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Sensor Based Irrigation Scheduling System for Efficient Water Resource Utilization

Muhammad Umar Farooq
Department of Computer Science
Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan
Email: umarf8620@gmail.com

Ayesha Hakim (Corresponding Author)
Department of Computer Science
Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan
Email: ayesha.hakim@mnsuam.edu.pk

Nasir Nadeem
Department of Agribusiness & Applied Economics
Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan
Email: nasir.nadeem@mnsuam.edu.pk

Abstract:

Agricultural Sector in Pakistan is confronted with the major challenge of significantly increasing crop productivity to feed a fast-growing population. Decreasing availability and quality of natural resources is adversely affecting crop productivity in the short and long run. Pakistan is facing a severe shortage of water, making the country the fourth most water-stressed country in the world. Providing right amount of water at right time to any crop is important for the development of that crop. This is possible by intervening technology and automating the irrigation systems to be adopted to specific crop needs. The manual irrigation system leads to wastage of water and damaging of the crops due to uninformed watering, while commercially available smart irrigation systems are too expensive to be afforded by farmers. To overcome these problem, a low-cost smart crop monitoring and irrigation system is proposed based on IoT and mobile application. The primary aim of this project is the prevention of crop from spoilage during rain and reduce water wasting in irrigation process. Additionally, the system generates alarm to detect potential hazard into the farm. The operations have been performed using wireless sensor network technology with solar photovoltaic system, GSM module, Bluetooth, and sensors that are connected to the microcontroller. All experiments have been conducted in Multan, Pakistan during the year 2020-2021. By using this system, farmers will be able to improve crop productivity by controlling the water flow, monitoring the growth of crop, and securing the crops from potential hazards using mobile application.

Keywords: Internet of things, Smart Irrigation, Precision Agriculture, Solar Photovoltaic Cell, Mobile Application

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I. Introduction

Agriculture is considered as the foundation of life for the human as it is the main source of food grains and other raw materials. It plays a vital role in economic growth of Pakistan by contributing around 24% of Gross Domestic Product (GDP) and is the main source of income for most of the rural population. The agricultural sector in Pakistan is confronted with the major challenge of significantly increasing crop productivity to feed a fast-growing population. Decreasing availability and quality of natural resources is adversely affecting crop productivity in the short and long run. Pakistan is facing a severe shortage of water, making the country the fourth most water-stressed country in the world. A report released by the International Monetary Fund (IMF) placed Pakistan third in the world that is facing water scarcity (Team, 2015). According to Pakistan Council of Research in Water Resources (PCRWR), surface water availability has fallen below 1000 cubic centimetres per capita and is expected to decrease further (PCRWR, 2020). Researchers estimate that by 2040 Pakistan will face the most water scarcity in South East Asia. The bulk of farm land in Pakistan is irrigated through a canal system, but water is available in canal system only quarter of the year, due to lack of storage dams. One of the biggest problems in irrigation system of Pakistan is wastage of water that is worsening the shortage of water. In traditional irrigation system, most of the water is lost due to free irrigation. In such cases, efficient water use in agriculture is much needed, which consumes 96% of the surface water. This is only possible by intervening in technology and automating the irrigation systems to be adopted to specific crop needs.

Agriculture of Pakistan mostly relies on monsoons rains and therefore agriculture production is based on the trend of monsoons. Unfortunately, in Pakistan rain fall is unpredictable especially due to climate change (Alam, F. *et al.*, 2021). More than 75% of total rain fall occurs in four months between June and October (Peña-Arancibia, J. L. *et al.*,2021). On the basis of this, proper planning is needed to save water for remaining eight months. Plants need water for their survival, but in ordinary cases, plants are either under-irrigated or over-irrigated. This paper proposes a low-cost smart solution for irrigation according to the plants' need, which will save the water and have sound effects on plants' health and yield. The concept is "more crop per drop" ensuring food security.

The proposed smart crop monitoring and irrigation system is feasible and cost-effective in improving yields of crops and water resources for agricultural production. This irrigation system allows plants to be planted in water-scarce areas, thereby improving disaster resilience. In order to get the best quality out of this study, it is necessary to highlight some important features, such as proper power consumption, water supply, and proper system of irrigation of crops amid of existing problems of climate variability, water shortage, limited cultivable area, low per acer yield.

The study is focused on research and development of smart crop monitoring and automatic irrigation system that can be controlled by mobile application. The system will reduce the number of labourers in the fields, control water supply and electricity properly and effectively, use small amount of water to increase agricultural production, reduce manual intervention in irrigation operations, and at the same time increase the irrigation rate and protect plants from fungi. The system has an additional feature to protect crop from potential hazards such as intruders attach or fire to ensure farm security. All these characteristics make this study a sustainable option for improving agriculture and irrigation efficiency.

The electronical components of the system are powered by solar-charged battery to ensure cost-effective solution for real-time monitoring in geographically isolated agricultural fields. The low-cost smart crop monitoring and irrigation system is based on Bluetooth, GSM and Wiles network technologies. The system is robust, efficient, simple to use, and affordable to local farmers enabling them to remotely monitor the field and take informed decisions by using real time information provided through the mobile application.

II. Literature Review

The concept of precision agriculture (PA) was originated in developed countries such as the Canada, United States, and most Western and European countries in the 1980s. Precision farming is an application technology and principles for managing local and temporal changes related to all aspects of agricultural systems for improving crop production and environmental parameter quality. Over the last thirty years, it has not only matured, but has spread throughout the world due to its positive impact on agriculture development (Zhang, N. *et al.,* 2002). The combination of technology and farmer's experience brings various advantages, including improved crop health (RUMPF T. *et al.*, 2010), water management, and food security (Kaloxylos A. *et al.*, 2013). (Kumawat, S. *et al.*, 2017) proposed a system in which different image processing techniques are used to control irrigation by capturing an image and transfer to server using GSM technology. The proposed system tested the pH value, and type of soil using microcontroller, temperature, humidity, soil moisture sensors with solar photovoltaic system (SPV), and portable water tank. The system presented in this work contributes to energy and water saving and claims to ensure uniform irrigation of plants without manual intervention (Kumar, S. *et al.*, 2017).

A smart micro-irrigation system was developed in (Akter, S, *et al.,* 2018) that consists of Arduino UNO, soil moister sensor, motor (12V) relay diode, and battery. The systems gather information from soil moisture sensors and irrigate the land accordingly to prevent over-irrigation and inadequate irrigation. The system was designed for irrigation and flood management and was evaluated on sandy and clay soil that shows significant water conservation. (Kansara, K. *et al.*, 2015) proposed an IoT-sensors based automated irrigation system to generate alert when the water level is below or above an already defined level. Similarly, (Suman, S. *et al.,* 2017) proposed a solar powered automated irrigation control system based on soil moisture content. (Chikankar, P. B. *et al.*, 2015) used ZigBee technology in wireless sensor networks to monitor controllable parameters such as temperature, soil moisture and air humidity. More recently, (Munir *et al.*, 2021) proposed an intelligent and smart irrigation system that makes decision based on semantic data modelling and sensor-based information. The semantic model estimates crop type, level of water required for the crop, and soil type; it then controls the irrigation system based on real-time sensors reading.

Most of the existing systems mentioned in the literature are experimental studies that lack field testing and therefore not practically available at commercial scale to be used by local farmers. Those that are commercially available are too expensive to be afforded even by progressive farmers in the developing courtiers like Pakistan and India.

There is a dire need to develop a low cost workable smart irrigation system that is capable of sustainably utilizing water resources. The proposed smart system is based on sensing the variability of soil moisture along with relevant environmental factors to improve water productivity. It will help in reducing the labour and energy cost.

III. Materials and Methods

A. Software Requirements

Proteus (8.0) is a simulation program for circuit designs of microcontrollers. It has almost all microcontrollers and electronic components that makes this software widely used for simulation of project hardware. It is used to test software and embedded designs before actual hardware project testing equipment. Proteus can simulate microcontroller programming that avoids the risk of hardware damage due to improper design (PROTEUS. 2017).

EasyPC: After designing circuit diagram the next step is to design printed circuit board (PCB) of the circuit. In this project we use EasyPC software for (PCB) designing purpose. EasyPC is a schematic and PCB design system software. The system is built an integrated design environment provides all the tools needed for schematic and capture. Duplicate it by design and layout, with space-based analogue / digital simulator (EASYPC. 2021).

Arduino IDE: Arduino Integrated Development Environment or Arduino Software (IDE) is an open-source plat form that makes it easy to write code and upload on board. It consists of a content manager for composing code, a text console, a message zone, and a toolbar with buttons for general functionality and different numerous menus. All coding of the proposed system is done in Arduino IDE Platform in C language (Fezari and Al Dahoud, 2018).

B. Hardware Requirements

The hardware requirements of the proposed system include microcontroller Arduino unoATmega328P, Soil moisture and water level sensor, LDR sensor, Passive infrared sensor (PIR), Temperature sensor LM35, Rain sensor, Humidity sensor (DHT11), Gas and Smoke sensor, LCD display, LEDs, RC filter circuit, Power supply, Diode (IN4007), Voltage buzzers, Regulator (7805), Oscillator, Solar panel, and Batteries.

C. Blocks of the Proposed System

The proposed system consists of six functional blocks: Power Supply Block, Main block, Acquisition block, Monitoring block, Automatic Functional block, and Communication block.

Power Supply Block

This block consists of photo voltaic cell (PVC), charging batteries, adapter, potential transformer, filter capacitor, resistance and bridge. The main purpose of that block is to provide continuous supply of power to all others blocks. The main function of the power supply is to convert the load from the current source to energy with the appropriate voltage, current and frequency. In the proposed system we need a regulator to ensure exactly 12 volts of continuous power supply to the system.

Main Block

This block consists of variable resistances, NPN transistor 80945, LEDs and Arduino-UNO microcontroller which is a main hardware of this project as shown in Fig. 2. The developed board is equipped with digital and analog I/O pin groups, which are connected to various expansion boards (shield) and other circuits. The board contains 14 digital I/O pins (six PWM enable outputs) and 6 analog I/O pins, which are combined with IDE (Integrated Development Environment) and USB as shown in Figure 2. It can be powered by a USB cable or a 9-volt external battery, although it can accept voltages between 7 and 20 volts. The main block controls all components of the system. All sensors, communication module, monitoring block and relay pump are directly connected with the main board. Arduino-UNO microcontroller is one of the main components that receives information from different sensors and processes this information according to the requirements coded in the microcontroller.

Acquisition Block

This block consists of different sensors (temperature, humidity, rain, water level, PIR, soil moisture and gas sensor). Acquisition is a process of measuring physical and electrical phenomenon like voltage, current, temperature, pressure, sound with microcontroller. Sensors sense the environmental parameters and send the signals to microcontroller for further processing. Microcontroller takes directions according to the information that is provided by sensors from environment. This block consists of soil hygrometer (moisture) sensor (FC-28), light dependent resister (LDR) sensor, passive infrared sensor (PIR), temperature sensor (LM35), rain sensor, humidity sensor (DHT1), gas and smoke (MQ2) sensor.

Soil Hygrometer (moisture) sensor (FC-28)

It detects the level of moisture in the soil. This makes them ideal for experiment in the fields such as agricultural science, soil science, horticulture, environmental science, biology and botany. The soil moisture sensor contains two electrodes that are dipped into the soil that detects the level of moisture around when the current flows from one electrode to the other electrode. The current flows through the soil to the electrode and the resistance in the soil determines the soil moisture.

Temperature sensor (DS18B20)

Temperature sensor measures the amount of thermal or cold energy that a source produces. We use a resistive temperature detector that gives an exact value for our experiments. The DS18B20 series sensors are precision temperature sensors on integrated circuits. Output voltage of temperature sensor is proportional to the procession of temperature Celsius (Co). Range of DS18B20 sensor is -55 to +55 Co.

Humidity sensor (DHT11)

In the proposed system we are using humidity DHT11 sensor. It is humidity and temperature sensor that gives the calibrate digital output. DHT11 is a low-cost sensor that measures the temperature and humidity from air and provide high reliability and long-term stability. Operating voltage of humidity sensor is 3.5v to 5.0v with a range of 20% to 90%.

Rain Sensor

Rain sensor is a simple switching tool to detect rain. It can be used as a switching button when the rain falls on its surface. It is also used to measure the intensity of rain. The rain sensor is made of nickel-plated strips and works on the principle of resistance. Operating voltage of rain sensor is 5V and size of PCB 5 cm × 4 cm nickel plate on side.

LDR Sensor

LDR sensor is used to detect the presence of light and also measures the intensity of light. The output power of the LDR sensor increases in the presence of light and decreases in the absence of light. Signal detection sensitivity can be adjusted using a potentiometer. LDR is also less sensitive than LEDs and transistors. Operating voltage of LDR sensor is 3.5v to 5.0v and size of PCB is 1.6cm to 3.0 cm.

PIR Sensor

A Passive Infrared Sensor (PIR) is an electronic sensor that measures Infrared Radiation (IR) that separates itself from objects in its field of view. IR sensors are commonly used in burglar alarms and automatic lighting systems. It is also used in physical imposter detection in agriculture field. In this project we are using PIR sensor for detection of animals and physical imposters that may destroy the crops. Using the readings of PIR sensor, the farmer would be alerted if there is any imposter in the field. Range of PIR sensor is 20 to 30 feet with detection range of 360-degree conical angel. Its operating voltage is 3.5v to 5.0v.

Gas and Smoke sensor (MQ2)

The MQ2 gas sensor is an electronic sensor that can measure the gas concentration in the air, such as liquefied petroleum gas, hydrogen, methane, propane, alcohol, flue gas and carbon monoxide smoke. It is metal oxide semiconductor sensor. The gas concentration is measured using a voltage separator network situated in the sensor. It is also used in air quality controls. The smoke sensor is a fire protection device that can automatically detect smoke and issues a warning to the farmer in case of fire in the field. Sensor works on 5v DC. The range of gas detection is concentration of 200 to 10,000 ppm.

Monitoring block

Monitoring block consist of 16cm x 2cm LCD screen unit. It is very simple and commonly used in different devices and circuits. LCD screens are economical and easy to program. It shows the values of sensors and display the pump status.

Automatic Functional block (AFB)

This block includes the automatic watering function of the system. The automatic function consists of four main control units namely relay unit, solenoid valve, buzzer and DC irrigation pump. The relay is an automatic electrical control switch that uses an electromagnet to open or close the switch pump that always works under the supervision of relay. When the humidity, soil moisture content is lower from threshold level, Arduino send signal to relay to open solenoid valve unit and pump automatically. Once the system detects that there is enough water in the soil, the relay will close the pump and solenoid valve.

Second component of AFB is solenoid valve. It is an electric control valve used to regulate flow of water. Third component of block is water pump. We are using 12 volts DC Pump for watering purpose. Fourth component of the block is Buzzer. We are using sensor buzzer that is like a passive buzzer, also known as magnetic speaker. Passive buzzer operates on different frequencies and generate sounds according to the frequency which is passing that time. The pitch of buzzer becomes louder when the frequency is high. We are using buzzer for imposter and fire detection. When any animal enter in the field PIR sensor detects the imposter and opens the buzzer which is a sign for farmer that someone enter in the field and destroy the crop. The alert will also be generated through mobile application. In case of fire, gas sensor sends the signals and buzzer will open for quick alarm. The alert will be sent to farmer through mobile application. Automatic functional block of proposed system.

Communication block

Communication block consists of Bluetooth module (HC-05) and Global system for Mobile (GSM) to transfer data from micro controller to farmer cell phone through mobile application graphical user interface.

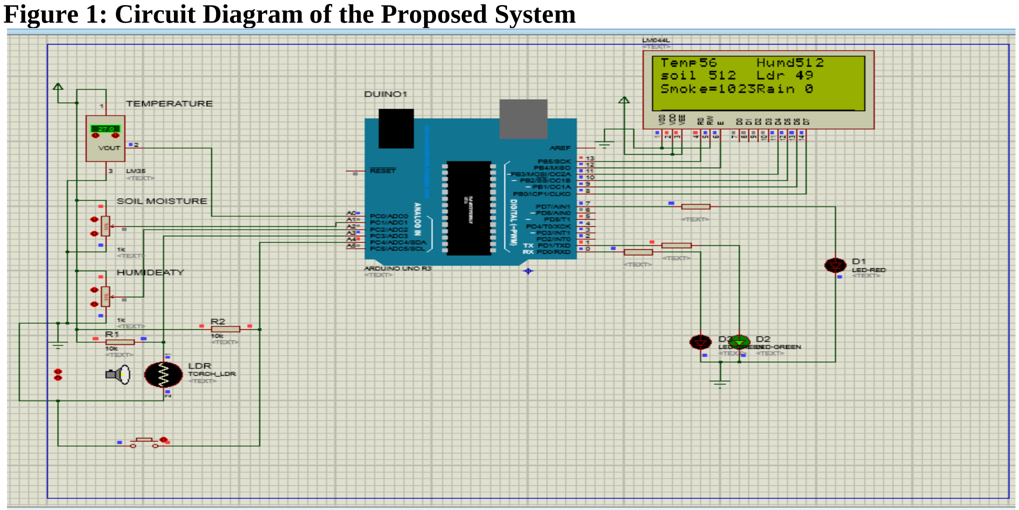
Bluetooth Module (HC-05)

In the proposed system, Bluetooth module (HC-05) is used for communication. It consists of 6 pins out of which we used second (VCC) and third (GND) pin to connect to the VCC and GND of the Arduino board and the first (TXD) and fourth (RXD) pin goes to the pins 0 and 1 of the Arduino board respectively, which are at the lowest point of 13 digital pins. A sensor values is sends on farmer mobile application using wireless sensor network technology.

Global System for Mobile (GSM) Module

The connection between the two mobile networks is established using GSM. The soil moisture sensor sends a signal to the microcontroller when it detects that the soil moisture content is above or below the threshold.

Figure 1: Circuit Diagram of the Proposed System



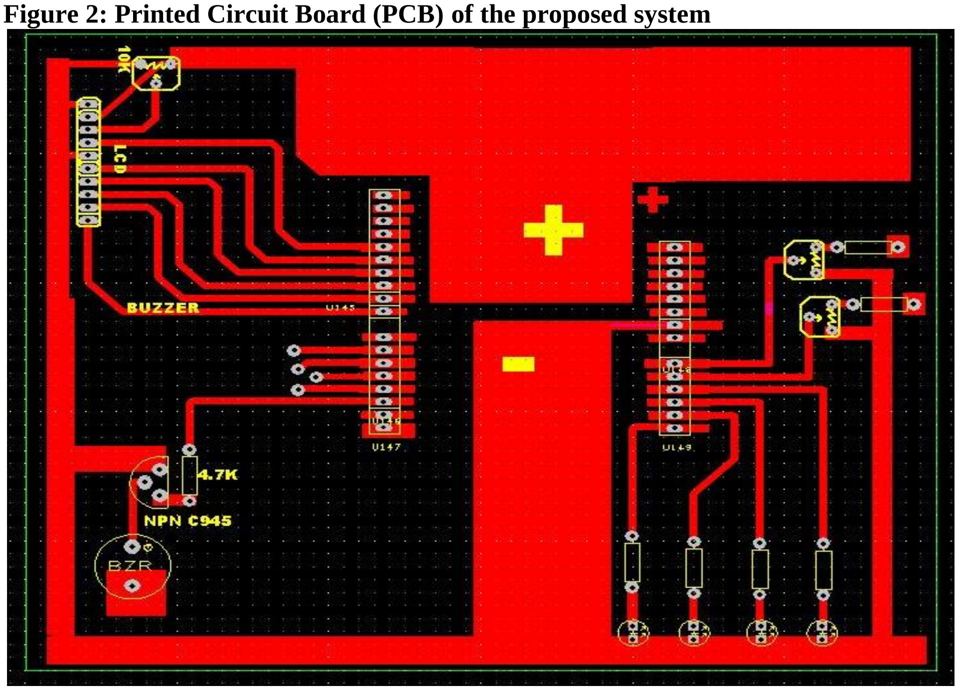
The microcontroller then sends a signal to the GSM module, which transmits a message to the cell phone of farmer through mobile application. GSM module consists of a subscriber identification module (SIM) of any network for secure communication. Farmers (end user) may perform various tasks by sending messages through mobile application that goes through GSM to microcontroller and perform different task without personally visiting the field.

Circuit diagram of proposed system

Before integrating all hardware components together, we designed simulation of proposed system using Proteus (8.0) to test software and embedded designs before actual hardware project testing equipment. As discussed above, the proposed system consists of PT (potential transfer), Power supply, Sensors (temperature, rain, humidity, PIR, LDR, soil moisture, gas and smoke), relay, Buzzer, microcontroller Arduino UNO 328Atmega and communication module includes Bluetooth, GSM and WSN technology.

There are eight sensors integrated into the circuit that are used for measuring the environmental factors like temperature, gases, smoke, humidity, soil moisture, and intensity of light, motion of imposter, and water level of the crop. Microcontroller consists of 14 digital and 6 analog pins. Temperature sensor is contacted with A0 that is for 8 bits. Humidity sensor for 8 bits is connected with A1 Pin of Arduino. Soil moisture sensor is connected to A3 digital pin. PIR sensor is connected to A4 digital pin of Arduino. Rain sensor is connected with A4. LDR sensor is connected with A5. Eight to thirteen pins reserved for LCD. Px and Rx are reserved for Bluetooth and GSM. Rest of the pins are connected with relay, LED, buzzer, button.

Figure 2: Printed Circuit Board (PCB) of the proposed system



Before evaluating the functional operation of circuit diagram, it needs power supply to the whole circuit. For power supply, there is a need of regulated IC of 5 volts for sensors, 12 to 20 volts for Arduino and 5 volts for LCD and communication module.

The sensor readings are in the form of analogue signal and the ADC output in the controller converts the analogue signal to digital. The controller then accesses the information and all sensors values are displayed on the LCD. Simulation of the proposed system shows that the system is correctly working and ready to be implemented in the actual hardware components. Circuit diagram of proposed system is shown in Figure 1.

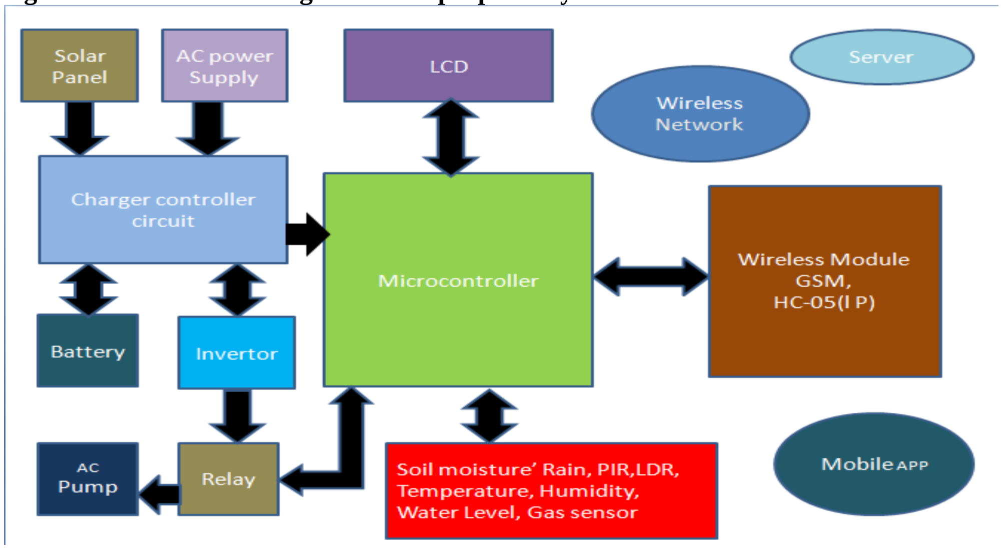
Printed Circuit board (PCB)

A printed circuit board, or PCB, is used to support and operate electronic components. We are using Easy PC software for designing the PCB of the circuit. The PCB consists of Arduino Uno, NPN Transistor, Button, Variables, Re-entrance, and LED. PCB of the proposed system is shown in Figure 2.

Block diagram of system

The block diagram of the system is shown in Figure 3. The first major component of the system is the continuous source of power supply. This component consists of solar photo voltaic cell (SPV), potential transformer, adapter, charge converter, batteries and inverter. The basic function of this component is to provide continuous power supply to the system using the charger that is connected to the battery, inverter and AC power supply. If the solar panel voltage is lower than the battery voltage, the solar panel will be disconnected from the circuit and the battery will be the only source of power to the pump. The system used AC power supply and shifted to DC supply of SPV in case of disconnected AC supply. We need regulated 5 volts for sensors, LCD, communication module and relay and 12 to 20 volts for 8-bit Arduino UNO ATMEGA328.

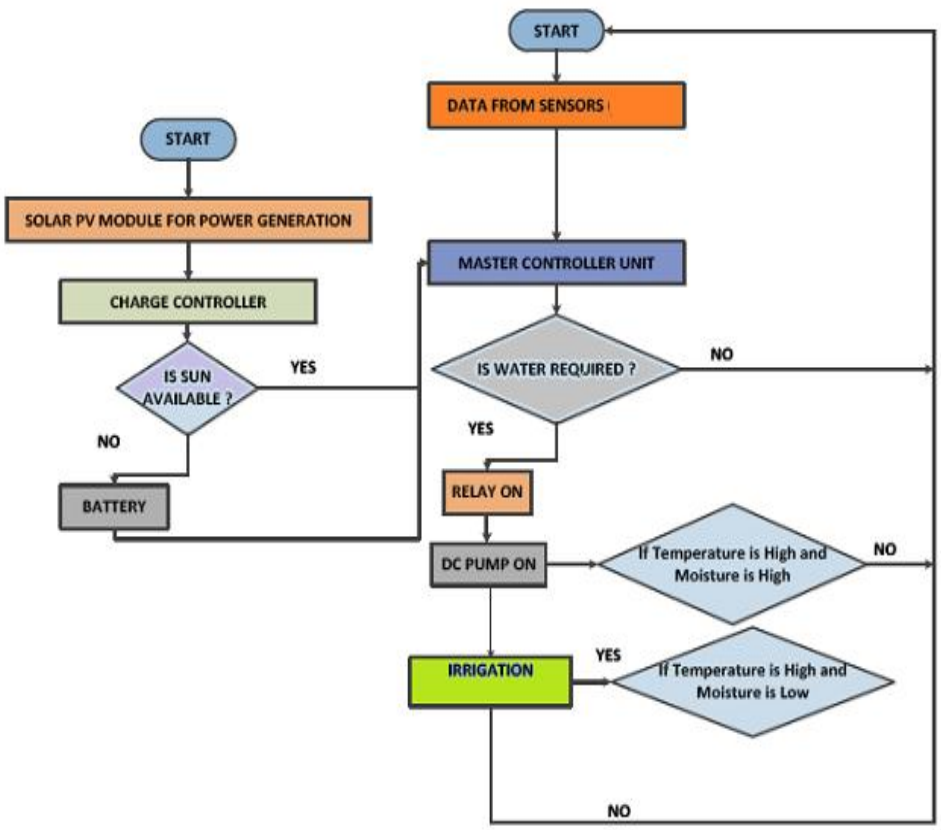
Figure 3: Block diagram of the proposed system



The second component of the system is main board that consists of Arduino Uno 328ATMEGA directly connected to all other components of the system. All processing and operation are performed through this component. Arduino Uno controller consists of 20 pins out of which 14 are digital and 6 are used as analogue. All sensors are connected with the microcontroller as discussed in previous sections.

The third component of the block diagram consists of sensors: soil moisture, temperature, humidity, gas and smoke, rain, PIR and LDR. These sensors measure the environmental parameter from environment and send values to microcontroller. The fourth component of the system consist of relay and a buzzer. Relay works as button or switch that controls the on/off of the pump. Buzzer is used for audible indication to the end user (farmer) in case of any error and alarm in case of imposter or fire detection. When any animal enter in the field PIR sensor detects the motion and open the buzzer which is a sign for farmer that someone enter in the field and destroy the crop. In case of Fire situation gas sensor sends the signals and buzzer will open to alarm the farmer. All these alerts are also generated to cell phone of farmer through mobile application.

Figure 4: Flow chart diagram of the proposed system



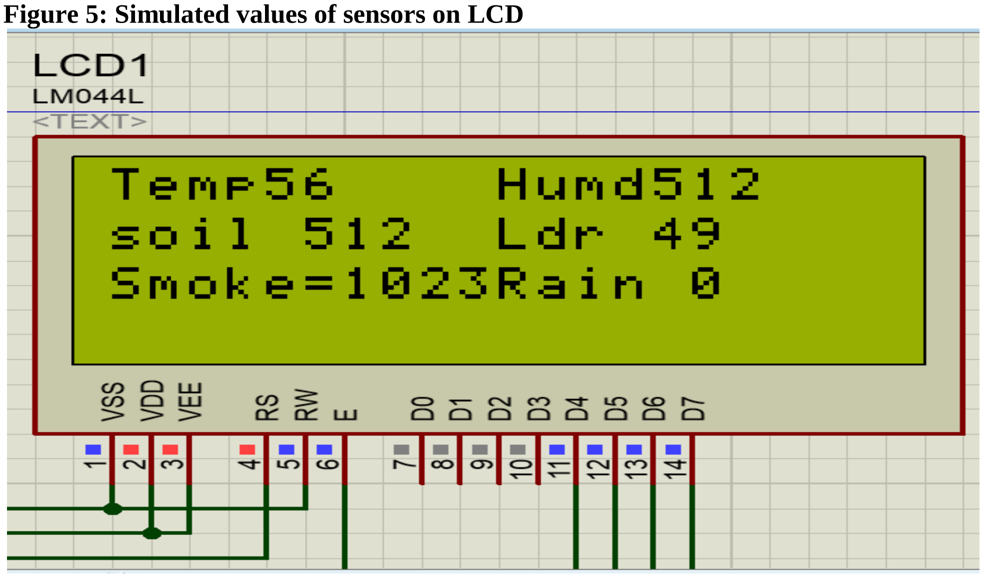
The fifth portion of system consist of communication module and technologies. The data is transferred from Arduino Uno to mobile application by using Bluetooth technology, and GSM is used for message alert. All the sensors readings are displayed on farmer cell phone in real time through mobile application. Microcontroller is setup in two modes: auto and manual. In auto mode, micro controller takes decision based on already coded instruction based on the environmental factors. In the manual mode, it waits for the instructions from the user (farmer). Farmer can submit commands in two ways, by using mobile app and alert system.

We are using wireless network technology for communication purpose. The ultimate aim of the system is to monitor and manage the flow of appropriate amount of water through the irrigation system using mobile application. The sensors measure the environmental factors affecting crop irrigation (such as temperature, humidity, soil moisture, rain) and sends the signal to the micro controller. Micro controller receives the data from sensors for further processing. After processing the system sends appropriate short message service (SMS) to farmer about irrigation status of different plots. This system helps the farmer take informed decisions timely without personally visiting the field. This system will minimise the waste of water, improve the crop productivity, and reduce the need of labourers and farmers work load by intervention of technology.

Flow chart diagram

The flow chart of the proposed system is shown in Figure 4. It starts with the checking the power supply. After checking the power supply, the second step is to check all the sensors are receiving suitable power and transmitting correct values. Sensors measures environmental parameters and send these readings to the microcontroller. Microcontroller sends these values by using wireless network technology to the farmer on cell phone through mobile application. Farmer interact with the system in two modes: manual and auto. In the manual mode, the farmer takes decisions on the basis of sensors values. In the auto mode, the microcontroller takes decisions of turning the pump on or off based on already coded instructions.

Figure 5: Simulated values of sensors on LCD



IV. Results and Discussion

After configuring sensors and microcontroller, we performed simulation of the proposed system. The sensor values are displayed on the LCD, as shown in Figure 5. For experimental evaluation of the system, we deployed sensors in the field of one acre of wheat crop and setup various environmental conditions such as water level below threshold, water level above threshold, sprinkling artificial rain, various temperature levels (throughout the cropping season). The actual values of sensors are shown on the LCD of the smart irrigation system as shown in Figure 6. The system accurately controls the water pump based on the sensor values.

All these values are also displayed on the farmer's cell phone through mobile application. Farmer remotely connects with the farm and can monitor and control the pump through mobile application. Figure 7 and Figure 8 show the sensor value and pump status on mobile application.

Figure 6: Values of sensors on LCD of the proposed irrigation system

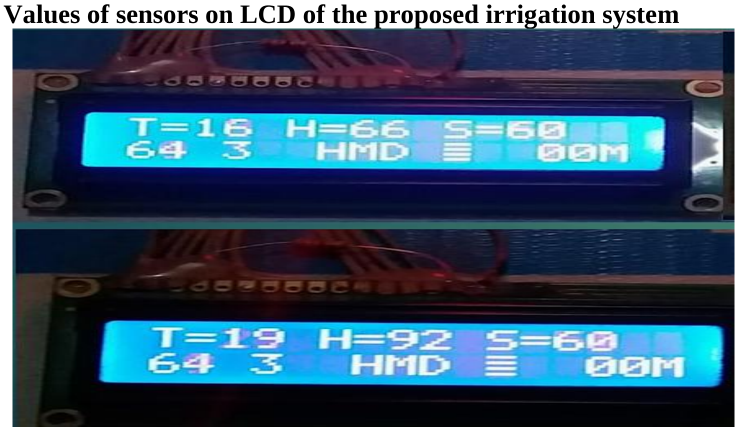


Figure 7: Graphical illustration of humidity and temperature sensor values. X-axis shows time in days and y-axis shows sensor values

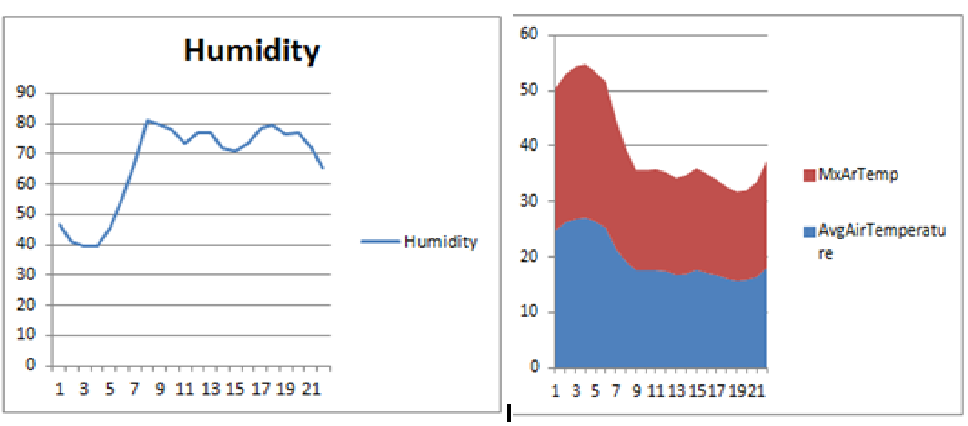
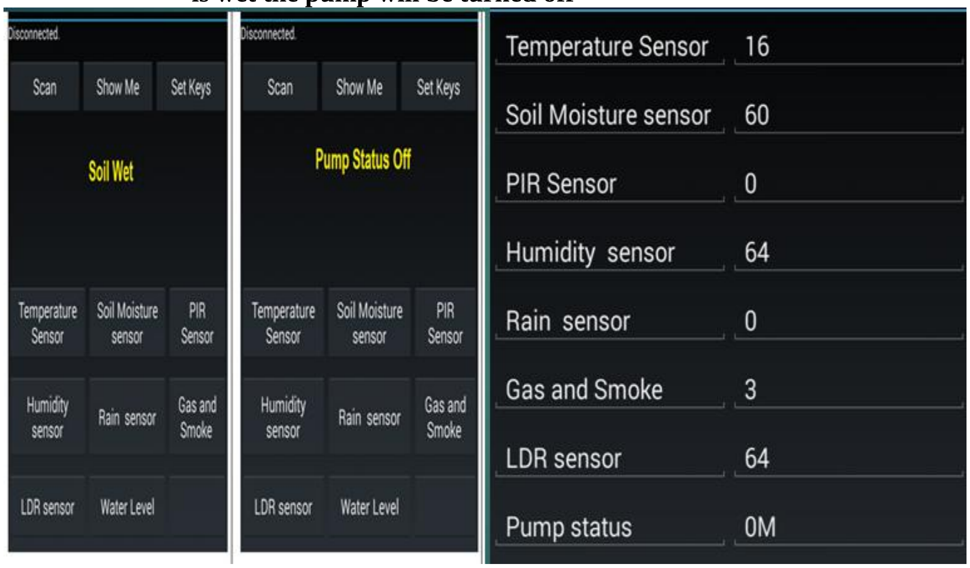
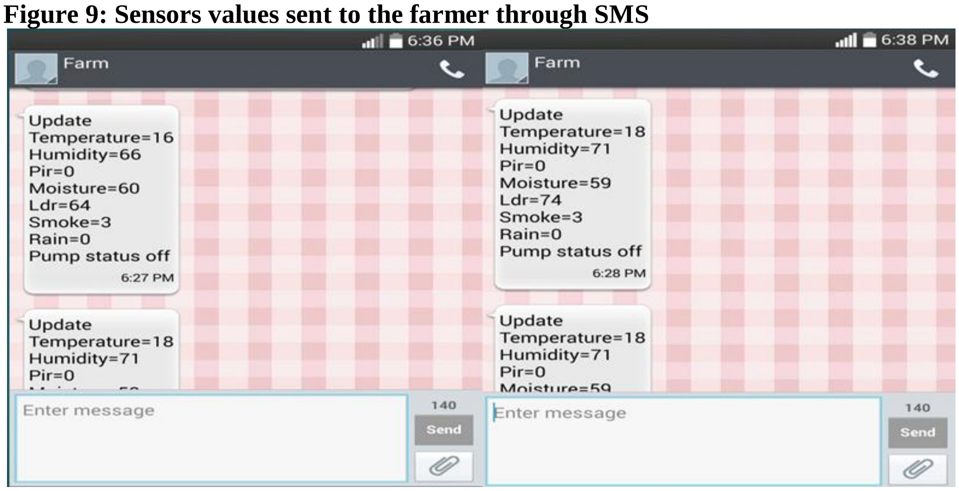


Figure 8: Interface of mobile application, showing the scenario when the soil is wet the pump will be turned off



To send real time alerts to the user (farmers), the system used GSM for text messages as SMS as shown in Figure 9.

Figure 9: Sensors values sent to the farmer through SMS



V. Conclusion

This paper presents an affordable smart crop monitoring and irrigation based on the Internet of Things and mobile applications for irrigating fields and measuring environmental parameters. The proposed system consists of six blocks: power supply block, main block, acquisition block, monitoring block, automatic functional block and communication block. Sub-components of the proposed system are Arduino UNO, micro-controller, Sensors, Solar Panel, Battery, Charge controller, Inverter, GSM module, Bluetooth module and pump, water tank and irrigation kit. The system has been thoroughly tested under various environmental conditions and the results determined that smart crop monitoring and irrigation system would be an effective tool for those who aims to conserve water and face electricity shortages where there is enough sunlight.

With solar charged battery, the system can run up to 7-9 hours per day, and 5-7 hours per day directly without consuming solar power. Bluetooth module HC-05 or GSM module enables the system to transmit the pump status and sensors values to farmer's cell phone through mobile application. The system successfully detects the potential hazards in the field such as physical imposter as well as smoke and other gases in the case of fire and generate alarm. The irrigation system can be controlled through an Arduino digital pin through mobile application. Automatic irrigation system is an economical and cost-effective technology that optimizes water resources to increase agricultural production.

VI. Policy Recommendations

In Pakistan, where agriculture is the backbone of the economy, modern technology is much needed to use sustainable agricultural production resources efficiently. The government is urging farmers to reduce water loss through proper management. Various precision agriculture technologies have been introduced and subsidized, such as precision land levelling and high efficiency irrigation systems (HEIS) including drip and sprinkler irrigation systems. The performance of the existing efficient irrigation technology can be increased through sensor based irrigation scheduling system. Therefore, the government should promote the development of such efficient systems which are based on new technologies such use of wireless sensor networks (WSN) and internet of things (IoT) in agriculture to do smart farming.

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