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Solar Based Smart Irrigation System Using PID Controller

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Abstract. An approach to minimize the human interface for the agriculture sector is presented in this paper which provides comfort to the farmer in monitoring and performs automatic irrigation operation. Here, a combination of software integrated microcontroller that is Arduino, four real-time sensors fetching input data from field and a DC motor pump as output are used. A controlling technique Proportional Integral and Derivative (PID) controller is integrated into Arduino. The inputs include four sensors: wind speed, ambient temperature, humidity, and radiation sensors while taking soil moisture as the reference point. These four sensors work at different ratios on the basis of PID and penman model of evapotranspiration. The system is powered by a lead-acid battery which is recharged by a solar panel. The four designated sensors measure field conditions and simultaneously send information through wireless communication to a remote placed monitoring device which has a Liquid Crystal Display (LCD). The complete hardware and software modeling is performed in this paper.
Keywords: Arduino, Irrigation System, Lead Acid Battery, Moisture sensor, Penman Model of Evapotranspiration, Proportional Integral and Derivative (PID), Solar Panel.

1. Introduction

Water is an indispensable element of human life and plants. The Food and Agriculture Organization of United Nations estimates 70% of water consumption is for agriculture, 20% for industry, and 10% for domestic usage [1]. A design should be devised or adopted by such methods to decrease the wastage of water as well as maintain the basic parameters required for the growth of a plant. In literature proposed methods that not only control the moisture level/water level but also control the supply of water in the fields. However, our proposed system has four sensors which work simultaneously to perpetuate the basic parameters of plant and control the water level even if the farmer is not in the field. Moreover, it also gives signals to the farmer either it is an overflow condition or underflow condition.

There are some problems regarding the irrigation system: the specific amount of nutrients and water is applied to the soil, to cope with this issue, a new adaptive smart irrigation system algorithm is applied. In this algorithm, the water is balanced in a control tray by measuring the information provided by the sensors. For this purpose, a controller is designed which is a PI controller. A feedback process is used to measure the current and future situation of the tray then it is controlled by the PI controller. An open loop-controlled technique for irrigation is used by simple relay based ON and OFF mechanism. The communication is performed between the receiving and transmitting end by GPRS/GSM modules [2]. An automatic solar-powered drip by Wireless Sensor Network (WSN) for irrigation is present. Arduino

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is used for controlling the soil moisture input [3]. A method by Mobile Irrigation Care Unit (MICU) has previously used: a smart wireless monitoring system mounted on a solar-powered vehicle which ensures proper irrigation of each plant [4].

D. Rodriguez et al. [5] presented a work, based on Wireless Sensor Network (WSN) technology which is cost effective and less energy consuming system. It works on multi-sensors simultaneously and senses the water level, moisture in the field and inform the farmer either by a text message or by an alarming unit. If the level of water is less or above than the predefined value, then it alarms the controller to ON/OFF. P. B. Chikankar et al. [6], presents a modified form of PID controller along with an integral function which efficiently demonstrates implicable regulation of soil moisture by supplying the appropriate amount of water to the agricultural field and meet all the requirements of the field. Moreover, it also controls the rapid changes in the environment like rainfall, underwater and makes rapid ON/OFF actions in the controller.

The Artificial Neural Network (ANN) is presented using MATLAB, [7]. The input parameters like air, temperature, soil moisture, radiations, and humidity are modeled, then the amount of water required for irrigation is estimated and afterward associated results are simulated. PID controlled irrigation system using temperature, humidity, and moisture is presented in [8], which is powered by a solar panel. The control tray is designed which is simply an ON/OFF mechanism to control the amount of water but it is not so simple there is a need to develop a controller i.e., PID controller which allows fully automatic control operation and reduces the cost of equipment, [9]. A closed loop controller based on modified PID is used with constrained integral that provides good soil moisture regulation by applying the appropriate amount of water and is fast to environmental change, [10].

An innovative application of PID technique is introduced which uses penman model of evapotranspiration [11] for irrigation purpose. Here modeling of four parameters, as discussed in the above paragraph, for the operation of DC pump controlling using PID Controller algorithm on Arduino provides a comprehensive study of irrigation in the agriculture sector. The penman model is considered the most scientific model for evapotranspiration. A general penman model of evapotranspiration is explained with a moderated correlation.

2. Methodology

The irrigation system by PID techniques which is real-time need of irrigation sector. The researchers combined two different fields of studies by a combination technique model: Irrigation with penman model of evapotranspiration and an Arduino as the most used microcontroller in modern electronics applications with an efficient PID as a controlling algorithm, as shown in figure 1.

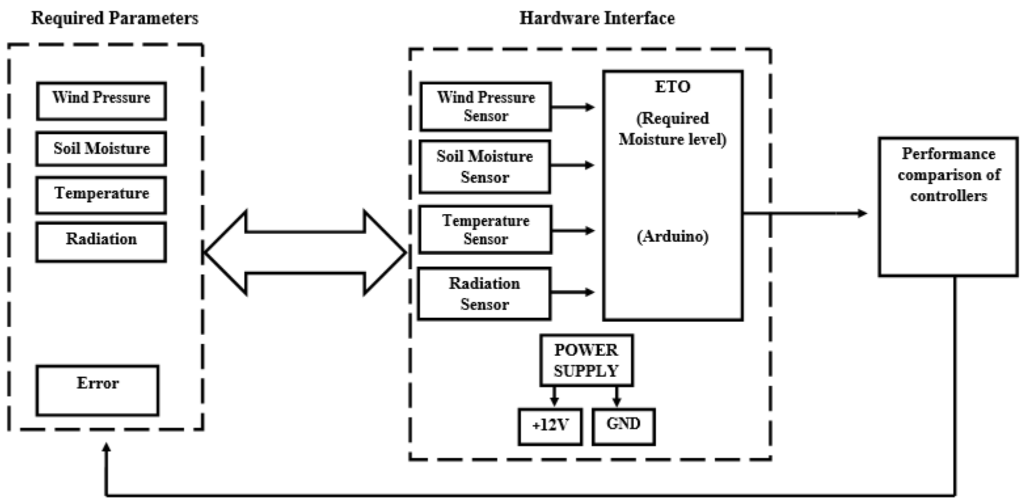

Figure 1. General Configuration of Proposed Methodology.

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This work is comparatively efficient with respect to the previously lesser number of input sensing parameters in this field of research. Further, PID Controller is designed on the aggressive and non-aggressive model which efficiently reacts to small variations in sensors values. The system discussed in figure 1 consists of hardware and back-end software interface.

The hardware consists of an Arduino system with four required sensors; namely as, ambient humidity, wind pressure, solar radiation and soil moisture sensors that substantiate to take the required moisture level for the irrigation purpose. The Arduino requires 12 volts DC source for this purpose the complete system is solar powered with a battery backup. The output values of our sensors are transferred to the PID controller to perform the governing decision for the DC pump operation. Hereafter, the performance comparative controlling techniques are used for measuring all the sensors to its required moisture level. The software interface is based on Arduino coding that provides a timely change in the ratios of sensors input to PID controller and set point on soil moisture i.e., in case of rain and long-term corps routine. The sensors unit is integrated with the Arduino in the field which transmits radio signals to the receiver end. The receiver is used for monitoring and displaying output signals and these signals are converted into a required form for observation i.e., analog and digital readings. In this system, the back-end software and hardware have two-way communication with the wireless a device (Radio Frequency based) module which continuously observes and displays transmitter values.

2.1. Irrigation System Hardware

The complete hardware of this work is shown in figure 2, which contains a solar panel, fake sun, electric dimmer switch, transmitter, receiver, DC motor pump, four sensors, two black buckets: one contains the dry soil and other with water, and a Digital Multi-Meter (DMM) for measurements.

Figure 2. Complete Hardware of Irrigation System.

2.2. Arduino Uno Microcontroller

In this system, an open source platform Arduino Uno microcontroller is used, which contains two parts: a physical Printed Circuit Board (PCB) and ATmega328P microcontroller. It has 14 digital inputs and output pins. Six of them can be used as Pulse Width Modulation (PWM) outputs, six pins are for analog inputs, a USB connection, and a power jack. The Arduino software (IDE) 1.0 for programmable coding is used.

2.3. DC Motor Pump

This project includes a DC Motor Pump for irrigating the soil with the help of PWM technique which controls the DC Pump to water the soil up to its requirement while maintaining upper and lower limits. The DC pump is the only output in this project as shown in figure 3 that reacts on the given set of values which includes wind, humidity, irradiation and moisture values. Figure 4 shows the PSpice (Electronic Circuit simulator) diagram of DC pump modeling.

Figure 3. DC Pump used for Irrigation.

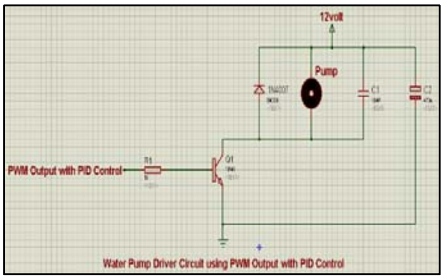

Figure 4. Equivalent model of DC Pump Simulated in PSpice.

2.4. Soil Moisture Sensor

The soil moisture sensor measures soil moisture content in the active root area. The soil is nonconductive in nature; however, due to the presence of water content in soil increases its conductivity. The variation in conductivity of soil depends on moisture which is opposite to resistance (0-5 kilo Ohms). In this way, a soil moisture sensor measures soil conductivity in an analog waveform which is further converted into digital format for microcontroller processing.

2.5. Fake Sun and Solar Panel

The fake sun is to demonstrate a prototype of the sun in figure 5. Here two 100 Watts incandescent bulbs are used which show the visible region of a sun irradiance. In addition to make this setup compact the black surrounding is used to capture heat for our calculation.

Figure 5. Fake Sun setup enclosing two incandescent bulbs and solar panel at top of the bucket.

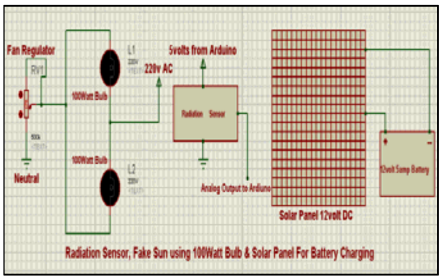

Figure 6. Equivalent model of fake sun and solar panel simulated in PSpice.

In this setup solar panel of 12 volts and 5 amperes is placed at top of the fake sun. The solar panel produces a different amount of output depending upon the sunlight versus time in a day, and to demonstrate this phenomenon of variation in solar irradiance, the researchers used an electric dimmer switch which can vary the electric power of bulbs i.e., the intensity of light can be changed. Figure 6 manifests a solar panel of the monocrystalline structure is used, which is cost effective with 21.3% of efficiency. Here the solar panel is directly charging 12 volts battery that does not need any charge-controller for tracking maximum power output due to two reasons. Firstly, the desire irradiance can be adjusted by electric dimmer switch which set desire intensity of light bulbs. Secondly, battery withdraws a fixed amount of charge for charging versus any variable loads where the continuous tracking is required to harvest the maximum amount of power from solar panels.

2.6. Lead Acid Battery

The table 1 exhibits lead acid battery and other exiting batteries including Nickel Metal hydride, Sodium Nickel (ZEBRA) and Ultra-Capacitors comparison. This comparison includes the cost in dollars per kilo Watts hours ($/KWh) and self-discharge rate per day (%/day) which explains how much a battery discharge due to internal reactions. In table analysis, it is clear that lead-acid battery is suitable in terms of cost ranging from 100- 150 ($/kWh), and self-discharge of 0.29-0.57(%/day) for our work.

Table 1. Comparison of Lead-Acid Battery vs Other Exiting Batteries in the Market.

Specifications	Lead Acid	Nickel Metal Hydride	Sodium Nickel (Zebra)	Ultra-Capacitor
Cost ($/Kwh)	100-150	150-250	100-200	300-2000
Self-Discharge (%/Day)	0.29-0.57	01-1.43	15	20-40

2.7. Transmitter Module

The complete assembly of the transmitter, which contains Arduino and input parameters (sensors) shown in figure 7. We have set a different ratio criteria for all input parameters on basis of their importance that can be modified as per agriculture needs: crop type, field type and sessional variation. Input sensors requires different voltages for their operation which is shown in table 2.

Table 2. Voltage distribution of sensors.

Input Voltage	Wind Speed	Ambient Temperature	Air Humidity	Soil Moisture	Radiation
12 DC	0-12V	0-5V	0-5V	0-5V	0-5V

This system has 12 Volt DC motor pump which variates its speed using pulse width modulation technique (PWM): a power electronics technique used to control DC-DC voltage conversion with no power losses.

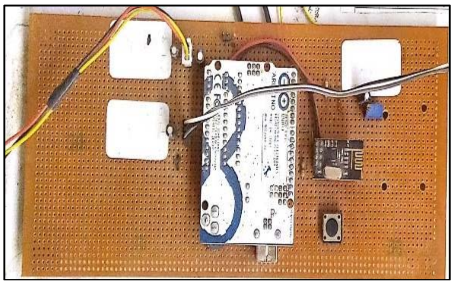

Figure 7. Hardware of transmitter end including and wires corresponding to sensors.

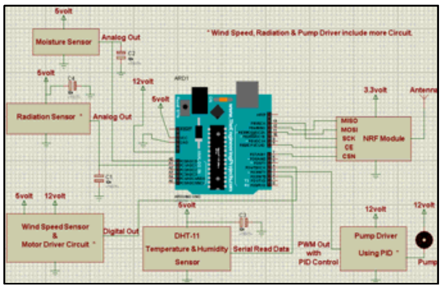

Figure 8. Equivalent model of a transmitter including wind speed, radiation, NRF, DHT-11 and moisture sensors; NRF Module; DC Pump simulated in PSpice.

NRF (Radio frequency based device) is used for communication between transmitter and receiver. This device makes our system out performed previously developed system in terms of cost effectiveness and long distant communication with increased number of sensors. These four input sensors produce analog signals which are translated into digital format to be processed and make decision in terms of activating DC motor pump. furthermore, the transmitter simultaneously send signal to receiver which contains

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updated values of all parameters: wind, ambient temperature and air humidity, solar radiation and soil moisture variations, keep farmer informed of any variations.

2.8. Receiver Module
We designed a portable equipment for the formers that enables them to monitor field parameters remotely. This module consist of an Arduino, NFR (for wireless communication), Liquid Crystal Display (LCD) and a 9 Volts battery as shown in figure 9 (hardware) and figure 10 (Simulated setup). The receiver module efficiently keeps updating its values which includes: ambient temperature, moisture, humidity, wind speed, and radiation.

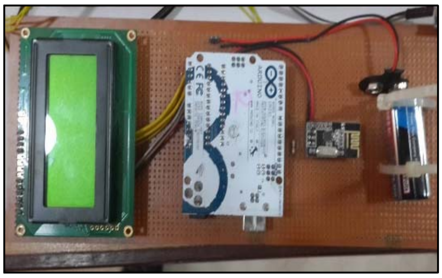

Figure 9. Hardware of Receiver End Including NRF.

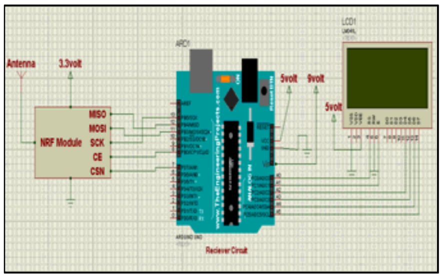

Figure 10. Equivalent Model of a Receiver Including LCD and NRF Module in PSpice.

3. Proportional integral, and Derivative (PID) Controller for The Irrigation System
The PID controller is fast and efficient in terms of their decision-making capability. We integrated PID for a simple application with its pragmatic implementation for irrigation control in agricultural sector, operating a PID algorithm in aggressive and non-aggressive mode for DC motor pump speed controlling and deciding either/whether to turn on or turn off the pump. The pump is automatically controlled by PWM which variates the speed of DC pump in different situations: mainly at starting and just before the end of desired amount of water with precision.

We provided different input ratios to PID algorithm; the ratios are set on the basis of input sensors (air humidity, wind speed, radiation, and soil moisture) importance and other effecting variables as shown in table 3. In Addition, The penman model of evapotranspiration model has four most important parameters which we integrated with PID controller, [11].

Table 3. Sensors Percentage for PID Controller.

Sensors	**Wind Speed**	**Ambient Temperature**	**Air Humidity**	**Soil Moisture**	**Radiation**
Percentages	0.3%	1.2%	0.3%	98%	0.2%

4. Modeling of Input Parameters
The process evapotranspiration is influenced by four parameters (ambient temperature, air humidity, wind speed, radiation and soil moisture). The modeling of parameters is remodeled into Arduino coding. The penman model of evapotranspiration discuss parameters:

4.1. Air Humidity: It is modeled as
- A sine wave with an amplitude of 10 %
- Biasing of 60% (constant)
- A frequency of 0.2618 rad/h

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4.2. Wind Speed: It is modeled as

- A sine wave with an amplitude of 1 Km/h
- Biasing of 3.5 Km/h (constant)
- A frequency of 0.2618 rad/h

4.3. *Radiation:* It is modeled as maximum possible radiation at earth's surface (Rmax).

- A sine wave with an amplitude of $\frac{2\mathrm{MJ}}{\mathrm{m}^2}$
- Biasing of 112 MJ/m
- A frequency of 0.2618 rad/h

5. Evapotranspiration Model

We related irrigation with the Penman-Monteith equation (01) of evapotranspiration [11] that has generally been considered and accepted as a scientifically sound formulation for evapotranspiration (ET_O) as reference estimation (comprehensive model for irrigation). This equation is expressed as a combined function of air humidity, radiation, maximum and minimum moisture, vapor pressure and wind speed. The updated method by Food and Agriculture Organization (FAO) in May 1990, of Penman equation is given as under:

$$\boldsymbol{ET_o} = \frac{\left\{\mathbf{0.408}\Delta(\mathbf{R}_n - \mathbf{G}) + \gamma \frac{\mathbf{900}}{\mathbf{T+273}} \mathbf{u}^2(\mathbf{e}_s - \mathbf{e}_a)\right\}}{\Delta + \boldsymbol{\gamma}(\mathbf{1} + \mathbf{0.34u}^2)} \quad (01)$$

*W*here:
ET_0 = reference evapotranspiration, mm day^{-1}.
Rn = net radiation at the crop surface, MJ m^{-2} d^{-1}.
G = soil heat flux density, MJ m^{-2} d^{-1}.
T = mean daily air temperature at 2 m height, °C.
u^2 = wind speed at 2 m height, ms^{-1}.
e_s = saturation vapor pressure, kPa.
e_a = actual vapor pressure, kPa.
$e_s - e_a$ = saturation vapor pressure deficit, kPa.
Δ = slope of the vapor pressure curve, kPa ºC^{-1}.
γ = psychrometric constant, kPa °C^{-1}.

6. Software Modeling and Devices Communication

The work includes four real-time sensors fetching data. The microcontroller is working on software-based programming and tunning each of the parameters (sensors) with respect to system desire conditions. As discussed above, the Arduino (microcontroller) performs analog to digital conversion for data analyzing for PID controller.

Transmitter end consists of sensors with controller input and DC motor pump as the output of the system. To keep a timely monitoring for system performance in all conditions this may include transients in sensors values, self-generated values of PID or any malfunction of the system. In addition, the monitoring gives the first-hand comfort to a farmer for distant monitoring the field parameters. For monitoring parameters and system performance, efficient wired or wireless communication is required. In this paper, wireless communication is carried out by NFR24L01 (Radio frequency model number). Which enables the farmer to monitor all parameters from the distance of 100 meters. LCD screen shows values on receiver end which includes air humidity, ambient temperature, solar radiation, wind speed and soil moisture I n figure 11.

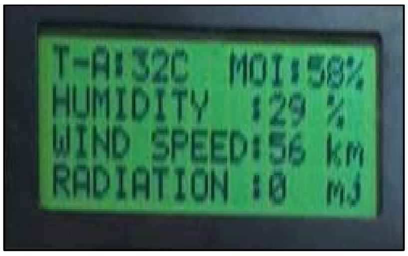

Figure 11. LCD display of receiver end which shows T-A (ambient temperature), MOI (moisture), HUMIDITY (air humidity), wind speed and radiation sensors values.

7. Conclusion

The proposed work has emphasized on the importance and significance of modernization of irrigation in agriculture field while considering all-natural parameters including temperature, air humidity, wind speed, radiation and soil moisture which have scientific importance. The consideration involves modernization sometimes makes system costly; however, in this research all components are not only cost effective but also robust in performance. In addition, this work is a professional and practical combination of hardware and controlling technique; such as, a PID controller. This work is intended to widen the knowledge in parameters consideration for irrigation and simple in system designing. Furthermore, the purpose of this model is to facilitate and help farmers for controlling and managing water wastage, and providing them proper monitoring while excluding human error which is one of the most practical solutions of agriculture sector in Pakistan and other under developing countries of the world.

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