Design of Automated Irrigation System based on Field Sensing and Forecasting

Jayendra Kumar
Department of Electronics and Communication Engineering
National Institute of Technology
Jamshedpur-831014,
Jharkhand, India.

Srinath Mishra
Department of Electronics and Communication Engineering
National Institute of Technology
Jamshedpur-831014, Jharkhand, India.

Anurag Hansdah
Department of Electronics and Communication Engineering
National Institute of Technology
Jamshedpur-831014, Jharkhand, India.

Ratul Mahato
Department of Electronics and Communication Engineering
National Institute of Technology
Jamshedpur-831014, Jharkhand, India.

ABSTRACT
The conventional irrigation systems tend to waste irrigation water by not considering the upcoming precipitation. The precipitation in India being erratic in nature calls for the use of efficient forecasting methods. This paper proposes a design of irrigation system that employs a weather forecasting algorithm to calculate the water requirement and control irrigation based on soil moisture for the sustainable irrigation of crops. Statistical forecasting methods are most suitable for this application as they can predict extreme weather conditions that could have occurred previously and needs negligible time to deploy the algorithm. Here a modified version of the sliding window algorithm has been used to fit the requirements of the irrigation system [4]. However, the design can work with other forecasting methods due to implementation of modularity.

Keywords
PID control, Max-min normalization, Variation trend Matching, Euclidean distance.

1. INTRODUCTION
For the world over, the irrigation sector is the largest user of water- almost 80 percent of the water in the world is taken up by irrigation where India uses almost 85 percent of its available water resources [1].

.The annual water resources (ARW) available per capita is optimum considering the safe level of 1700 cubic meter of water per capita, but will soon degrade to below safe level by 2025 [1]. To further aggravate the issue of scarcity of water, a significant part of irrigation water is now deducted to provide for the basic needs of rapid urbanization. The availability of water resources for artificial irrigation being limited and erraticity of rainfall in India, the need for efficient irrigation system is acute.

This paper incorporates an added improvement to the existing prototypes by a) A proper sensing of soil moisture

and b) An automated irrigation system [2], ensuring optimum yield by carefully tailoring the requirements of each field or crop specifically, ensuring no unnecessary wastage of water. The irrigation control mechanism samples soil moisture content regularly and irrigates the land accordingly. This system can be integrated with the microprocessor/microcontroller and soil moisture sensor [3] for better performance.

But upon thorough speculations, the system was designed to be modular. This not only enhances the independency of the irrigation control system from the forecasting system, but to effectively compare performances of different forecasting methods. Re-evaluation and reporting functions in the system suggests the use of machine learning that can perform its training regularly with different epochs.

But using an advanced forecasting method [4] will increase system's efficiency and cost making it unsuitable for farmers with medium or low financial status. Since, systems must be affordable across farmers with different financial status.

The following section will introduce to necessary calculation on which the control action depends. The appropriate actions initiated and regulated under different conditions are categorized and dealt with in modes which further enhances modularity. Simple uniform irrigation or Proportional-Differential-Integral (PID) control can be used under different circumstances. However, PID control is not necessarily required and could be replaced by a fuzzy system [5]. However, selections/adopting a certain technique method.

Even though the control systems design is abstract, but the most important aspects like functions and control mechanism are depicted precisely in their respective 'operation modes'. Segregation of different functions into a cluster or mode renders various advantages like a simplified design for implementation and rapid fault detection and control. Lastly, cost and performance are two opposing aspects which must be considered in realizing the system.

2. MATHEMATICAL APPROACH
The control system that will control irrigation based on parameters that affect the soil moisture at present and in the future performs some necessary calculations. These calculations need these parameters discussed earlier to determine the magnitude of other dependent variables. These dependent variables are:

(i) Mean Soil Moisture Decay Rate
(ii) Minimal Volume of water moisture maintenance

There are various parameters that will be taken in account for determining the magnitude of the variables discussed above. Inclusion of these parameters depend on the degree to which they affect the dependent variables. Lastly, these calculations are intended to cover all aspects of irrigation.

Before the total volume of water required in the next 24 hours is determined, Mean Soil Moisture Decay Rate is calculated. It is denoted by 'd' and is expressed as:

$$d = a_1X_1 + a_2X_2 + a_3 X_3 + ... + a_nX_n \quad (2.1.1)$$
$$or, \quad d = \sum a_i X_i \quad (2.1.2)$$

Where 'X_i' - Predicted Parameter that affects 'd'
'a_i' - Coefficient for each Parameter

Ambiguity around the parameters is formed to account for the uniqueness of climatic conditions for different geographical locations. Parameters like Temperature, Pressure, Humidity, Wind Speed, etc., affect the rate at which soil loses its moisture. To compensate for this decay rate, is why irrigation is done in the first place.

Hence, the total volume of water lost over 24 hours (W_d) is given by:

$$W_d = (d\, A)\, X\, 24 \quad (2.2.1)$$

where 'A' - Area of the Land being irrigated.

The decay rate in eq (2.2.1) is of the same dimension as that of the measured rainfall. It is also important to note that decay rate is in its averaged form. Decay rate is measured by the soil moisture sensors in regular intervals attributed to the differential part of the Proportional-Differential-Integral control in the control system's 'Normal Mode'.

Minimal Volume of water for moisture maintenance depends on the difference between soil moisture averaged (with weights) over the last 24 hours and optimal soil moisture content.

This is expressed as :

$$W_m = \rho(\omega_{optimum} - < \omega >)\, Ah\, x\, 24 \quad (2.3.1)$$

Where, W_m - Minimal Volume of moisture maintenance
ρ - Density of the dry soil
$\omega_{optimum}$ - Optimum Soil Moisture
$< \omega >$ - Soil Moisture averaged over past 24 hours
h - Effective depth in which water is available to roots for irrigation.

3. OPERATION MODES

Irrigation control system must be prepared to encounter different types of situations. Handling these conditions in one single operating mode will unnecessarily make the system complex and ambiguous for the user. So to deal with the broadly categorized conditions of the control system's environment, i.e., raining conditions, water shortage due unexpected conditions, normal condition; the control system will operate with four basic modes [6]. Switching from one mode to another is based on the fulfillment of certain conditions.

3.1 Normal mode

The Normal mode is active only when the difference between current Decay Rate and Mean Decay Rate is below certain 'threshold value' or is not persistently above 'threshold value' for certain 'threshold interval'.

Normal Mode is the only mode when PID (Proportional-Differential-Integral) control mechanism is deployed. Irrigation control system operating in this mode indicates that the prediction of the parameters was not faulty and its corresponding implementation and computation of dependent variables is within desirable limits so far.

All re-evaluations made after every 24 hours are for the system to operate in normal mode for as long as possible. Since controllable parameters are within desirable range, the irrigation system will have the luxury to analyze more minute details of the environment it is working on. Another mode of operation called the 'Critical Mode' is the condition when system state are not acceptable for operating mode normal mode. This also means 'threshold value' and 'threshold interval' must be chosen wisely so that undesirable switching between modes is prevented.
The PID control is given by,

$$W_c = \rho(K_p(\omega_{optimum} - \omega) + K_d\, d(\omega)/dt + K_i \sum\omega))\, Ah \quad (3.1.1)$$

Where Wc - Irrigation water to be supplied
ω - Current Soil Moisture content

Eq (3.1.1) is a simple single stage PID control and its constants are determined through trial and error. Adjustment of constants can also be achieved by another more intelligent system (employing Machine Learning) [7].

3.2 Critical mode

As stated earlier in the previous section, the critical mode comes into action when the system fails to satisfy condition of operating in normal mode. Hence, critical condition is activated when the difference between current Decay rate/ Optimum Soil Moisture and Mean Decay rate/Current Soil Moisture (determined from predicted parameters) has persistently crossed a certain 'threshold value' for a certain 'threshold interval' .
In this Mode, The PID control mechanism is deprecated. Decay rates and Soil Moisture Content values do not affect the irrigation. The System alerts the user of the undesirable condition and prompts user to supply water from the emergency water reservoir. Meanwhile, the system distributes remaining water in terms of mass of land to be irrigated and remaining time (in hours) until the next re-evaluation.

After system gets over the Critical Mode back to Normal Mode. A report of this anomaly is made to the forecast source and user.

3.3 Hibernate Mode

The System switches to this mode only during rainfall. No Irrigation is done, but it still monitors the ambient environment through sensors. This is to notify the user of the necessary drainage that must be initiated when there is over damping of soil due to excessive rainfall.

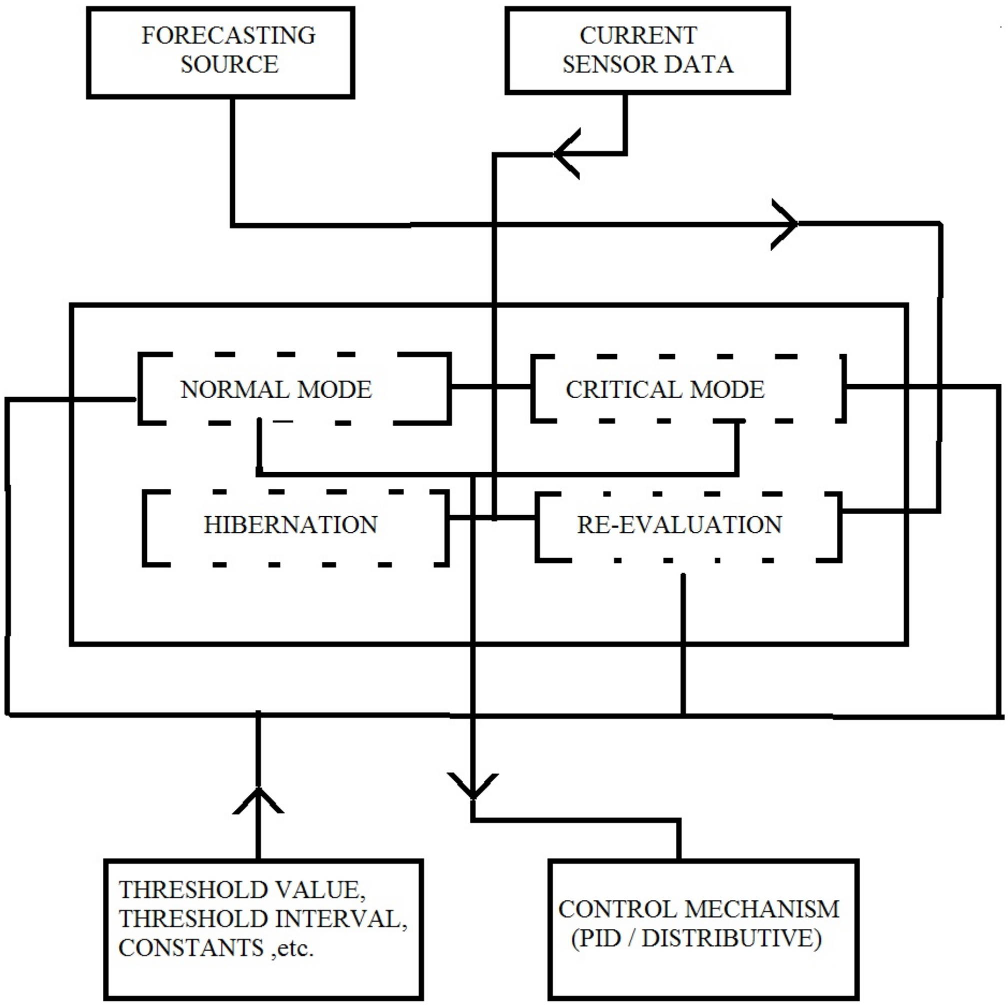

FIGURE 3.1: Flow of Data from different Data sources to the Control Mechanism

After rainfall, re-evaluation is performed to re-assess available water, soil moisture and which mode to start to operate in, etc.

3.4 Re-Evaluation

This mode has a definite interval, unlike the above stated modes. Re-evaluation done after rainfall has a longer interval than the periodic one that activates after every 24 hours. This is because after rainfall the system needs to know about the mode in which it should operate in (i.e., between normal or critical). Periodic re-evaluation does not switch modes i.e., the mode after and before the re-evaluation are same.

Re-Evaluation handles the systems at a macro level. Computation of total irrigation water which is the sum of the Minimal Volume for moisture maintenance and Mean Decay Rate Compensatory Volume.

4. PRACTICAL ASPECT

This section illustrates one of the possible designs that can be proposed based on the abstract-level design suggested in the previous sections. The design is made to exploit minimum resources to achieve desirable results. For instance, only one Water pump (with adequate capacity) is used to irrigate the land being supervised and maintained by the Irrigation system.

Data Flow Diagram shown in Fig 3.1 in Section III seems to be the best way to express the functionality of the Irrigation System in terms of how it utilizes data obtained or generated within the System. Every Block/Section in Fig. 3.1 is placed & mapped into the Proposed Design [8] in Figure 4.1, in the manner which is explained briefly as:

- Every section in the Data Flow Diagram is placed inside the Controller, except sections like Forecasting Source and information about Constants which are placed inside Database.

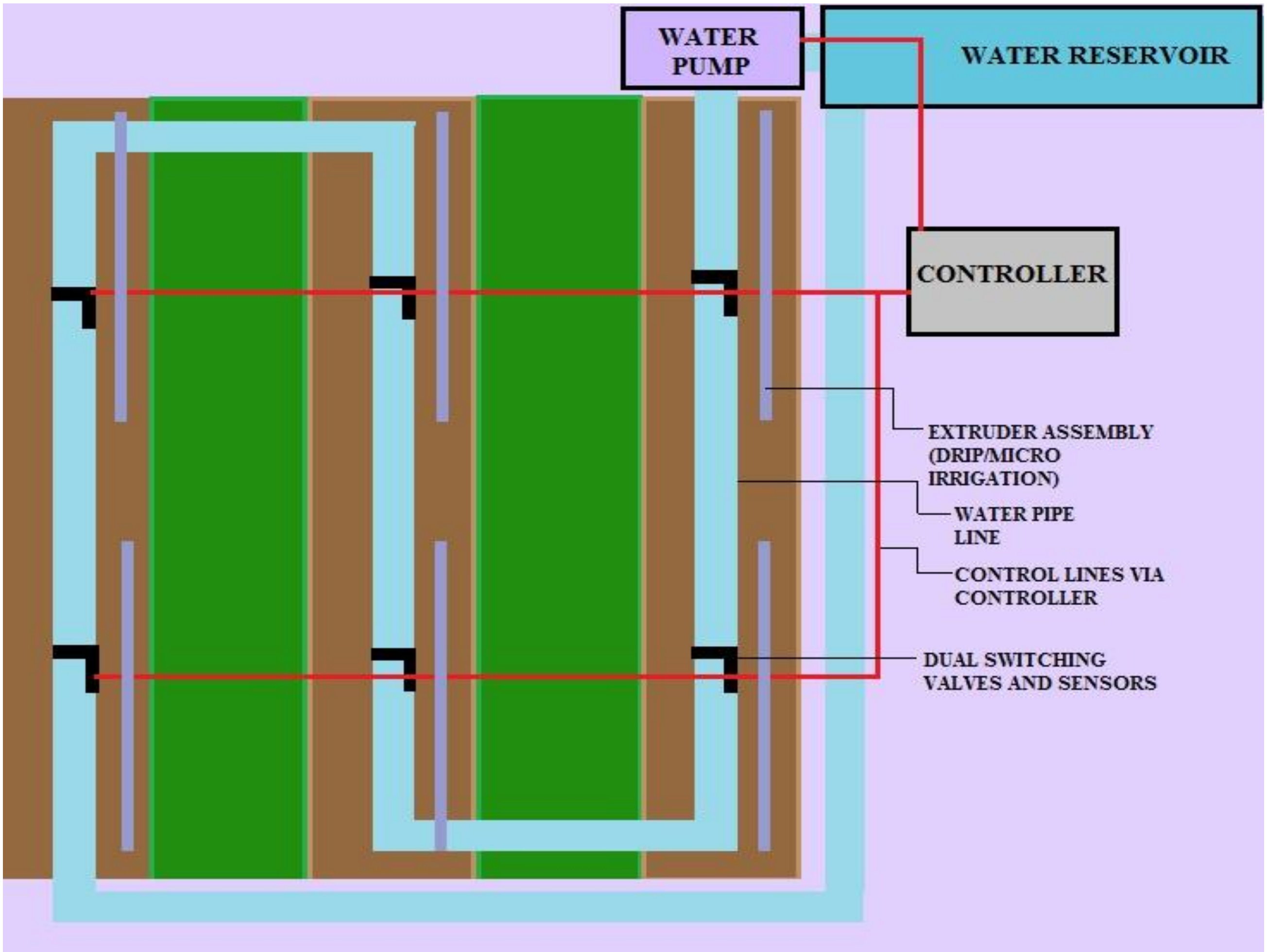

FIGURE 4.1: Practical Design for Irrigation in Flat Surfaced - Trench Irrigation

- Current sensor data are obtained from the sensors which are integrated with the dual switching valve system. The Sensor includes two types of sensors - Soil sensor and Pressure sensor. The Soil sensor senses soil moisture content and gives relevant information to calculate Decay Rate. Pressure sensor senses abnormal change in pressure in the water pipe.
- The Extruder that directs water flow from the pipes to the soil can be placed in two ways. Either Extruders will be above the soil in which we will employ drip irrigation Technique or they can be placed at the root level. Root level irrigation or Micro-Irrigation is recommended that saves water by preventing it from evaporating.
- Re-assuring minimum redundancy, a single water pipeline, which is supplied by a (water pump that maintain adequate pressure in response to the control signals from the controller) is used. This also reduces system complexity. If an area of land is

  too big for single water pipeline, then it also means that the soil moisture will vary greatly at two extreme points in the field. This means employing two or more Irrigation Systems, which will likely share some common data.
- Control lines via controller sends control signals and receives sensor data. Since, system is not a critical one there is no necessity for introducing redundancy into the system. Hence, control lines adopts half-duplex transmission mode cycle between sending and receiving data using the same communication link/line.
- In Fig 4.1, we show how irrigation system can be applied to trench irrigation. Appropriate adjustments in the adjustments of equipments are expected to make if a different cultivation pattern is used.
- The Dual Switching Valve is a special arrangement of two electrically triggered valves that will cause of the flow of water to irrigate the land when appropriate control signals are applied. It consists of two valves that are placed in perpendicular arrangement. One valve controls the flow of water from in the cross section of the Water Pipe. Another valve controls the Flow of water from the Water Pipe to the Extruder Assembly that is laterally attached to the pipe.
- When Irrigation is to be done through a particular Extruder, one of the cross-sectional valve blocks the flow of water to the subsequent parts of the pipe, followed by the opening of the lateral valve of the extruder through which irrigation is desired.
- The Controller closes the Cross-sectional Valves in Round-Robin Fashion to periodically operate the Extruders. Multiple adjacent Extruders can be

operated by closing the Cross-sectional Valve that is immediately next to the Extruder farthermost from the Water Pump that is to be operated. Using this functionality, several cycles of the controller can be saved when it is operating in "Normal Mode".

5. SUGGESTED HARDWARE SPECIFICATION

This section includes brief description of hardware and alternatives to them that can be used.

5.1 Microcontroller

The Microcontroller will handle all necessary computation related to controlling the Irrigation System. One of the important requirements that serves becomes a major factor in selection of microcontroller is handling of large amount of inputs and output. Any 8/16/32-bit Microcontroller such as Atmega32/ PIC32MX series [9] [10] [11] will be optimum in terms of cost and performance. If by any chance the input/output fall short of the requirement, then a external de-multiplexer in synch with microcontroller or internally programmed de-multiplexing can be performed sacrificing some clock cycles.

5.2 Processor

A DSP processor like low power C5000 series of DSP Processor [12] would serve the purpose as it requires making several iterations before forecasting the weather parameters and Soil Moisture Decay rate. If a DSP processor is not used, these iterations would not only increase computational load on microcontroller, but also waste clock cycles intended for irrigation control.

5.3 Soil Moisture Sensor

For constant field sensing, a low cost soil moisture sensor [13] can be used. Also air moisture can be modified to make the appropriate soil moisture sensor. Offsets are acceptable to some extent, but moderate overshooting and undershooting can cause severe issues.

5.3 Storage

Internal storage for frequent recall can be provided by using solid-state storage devices like Higher Classes of Micro-SD cards. For Archival Storage, Magnetic tape Hard-disks are appropriate.

6. CONCLUSION

The Irrigation system presented was inspired from [14] which also served as a guideline while strategizing the system design. To make it efficient, this stated the use of forecasting methods and different controlling methods considering the diversity in climatic condition of a region. Here efforts have been made to reduce the overall cost of the system which included use of lesser equipments to irrigate the same area of land (using a single pipeline and water pump, Section IV).

Though, the proposed practical design it will not be suitable for some topography, but the irrigation techniques mentioned in [14] can be implemented using the abstract design (Section III) and hence suggesting a use of a different Irrigation System.

7. REFERENCES

[1] Rural Infrastructure chapter-6, India Infrastructure Report 2007

[2] Arefin, M.T., Banik, M., Rahim, I., Islam, T. and Biswas, T., 2012, May. Automated irrigation control system: An advanced approach. In *Informatics, Electronics & Vision (ICIEV), 2012 International Conference on* (pp. 516-520). IEEE.

[3] Hanswal, P., Dale, O., Gupta, D. and Yadav, R.N., 2013, April. Designing a Central Control Unit and Soil Moisture Sensor Based Irrigation Water Pump System. In *India Educators' Conference (TIIEC), 2013 Texas Instruments*(pp. 306-310). IEEE.

[4] Kumar, Jayendra., Mishra, Srinath., Hansdah, Anurag., Kumar, Rajiv., 2016, Modified Sliding Window Algorithm for Weather Forecasting. Accepted for publication in *Technological Innovations in ICT for Agriculture and Ruler Development* (TIAR 2016). IEEE

[5] Sivanandam, S.N., Sumathi, S. and Deepa, S.N., 2007. *Introduction to fuzzy logic using MATLAB* (Vol. 1). Berlin: Springer.

[6] Benzekri, A., Meghriche, K. and Refoufi, L., 2007, July. PC-based automation of a multi-mode control for an irrigation system. In *2007 International Symposium on Industrial Embedded Systems* (pp. 310-315). IEEE.

[7] Zhou, G. and Birdwell, J.D., 1992, March. PID autotuner design using machine learning. In *Computer-Aided Control System Design, 1992.(CACSD), 1992 IEEE Symposium on* (pp. 173-179). IEEE.

[8] Lucksman, S., Subramaniyam, P., Suntharalingam, H., Fernando, S.G.S. and Manawadu, C.D., 2013, April. Ralapanawa RND-Automated water management system for Irrigation Department, Sri Lanka. In *Computer Science & Education (ICCSE), 2013 8th International Conference on* (pp. 213-217). IEEE.

[9] Atmel 8-bit Microcontroller with 32KBytes In-System Programmable Flash (ATmega32 ATmega32L) http://www.atmel.com/avr

[10] Atmel 32-Bit AVR Microcontroller (AT32UC3Axxxx, AT32UC3A1128B) (http://www.atmel.com/avr

[11] Microchip Low- cost PIC 32-bit Microcontroller (http://www.microchip.com).

[12] Texas Instruments C5000™ ultra-low-power DSP (www.ti.com/lsds/ti/processors/dsp).

[13] Soil Moisture Sensor SEN - 13322, SparkFun.

[14] Brouwer, C., Goffeau, A. and Heibloem, M., 1985. Introduction to irrigation; a manual. *Irrigation Water Management. Training manual (FAO).*