture sensor including its sensing, processing and display sub-systems, and, its interconnection with the Arduino Uno.

inverting input of comparator A (INA+), i.e. pin 3 while the inverting input of comparator A (INA-), i.e. pin 2 is connected to the threshold voltage signal delivered by the potentiometer. The output of comparator A (OUTA) i.e. pin 1 goes to the high state if the voltage at INA+ is greater than the threshold voltage derived from the potentiometer at INA-. On the other hand, if the voltage at INA+ is less than that at the INA- pin corresponding to the potentiometer derived threshold voltage then pin 1 (OUTA) goes to the low state. The high and low states of pin 1 (OUTA) correspond to $+V_{sat} \approx V_{cc}$ and zero respectively. The comparator logic can be summarized as:

$$\text{If (INA+)} > \text{(INA-) then OUTA} = +V_{sat} \approx V_{cc} \tag{1}$$

$$\text{If (INA+)} \leq \text{(INA-) then OUTA} = 0 \tag{2}$$

The display unit of the sensor comprises two light emitting diodes (LEDs) D1 and D2 and corresponding current limiting resistors R3 and R4 respectively. The series combinations of D1 and R1, and, D2 and R2, are connected across pins 8 (Vcc) and 4 (Ground, Gnd), and, pins 8 (Vcc) and 1 (OUTA), respectively. This clearly implies that LED D1 will always be glowing indicative of the availability of the supply voltage (Vcc) and effective ground (Gnd) both of which are obtained from the Arduino Uno board. On the other hand, LED D2 will glow when (2) is valid, indicative of low conductivity corresponding to low soil moisture level, thus, alerting the farmer about the need for the irrigation pump motor to be switched ON. If (1) is valid, suggestive of high conductivity and, therefore, high soil moisture content, LED D2 will not glow, thereby, revealing to the farmer that the motor needs to be kept in the OFF condition.

Capacitors C1 and C2 are used to filter out the high frequency noise at pins 8 (Vcc) and 3 (INA+) respectively of LM393. The output pin1 of comparator A (OUTA) is also connected to one of the input pins of the Arduino Uno to enable it to process the signal and initiate suitable action regarding the operation of the irrigation pump motor via the power controller after getting the response from the farmer through the smart phone.

V. Experimental Prototype

The feasibility and design of the proposed Arduino Uno-based automatic irrigation system with remote control using the Android smart phone was investigated and tested using a prototype fabricated in the laboratory. All the sub-systems indicated in Fig. 2 were actually used except for the irrigation drive system. Instead, a drive system, shown in Fig. 5, comprising a 9V dc supply derived from batteries, motor driver IC L293D, and a 9V, 80 rpm dc motor coupled to a fan was used. The L293D is a quadruple high-current half-H driver designed to provide bidirectional currents of up to 600mA in the voltage range 4.5V to 36V. Each drive is a totem pole output. The drivers are enabled in pairs with drivers 1 and 2 enabled by 1,2EN i.e. pin 1 and drivers 3 and 4 enabled by 3,4EN i.e pin 9. When an enable input is high, the corresponding drivers are enabled and provide active outputs that are in phase with their inputs. Alternatively, when the enable input is low, those drivers are disabled and their outputs are deactivated and in the high-impedance state. With the appropriate data inputs each of the two pairs of drivers 1and 2, and, 3 and 4 can be used as an H-bridge reversible drive. The data associated with use of the driver pair 1and 2 that involves input data to the pins 1,2EN (pin1), 1A (pin2), and 2A (pin7) in the L293D from the Arduino Uno and the corresponding data at the output pins 1Y (pin 3) and 2Y (pin 6) that determine the bidirectional operation of the motor are shown in Table II. In the table, H=high level, L=low level, X=irrelevant and Z=high impedance (off). The high and low levels correspond to 5V and

TABLE II. Bidirectional Dc Motor Control

1,2 EN	1A	2A	1Y	2Y	Operation Of Motor(M)
H	H	L	H	L	Forward motion
H	L	H	L	H	Reverse motion
H	H	H	H	H	Quick stop
H	L	L	L	L	Quick stop
L	X	X	Z	Z	Free-running stop

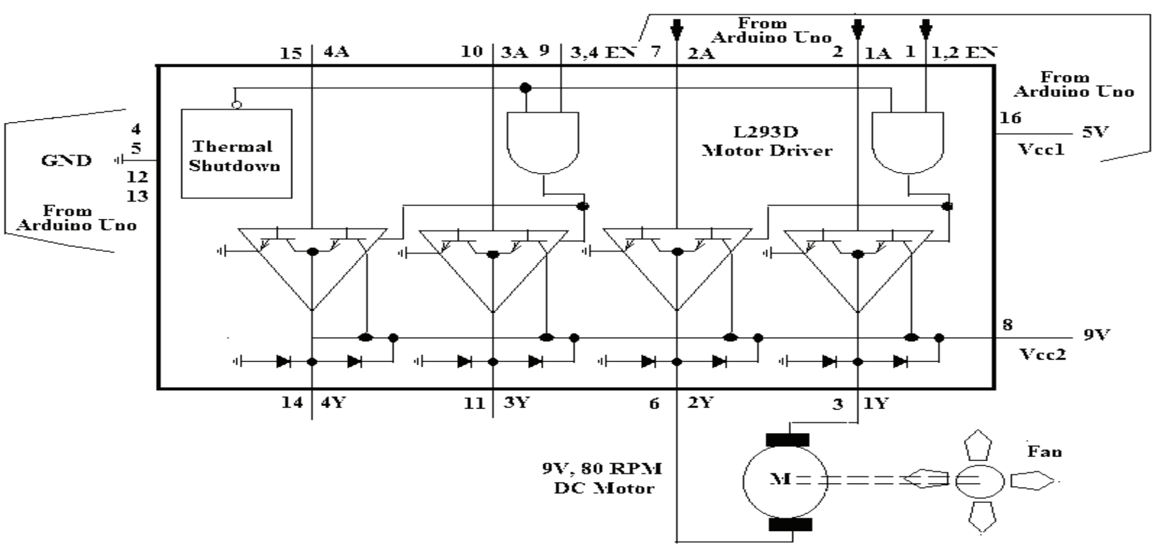


Fig. 5. Circuit diagram of the drive system comprising the L293D motor driver, dc motor and fan load used in the prototype.

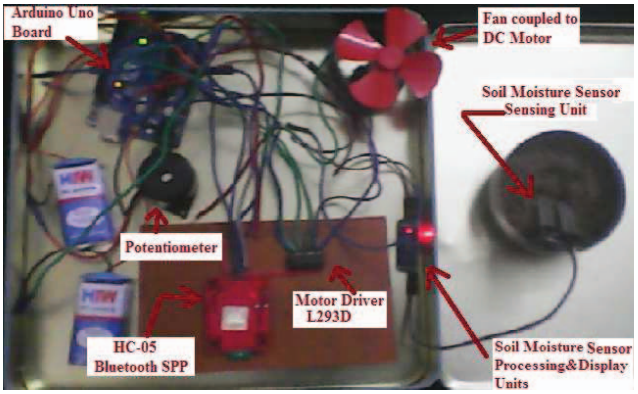
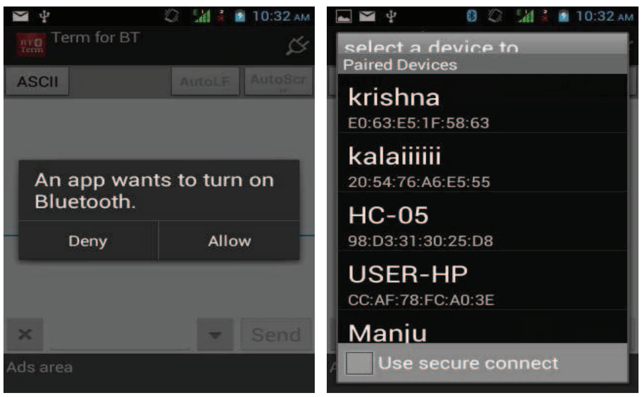
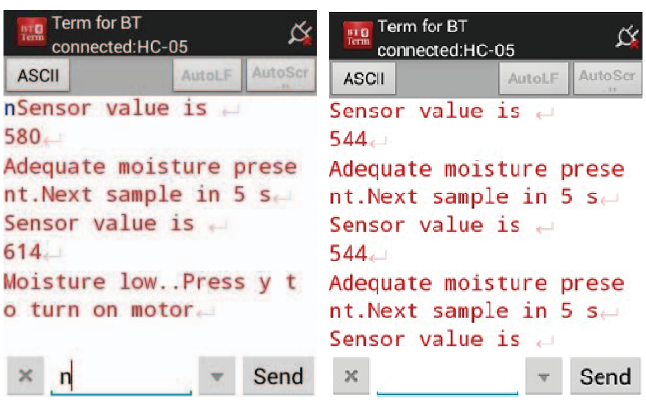


Fig. 6. Experimental set up of the Arduino Uno based automatic drive.



(a) (b)

Fig. 7. Screen shots of the S2 application in the Android smart phone.



(a) (b)

Fig. 8. Display of soil moisture data based logic on the smart phone screen.

0V respectively. It is noteworthy, in the L293D driver, shown in Fig. 5, the 5V at Vcc1 (pin 16) that activates the internal logic and the ground at pins 4, 5, 12, and 13 are derived from the Arduino Uno board. Also, the other driver pair that is not connected can be used in the case of any problem with the driver pair 1 and 2.The experimental set up is shown in Fig. 6.

S2 Bluetooth Terminal, an IDE for Android Applications is used for developing an Android UI (user interface) application, for ease of communication, in the smart phone. This application is the terminal software for communicating with HC-05 - the Bluetooth device [1-4] using SPP(RFCOMM). The application detects the HC-05 chip, displays the device details and asks the user permission to begin communication. These are indicated in Fig. 7. The soil moisture data is retrieved and displayed on the smart phone screen. Depending upon the moisture value the user decides to switch the motor ON or OFF. The screenshots of S2 terminal are illustrated in Fig. 8. In Fig. 8(a) the screen shot of the Android smart phone shows the message derived from the data transmitted by Arduino Uno via the HC-05 for the condition corresponding to (2) i.e. low moisture level and prompting the farmer to respond with a 'y' to switch ON the motor. Fig. 8(b) shows the screen shot of the smart phone corresponding to (1) i.e. adequate moisture level. In both the screen shots it is clear that the sampling of the values is done every 5 seconds in the case of the prototype. The duration of sampling can be varied. The real-time sampling rate can be set at 5 to 10 hours. The threshold and the duration for which the motor should be kept on can be set by the user itself.

VI. Conclusion

The greenhouse effect is a reality that necessitates precision agriculture which includes an automated irrigation system. An Arduino-based automated irrigation system that involves switching the irrigation drive as per the real time data provided by a soil moisture sensor has been proposed. The system was tested with various soil samples and crops for calibration at different moisture levels. A user interface was deployed on an Android smart phone to accomplish wireless communication between the phone and the Arduino Uno board to facilitate remote control operation of the irrigation drive. The automation and wireless communication controls that switch the drive have been successfully tested on a laboratory prototype. With some improvisations the proposed system can be used in the real time precision agriculture application.

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