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WSN Based Smart Control and Remote Field Monitoring of Pakistan's Irrigation System Using SCADA Applications

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Abstract One of the main factors to measure the economy of any country is its gross domestic product rate and the agricultural sector is one of its key entities. To support the agricultural sector, water is the main source to irrigate dry lands. This research entitles the idea of implementation of wireless sensor networks as remote terminal units (RTUs) and local control for supervisory control and data acquisition applications. These RTUs measure various factors including land and air humidity, type of field and its temperature. On the basis of this information, the amount of water needed at different types of fields can be supplied and fortunately great amount of water can be saved for other commercial applications. It has been visualized in this research that with the implementation of the proposed method on Pakistan's irrigation network, the productivity of lands can be increased by approximately 20–25% and yearly 2150 cusecs of water can be saved.

Keywords WSN technology · SCADA system · RTU · Irrigation network · Wireless sensors

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1 Introduction

In this modern era, there is a need for effective utilization of water and other natural resources. Therefore researchers all around the world are engaged in finding the solutions with the help of modest technologies. Pakistan is primarily an agricultural country where almost 70% of its inhabitants are dependent on the agriculture sector. Day by day the need is increasing for more and more productivity of yields to satisfy the requirements of individuals. Hence there is a need to adopt efficient methods for irrigation not only to save water resources but also to increase the productivity of the field. It was observed that the traditional methods of water distribution and supply must be enhanced or replaced with modern advanced techniques just like wireless sensor networks implemented with SCADA applications as RTUs [1]. This method is cost effective, safe, involves reliable data transfer and, with flexible network configuration, has easy deployment. This technique will clearly enhance the effectiveness of water distribution and the water would be supplied on the basis of field requirements. The wireless sensor networks collect information from different fields and with the help of wireless link they transfer those to a main sever at the central control center, were decision making steps are taken as per the measured values and then commands are generated to regulate the flow of water.

Another main disadvantage with traditional irrigation systems is that the farmers do not have prior information about important environmental parameters such as temperature, soil moisture, humidity and other parameters. If these parameters were properly looked after and monitored, water will be more effective to the crops.

In order to resolve the issues which incorporate destruction of soil fertility and also waste of water resources in agricultural yield, there is a need for an automatic irrigation system, which can provide water to farms according to their moist content and soil type. Sensor nodes are deployed across the different fields at RTU points to monitor and collect data regarding temperature, humidity and pH of the field [2].

David et al. [3] presented a wireless sensor network (WSN) design for monitoring and irrigation control. They analyzed United States (US) irrigation system with WSN technology and found that with the implication of such technology, reliability and controllability of irrigation has been increased. They also focused that the use of this system which has led to financial and labor savings, faster crop growth, reduced chemical application and reduced pests to farmers. Kohanbash et al. [4] demonstrated the use of wireless communications in supervisory control (SCADA) over the suggested test Irrigation network. They analyzed the use of a supervisory scheme for monitoring and controlling the pressures of irrigation pumps and the water quantity. They also practiced GPRS based communication for distant regulation. Burt and Styles [5] presented the modern control of water and its performance impact on irrigation systems. They collected data from different fields and analyzed their core contents to decide suitable water requirements in order to achieve high yield. Zhao et al. [6] analyzed the automatic irrigation system using wireless sensor networks (WSN) and Multi-Source Info Synthesis (MSIS) using entropy. They investigated that, the use of WSN and MSIS diminishes water ingestion and power feeding. They observed that the solitary trajectory for communication path may extend to 350 m and may grasp 6 stages for packet communication. Gao and Zang [7] presented a smart irrigation arrangement using a wireless sensor network based on fuzzy controls to facilitate the online monitoring and controlling. They evaluated the system which had the control technique of dual input and sole response fuzzy. They utilized fuzzy environmental tool box for demonstrating and investigating the scheme and established the association between junk of input and output responses. They prepared the control scheme much logical by utilizing fuzzy logic statements.

This research involves the application of wireless sensor networks as RTUs in SCADA system. The proposition was verified by means of LabVIEW software over the Pakistan's irrigation network. Initially a program was constructed with the given data values of irrigation network of Pakistan and then run in the control panel. Since the irrigation network of Pakistan has large roots, therefore for visualization we have limited our work to small Rice canal Larkana [8], a small part of Pakistan's irrigation network. With such analysis, this idea then can be taken to larger scales to rationalize our proposition just by expanding network.

2 Irrigation Network of Pakistan

Pakistan has one of the largest irrigation systems of the world with five long rivers, namely Indus, Ravi, Sutlej, Chenab and Jhelum [8] as shown in Fig. 1. The average annual discharge of [the average annual discharge of Pakistan's irrigation network varies from 100,000 cusecs to 1200,000 cusecs and may lead to floods in rough weather conditions. This may affect the human lives, crops and property, if not controlled and monitored properly. Pakistan's irrigation network is serving 3450 thousand acres of adjoining cultivated land. Indus River with its tributaries is the key source of water for irrigation in Pakistan. In order to control the water flow and to avoid the flood effects, three major dams namely Tarbela, Chashma and Mangla have been constructed on the given river system in Pakistan. The total storage capacity of these dams is about 12.5 MAF (Million Acre Foot), supplying 19 barrages, 12 inter-link canals and 43 autonomous irrigation canal directives [8].

Barrages are used to divert river water into off taking canals. Yearly, on average, 106 MAF of water is drawn from canals, with 50 MAF ground water storage per annum. Around 3 million distinct farms with an average size of about 12 acres are assisted through this network [8].

Pakistan has approximately 55 MAF ground water storage capacities. The environmental circumstances are most promising for pumping by tube-wells. Round about 15,550 large capacity tube wells and 469,546 low capacity private tube wells are installed currently in Pakistan. For the last ten years, the ground water storage in Indus sink has been increased from 33.4 MAF to 50 MAF. Since the quantity of water is variable, approximately 28% area of Sindh and 79% area of Punjab provinces of Pakistan rely on groundwater storage for irrigation [8].

In the Sindh province of Pakistan there are three big barrages namely Sukkur Barrage, Guddu Barrage and Kotri Barrage [8]. This research has taken the network of Sukkur Barrage for case study, which will be defined in Sect. 5.

3 Structure of the Proposed Working System

The entire working system is based on two sub systems, wireless sensor networks and SCADA monitoring center. At irrigation fields for monitoring and control, different sensor nodes, controller nodes, irrigation tubes, stem irrigation and irrigation regulating valves are installed [9]. The framework of the working system is shown in Fig. 2. In order to provide the coverage to the entire network and lessen the node energy feeding and the cost margin

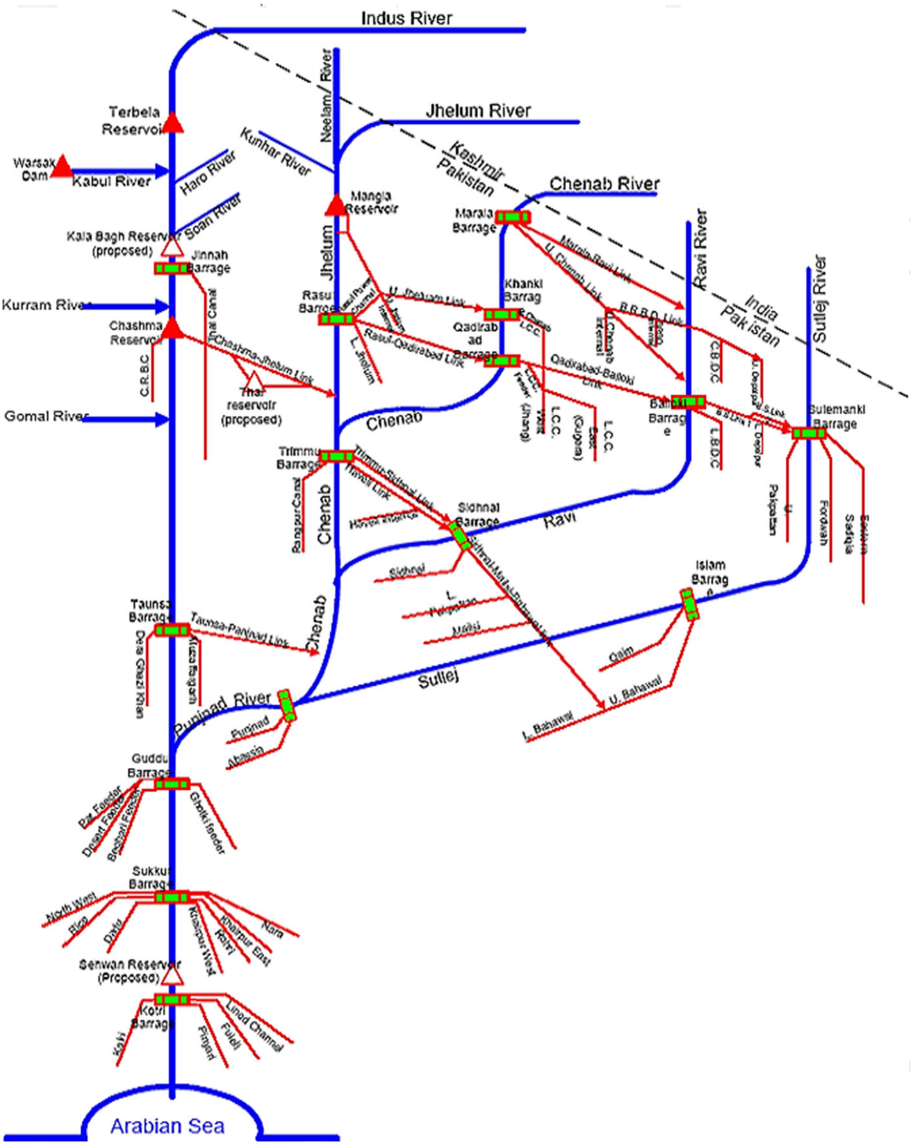

Fig. 1 Single line diagram of Pakistan's irrigation network [8]

simultaneously, routing nodes are used to collect data from sensor nodes and send them to the main sever with the help of the coordinating nodes. The majority of the sensor nodes behave as station units for gathering and directing data to routing or nearby coordinating nodes. SCADA control panel is extended to provide coverage to all sensor and coordinating nodes. SCADA functions can be preceded at conventional times and, according to irrigation commands received from the main sever controlling unit, valves can be opened or closed.

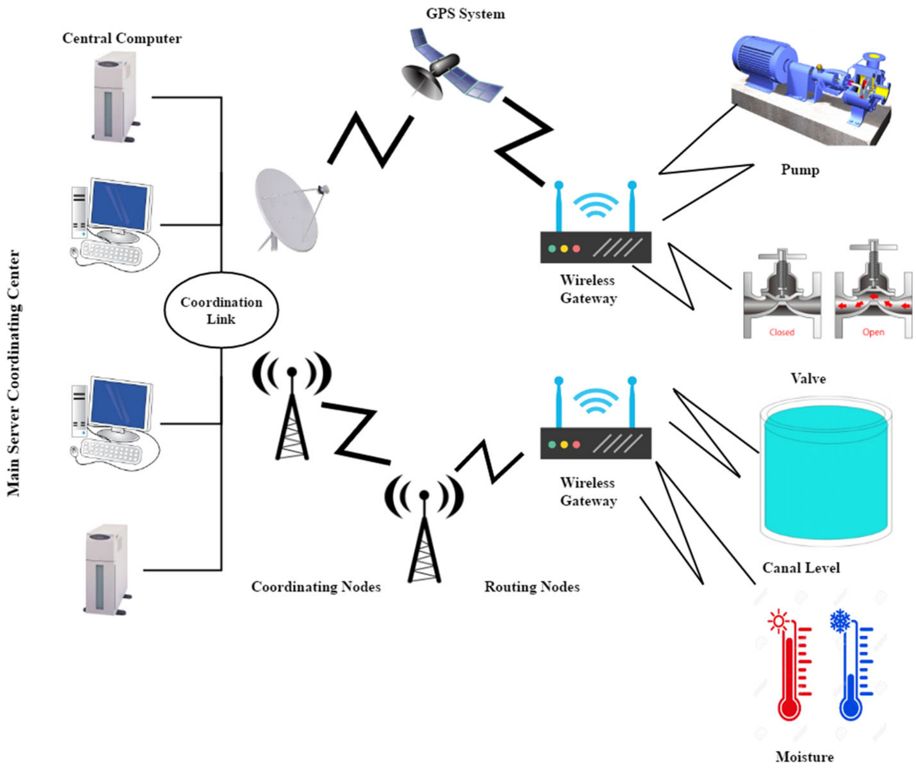

Fig. 2 Context of working arrangement [4]

Wireless sensor networks consist of sensor, routing and coordinating nodes and are powered through solar energy panel installed at the fields [10]. The temperature and humidity sensors collect the respective information and then transmit it to the wireless gateway through nRF 2401 [10], which is a 2.4 GHz wireless RF transceiver. The data from the wireless gateway is sent to the central computer by means of serial bus RS (Recommended Standard) 232 [10]. The main server at the monitoring center stores the real time soil moisture content data collected from all the sensor nodes into the database. It estimates water prerequisite for crop irrigation according to the plant physiology features in diverse plowing periods by comparing the collected values with reference norms. Then in accordance with these conditions, a signal is generated for the relay which actually controls the valve position for water flow. The relay is responsible for controlling, opening and closing the span of solenoid valve [11], to facilitate distant automatic alteration and regulation at irrigation fields.

4 WSN Nodes with Solar Energy Collecting and Management Module

All the wireless sensor network nodes are made of CC2530 IC. CC2530 features a RF transceiver with modern 8051 Microcontroller Unit (MCU), with 128/256 KB flash memory and 128/256 RAM and so many other controlling landscapes [12]. The CC2530

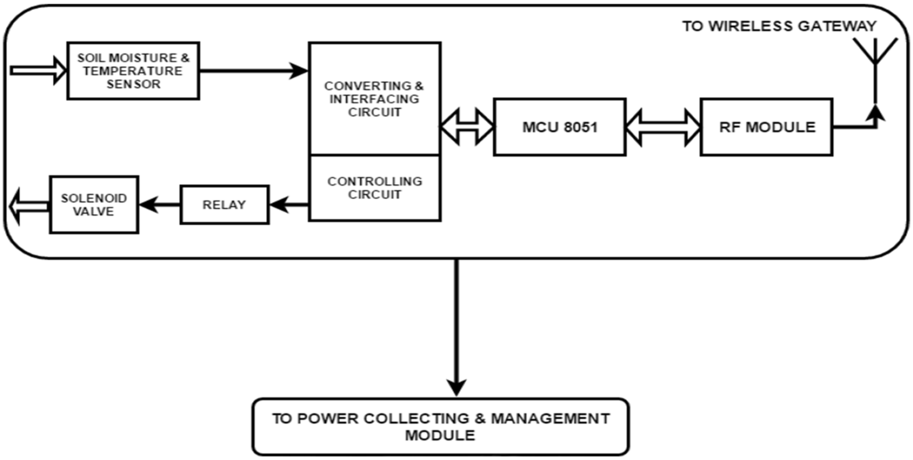

Fig. 3 Assembly of sensor node CC2530 [3]

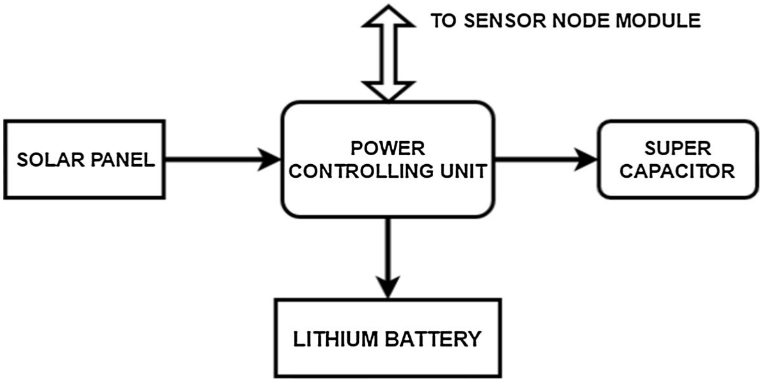

Fig. 4 The solar power collecting and management module [3]

unit has different operating modes, making it reliable for low power requirements of the network. The structure of the sensor node CC2530 is shown in Fig. 3.

In order to supply the sensor nodes, the solar energy based power supply system is adopted. This system is based on mainly solar modules with absolute capacitors and lithium batteries. Solar modules convert solar energy into electrical form and store it into super capacitors. Super capacitors supply energy to sensor nodes. Lithium batteries are installed for emergency supply [12]. The entire setup is shown in Fig. 4 as a part of Fig. 3.

The power collecting and management module is based on CN3063 IC, with single lithium battery unit. No external current sensor and current restraining diode are needed to CN3063 module. CN3063 module has 8 bit ADC which is helpful to operator for increasing the input of current for energy. CN3063 has a built-in modular circuit which maintains its temperature under declared limits. CN3063 module features a power down mode which enables power saving easily reachable and working current to remain below 0.003 A.

Table 1 Performance parameters of TDR-3A sensor

Field parameters	Performance catalogue
Temperature and humidity	Range: 0–1 Accuracy: ±0.02 Measuring field: 18 cm^2 Operational voltage: 12–24 V DC Working current: 0.05–0.07 A Output: 0.004–0.02 A

4.1 Soil Moisture Sensor

The type of soil moisture sensor applied in the working system is TDR-3A, manufactured by Jinjiang Sunshine Technology Company Limited [13]. This sensor has the ability of measuring soil humidity and temperature, with high precision rate. The performance catalogues of TDR-3A sensor are illustrated in Table 1.

4.2 Controlling Circuit Model

The controlling Circuit gives the signal to the relay, which is responsible for opening and closing the solenoid valve [3]. An NPN transistor is used for driving the relay as shown in Fig. 5.

The solenoid valve used in this research is 100-DVF which is manufactured by Rain Bird Corp [4]. Initially this valve is in the closed position. Its function is to control the flow

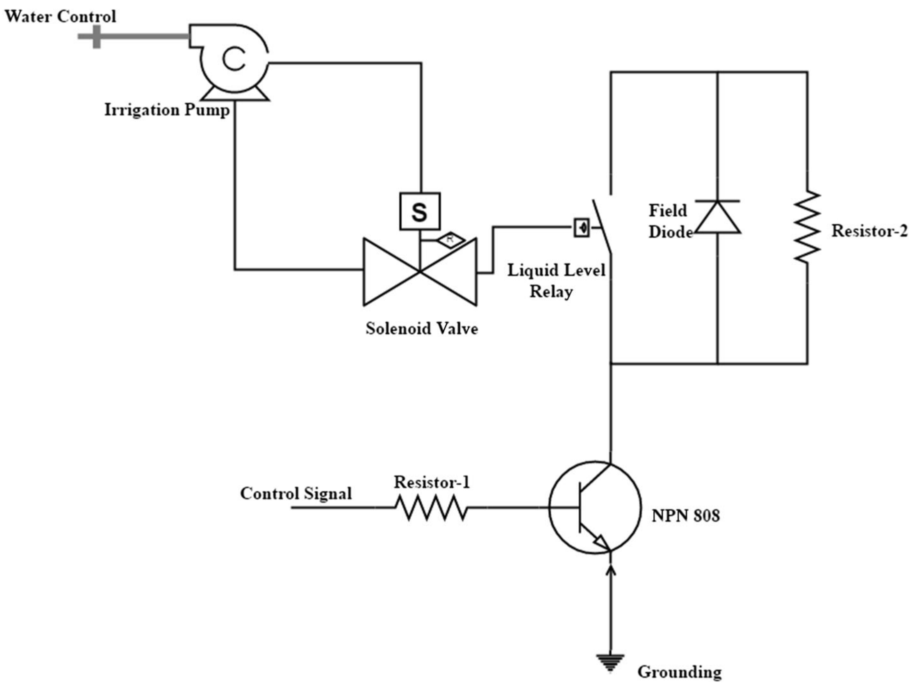

Fig. 5 Controlling circuit [6]

of water at the irrigation fields according to the command received from the central computer unit. TDR-3A is equipped with a battery operated irrigation control module, which is responsible for opening and closing the valve, by supplying the negative and positive signal to the transistor.

5 Case Study of Proposed System

From the large Pakistan's irrigation network, this research focus considers one of its barrages Sukkur Barrage for case study. Sukkur Barrage consists of 66 bays each of 60 feet was constructed in 1932 and is the world's largest unique united irrigation structure [8]. The irrigation area served by Sukkur Barrage on both sides of the Indus River through off taking canals is 8240 thousand acres. Out of this area, presently 7550 thousand acres are cultivated. Different canals tapped from Sukkur Barrage have a total operating capacity of 64,728 cusec as compared to total designed capacity of 47,530 cusecs. The Rice Canal one of the key distributing networks of Sukkur barrage is providing water to 250,000 acres for cultivations [8]. The Rice Canal has a length of 65 miles and demands 21,500 cusecs to meet its needs for the agricultural sector. But due to the use of traditional controls and monitoring areas, the Rice canal takes 23,650 cusecs of water from the Sukkur barrage. However with the implementation of our proposed method, 2150 cusecs of water can be saved on this small network of Pakistan's irrigation, which eventually increases the efficiency of our irrigation system when applied to the entire network.

Figure 6 shows the internal view of the SCADA based Wireless Sensing Irrigation system, with inserted parameter approximated for the given data of the Rice Canal of the Sukkur Barrage. With this arrangement, moisture content values were recorded from four different fields irrigated by the Rice Canal. Wireless sensor nodes recorded the moisture content values from these four different fields and then sent them to the gateway by means

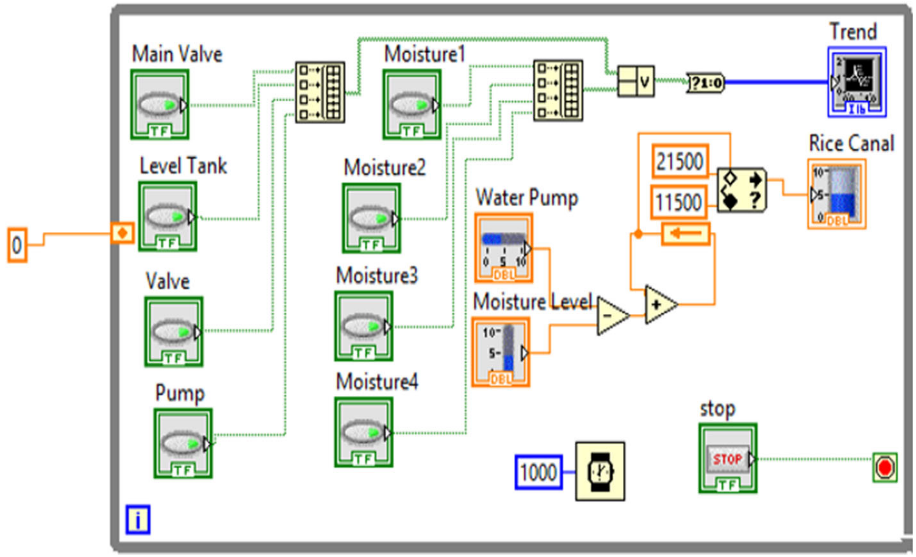

Fig. 6 Internal monitoring diagram for remote controlling at irrigation field

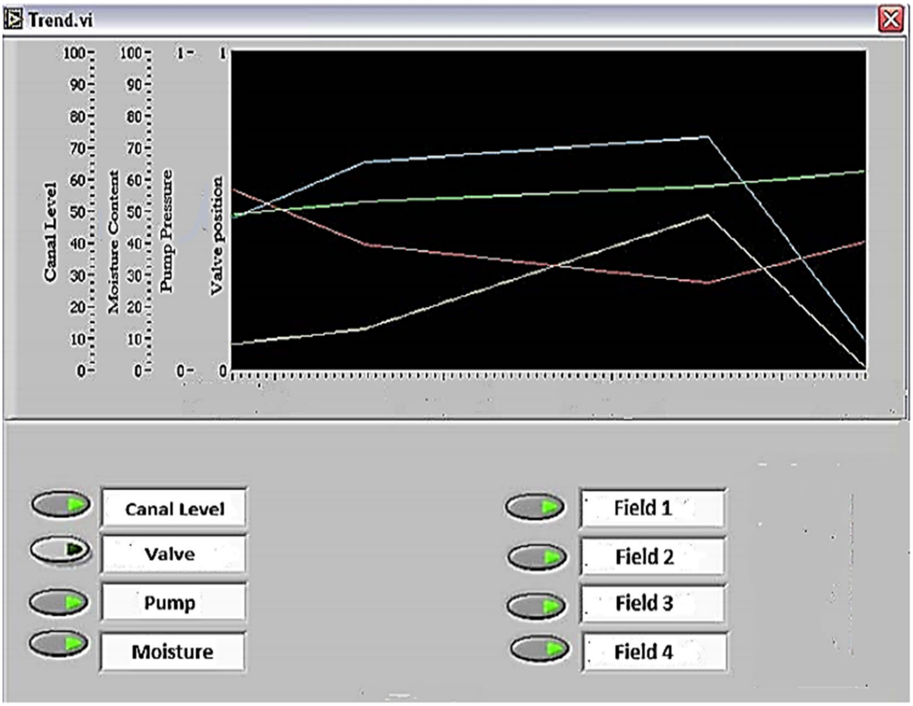

Fig. 7 Trend monitoring of remote irrigation fields

of wireless transmission. This data, by means of routing and coordinating nodes, was sent to the main SCADA sever computer as shown in Fig. 2. Then this moisture content data was compared with reference values and respective command was sent to the controlling relay to open or close the sinusoidal valve accordingly.

Figure 7 shows the trends of moisture contents recorded at various fields. In accordance with this moisture content data, the pressure of tube well pump fitted at the irrigation field was settled to the desired position. With this arrangement, the water level of the Canal was also measured. If its level dips down below 11,500 cusecs, which is its bottom limit then an alarm rings and the function would be stopped automatically. Since the low level of tank put the false condition in the looping statement and the loop halted then. It has been evaluated that with the implementation of proposed method the efficacy of irrigated lands can be increased by approximately 20–25% for different fields as shown in Table 5.

Table 2 shows the 2 h trend monitoring of four different fields. It has been observed that difference between the measured values and reference values is 2%. Therefore it is assured that with the implementation of WSNs as RTUs of a SCADA system, temperature and humidity values of different fields would be controlled so precisely that water-flow allowed from pumps will be in accordance [14].

Table 3 illustrates the data obtained with the help of sensors from four different fields for the optimal irrigation and yield productivity. For the irrigation field with peas and potatoes, in order to keep the moisture content low which is a need of this type of crop, the availability of water should be assured at 15%, with operating pressure of pump within the range of 0–15 kPa.

Table 2 Trend monitoring of moisture content at different fields

Operating time	Soil moisture content			
	Field 1	Field 2	Field 3	Field 4
1:35	61.4	9.6	48.5	49.2
1:45	52.3	14.5	49.2	54.7
1:55	41.2	19.7	49.8	57.5
2:05	37.6	25.6	50.2	59.3
2:15	32.7	29.7	51.6	62.5
2:25	28.7	34.8	51.9	65.2
2:35	25.6	38.4	52.6	69.7
2:45	24.7	40.6	54.3	52.6
2:55	28.9	32.6	55.1	36.7
3:05	34.6	20.4	56.8	18.3
3:15	39.7	9.8	57.4	11.1
3:25	41.5	1.2	58.7	7.8

Table 3 Data collected from different field for maximum water use capabilities

Name of crop	Optimal need of water (%)	Probability of moisture	Operating range of tube well pump (KPa)
Peas, potatoes…	15	Low	[0 0 10 15]
Trees, fruits…	30	Medium	[10 15 20 25]
Wheat	35	High	[20 25 40 40]
Rice	50	Pretty high	[45 50 55 60]

Table 4 Soil moisture content reading obtained from different fields

Moisture level (centibar)	Field condition	Operating range of pump
Soil moisture sensor reading		
10	Dry	[0, 0, 6, 12]
20	Normal	[6, 12, 18, 24]
30	Adequately wet	[18, 24, 30, 36]
40	Saturated	[30, 36, 60, 60]

Table 4 shows the condition of fields with respect to moisture content and pump operating pressure. It shows that when the moisture level is approximately 40 centi bars, the field is saturated. According to this information, the agricultural analyst can decide which crop will optimally be cultivated over this field, with the given range of pump pressure i.e. [30, 36, 60, 60] and so on. This whole data was collected through sensor nodes.

Table 5 reports the use of water, increase of productivity of different fields after evaluating moisture stress-yield functions and efficiencies of different fields based on crop coefficients for four different fields irrigated by rice canal. It can be visualized from Table 5 that enormous positive changes are obtained in terms of productivity, efficiency

Table 5 Performance evolution of different fields with proposed technique

Field name	Water quantity supplied (mm)		Productivity/yield (kg/ha)		Field efficiency (%)	
	Before	After	Before	After	Before	After
Field 1	845	620	4915	5585	47	68
Field 2	740	555	1190	1429	55	76
Field 3	562	401	5120	5710	45	70
Field 4	1748	1514	26,000	31,000	59	79

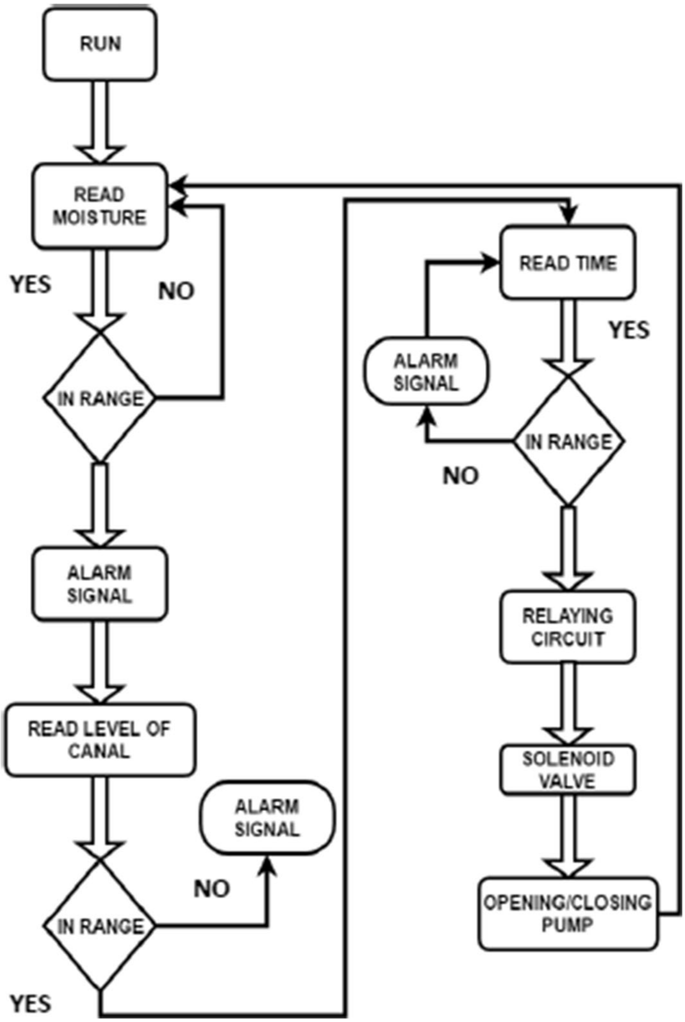

Fig. 8 Flow chart for representing sequence of system operations

and water savage, which proves the reliability, availability and ability of the proposed technique in the field of irrigation. Hence the GDP rate of Pakistan will increase if the proposed method is applied in real time applications over the irrigation network.

Figure 8 shows the flow chart of the proposed system, representing the sequence of the operations occurring in the SCADA system for the wireless based irrigation system. Initially a signal is sent to sensor nodes to record the data, if it is in range, then an alarm signal will notify the results, ultrasonic sensors will measure the water level of the Canal. If again its level is at defined limits, a signal will be sent to the relaying circuit to open or close the solenoid valve accordingly. Hence in this method the required irrigated water will be supplied to fields, which will not only facilitate water saving but it also ensures the maximum fertility of fields.

6 Conclusion

With the aim of removing or replacing traditional controls installed at Pakistani fields with advanced technologies, an idea was proposed to combine wireless sensor networks with the SCADA system for making irrigation automatic and efficient. The suggested design was modeled and analyzed through LabVIEW software over Pakistan's irrigation network. Keeping in view the daunting energy crisis of Pakistan, the solar management controlling system was adopted to supply power to sensor nodes installed at irrigation fields. The main server computer at the control center retrieved data from sensor nodes applied at different fields, which were responsible for collecting various field values like humidity, temperature and pH of field. According to the physical conditions of the irrigated fields, the main server transmitted commands to the relay for operating the solenoid valve, to open or close, in order to accomplish the objective of efficient irrigation scheme. Finally with this proposition, it was found that we had better yield, increased working efficiency and quality and enormous amount of water was assured. The results obtained after implementing the proposed method assured that not only water could be saved for future use but also the productivity and efficiency of irrigated lands would be enriched. It was concluded that with the implementation of the proposed method, 2150 cusecs of water per year at the Rice canal would be saved and efficiency of different fields would be improved by approximately 20–25%. This method when rationalized over the entire irrigation network of Pakistan would save more water and also increase the fertility of Pakistani irrigation fields that eventually would lead to the increased GDP rate of the country.

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