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WSN based Automated Irrigation System using GSM/GPRS Technology

[1]Madugula Kranthi Kumar; [2]N. Kartheek & [3]CH. Ramesh Babu

1. M.Tech, SVS Institute of Technology, Warangal, Hasanparthy, Bheemaram, Hanamkonda, Telangana 506015.
2. Asst. Prof, SVS Institute of Technology, Warangal, Hasanparthy, Bheemaram, Hanamkonda, Telangana 506015.
3. Associate Prof, SVS Institute of Technology, Warangal, Hasanparthy, Bheemaram, Hanamkonda, Telangana 506015.

Abstract—

An automated irrigation system was developed to optimize water use for agricultural crops. The system has a distributed wireless network of soil-moisture and temperature sensors placed in the root zone of the plants. In addition, a gateway unit handles sensor information, triggers actuators, and transmits data to a web application. An algorithm was developed with threshold values of temperature and soil moisture that was programmed into a microcontroller-based gateway to control water quantity. The system was powered by photovoltaic panels and had a duplex communication link based on a cellular-Internet interface that allowed for data inspection and irrigation scheduling to be programmed through a web page. The automated system was tested in a sage crop field for 136 days and water savings of up to 90% compared with traditional irrigation practices of the agricultural zone were achieved. Three replicas of the automated system have been used successfully in other places for 18 months. Because of its energy autonomy and low cost, the system has the potential to be useful in water limited geographically isolated areas.

I.INTRODUCTION :

AGRICULTURE uses 85% of available freshwater resources worldwide, and this percentage will continue to be dominant in water consumption because of population growth and increased food demand. There is an urgent need to create strategies based on science and technology for sustainable use of water, including technical, agronomic, managerial, and institutional improvements [1]. There are many systems to achieve water savings in various crops, from basic ones to more technologically advanced ones. For instance, in one system plant water status was monitored and irrigation scheduled based on canopy temperature distribution of the plant, which was acquired with thermal imaging [2]. In addition, other systems have been developed to schedule irrigation of crops and optimize water use by means of a crop water stress index (CWSI) [3]. The empirical CWSI was first defined over 30 years ago [4]. This index was later calculated using measurements of infrared canopy temperatures, ambient air temperatures, and atmospheric vapor pressure deficit values to determine when to irrigate broccoli using drip irrigation [5]. Irrigation systems can also be automated through information on volumetric water content of soil, using dielectric moisture sensors to control actuators and save water, instead of a predetermined irrigation schedule at a particular time of the day and with a specific duration. An irrigation controller is used to open a solenoid valve and apply watering to bedding plants (impatiens, petunia, salvia, and vinca) when the volumetric water content of the substrate drops below a set point [6]. Other authors have reported the use of remote canopy temperature to automate cotton crop irrigation using infrared thermometers. Through a timed temperature threshold, automatic irrigation was triggered once canopy temperatures exceeded the threshold for certain time accumulated per day. Automatic irrigation scheduling consistently has shown to be valuable in optimizing cotton yields and water use efficiency with respect to manual irrigation based on direct soil water measurements [7]. An alternative parameter to determine crop irrigation needs is estimating plant evapotranspiration (ET). ET is affected by weather parameters, including solar radiation, temperature, relative humidity, wind speed, and crop factors, such as stage of growth, variety and plant density, management elements, soil properties, pest, and disease control [8]. Systems based on ET have been developed that allow water savings of up to 42% on time-based irrigation schedule [9]. In Florida, automated switching tensiometers have been used in combination with ET calculated from historic weather data to control automatic irrigation schemes for papaya plants instead of using fixed scheduled ones. Soil water status and ET-based irrigation methods resulted in more sustainable practices compared with set schedule irrigation because of the lower water volumes applied [10]. An electromagnetic sensor to measure soil moisture was the basis for developing an irrigation system at a savings of 53% of water compared with irrigation by sprinklers in an area of 1000 m2 of pasture [11]. A reduction in water use under scheduled systems also have been achieved, using soil sensor and an evaporimeter, which allowed for the adjustment of irrigation to the daily fluctuations in weather or volumetric substrate moisture content [12]. A system developed for malting barley cultivations in large areas of land allowed for the optimizing of irrigation through decision support software and its integration with an in- field wireless sensor network (WSN) driving an irrigation machine converted to make sprinkler nozzles controllable. The network consisted of five sensing stations and a weather station. Each of the sensing stations contained a data logger with two soil water reflectometers, a soil temperature sensor, and Bluetooth communication. Using the network information and the irrigation machine positions through a differential GPS, the software controlled the sprinkler with application of the appropriate amount of water [13]. Software dedicated to sprinkler control has been variously discussed [14]. A data acquisition system was deployed for monitoring crop conditions by means of soil moisture and soil, air, and canopy temperature measurement in cropped fields. Data were downloaded using a handheld computer connected via a serial port for analysis and storage [15]. Another system used to achieve the effectiveness of water management was developed based on a WSN and a weather station for Internet monitoring of drainage water using distributed passive capillary wick-type lysimeters. Water flux leached below the root zone under an irrigated cropping system was measured [16]. There are hybrid architectures, wireless modules are located inside the greenhouse where great flexibility is required, and wired modules are used in the outside area as actuator controllers [17]. The development of WSNs based on microcontrollers and communication technologies can improve the current methods of monitoring to support the response appropriately in real time for a wide range of applications [18], considering the requirements of the deployed area, such as terrestrial, underground, underwater, multimedia, and mobile [19]. These applications involve military operations in scenarios of battlefield, urban combat, and force protection, with tasks of presence, intrusion, ranging, imaging, detection of chemical, toxic material, biological, radiological, nuclear, and explosive [20], [21]. In addition, sensor networks have been used in health care purposes for monitoring, alerting, assistance, and actuating with security and privacy to support real-time data transmission [22]. Vital sign monitoring, such as ECG, heart rate, body temperature, has been integrated in hospitals and homes through wearable or e-textile providing reports and alerts to personal in case of emergency and tracking the location of patients within the hospital limits [23]. WSNs have been used to remote monitor healthcare of dependent people at their homes through several biomedical sensors such as ECG, blood pressure, body temperature [24], and body motion [25]. Home applications comprised wireless embedded sensors and actuators that enable monitoring and control. For comfort and efficient energy management, household devices have been controlled through sensors that monitor parameters such as temperature, humidity, light, and presence, avoiding waste of energy [26]. Sensor networks have been used for security purposes, based on several sensors such as smoke detectors, gas sensors, and motion sensors, to detect possible risk situations that trigger appropriate actions in response, such as send an alert to a remote center through wireless communication [27]. In industrial environments, WSNs have been installed to provide real-time data acquisition for inventory management, to equipment monitoring for control with appropriate actions, reducing human errors and preventing manufacturing downtime [28], [29]. For example, industrial WSN have been implemented to motor fault diagnosis [30] and for the monitoring of the temperature-sensitive products during their distribution has been proposed [31]. In addition, there are wireless systems for structural identification under environmental an operational parameters, such as load in bridges [32]. In environmental applications, sensor networks have been used to monitor a variety of environmental parameters or conditions in marine, soil, and atmospheric contexts [33]. Environmental parameters, including humidity, pressure, temperature, soil water content, and radiation with different spatial and temporal resolution and for event detection such as disaster monitoring, pollution conditions, floods, forest fire, and debris flow is continuously monitored [34]–[36]. Applications in agriculture have been used to provide data for appropriate management, such as monitoring of environmental conditions like weather, soil moisture content, soil temperature, soil fertility, mineral content, and weed disease detection, monitoring leaf temperature, moisture content, and monitoring growth of the crop, automated irrigation facility and storage of agricultural products [37]–[39]. Various commercial WSNs exist, ranging from limited and low-resolution devices with sensors and embedded processors to complete and expensive acquisition systems that support diverse sensors and include several communication features [40]. Recent advances in microelectronics and wireless technologies created low-cost and low-power components, which are important issues especially for such systems such as WSN [41]. Power management has been addressed in both hardware and software with new electronic designs and operation techniques. The selection of a microprocessor becomes important in power aware design. Modern CMOS and micro-electro-mechanical systems (MEMS) technologies allowed manufacturers to produce on average every three years a enhance generation of circuits by integrating sensors, signal conditioning, signal processing, digital output options, communications, and power supply units [42], [43]. For example, the parallel combination of a battery and a supercapacitor has been used to extend the runtime of low-power wireless sensor nodes [44]. Energy harvesting mechanisms have been employed, in cases where it is difficult for changing or recharging batteries, hence this strategy has involved combining it with efficient power management algorithms to optimize battery lifetime. Power harvesting is a complementary approach that depends on ambient energy sources, including environmental vibration, human power, thermal, solar, and wind that can be converted into useable electrical energy [45]–[47]. On the other hand, several strategies have been implemented to reduce power consumption, such as power-aware protocols, resource and task management, communication, topology control and routing, models based on events, and congestion control mechanism to balance the load, prevent packet drops, and avoid network deadlock using a combination of predeployed group keys that allow the dynamic creation of high security subnetworks and optimizes energy efficiency of sensor networks [48], [49]. For instance, energy-saving strategies have been achieved through scheduling [50], [51], sleep or wake up schemes, and adaptive radio frequency (RF) in nodes, and choosing a network configuration [52]. There are also algorithms to maximize the network coverage ratio with a predefined balance the energy consumption in the whole WSN [53], to reduce both the transmission and the computational loads at the node level [54], and to estimate online the optimal sampling frequencies for sensors [55]. In a wireless node, the radio modem is the major power consuming component; recently, wireless standards have been established with medium access control protocols to provide multitask support, data delivery, and energy efficiency performance [56], such as the standards for wireless local area network, IEEE 802.11b (WiFi) [57] and wireless personal area network (WPAN), IEEE 802.15.1 (Bluetooth) [58], IEEE 802.15.3 (UWB) [59], and IEEE 802.15.4 (ZigBee) [60], and those open wireless communication standards for Internet protocol version 6 (IPv6) over low-power wireless personal area networks 6LoWPAN [61], [62], wireless highway addressable remote transducer Wireless HART [63], and ISA100.11a [64] developed by the International Society of Automation. In this paper, the development of the deployment of an automated irrigation system based on microcontrollers and wireless communication at experimental scale within rural areas is presented. The aim of the implementation was to demonstrate that the automatic irrigation can be used to reduce water use. The implementation is a photovoltaic powered automated irrigation system that consists of a distributed wireless network of soil moisture and temperature sensors deployed in plant root zones. Each sensor node involved a soil-moisture probe, a temperature probe, a microcontroller for data acquisition, and a radio transceiver; the sensor measurements are transmitted to a microcontroller-based receiver. This gateway permits the automated activation of irrigation when the threshold values of soil moisture and temperature are reached. Communication between the sensor nodes and the data receiver is via the Zigbee protocol [65], [66] under the IEEE 802.15.4 WPAN. This receiver unit also has a duplex communication link based on a cellular-Internet interface, using general packet radio service (GPRS) protocol, which is a packet-oriented mobile data service used in 2G and 3G cellular global system for mobile communications (GSM). The Internet connection allows the data inspection in real time on a website, where the soil-moisture and temperature levels are graphically displayed through an application interface and stored in a database server. This access also enables direct programming of scheduled irrigation schemes and trigger values in the receiver according the crop growth and season management. Because of its energy autonomy and low cost, the system has potential use for organic crops, which are mainly located in geographically isolated areas where the energy grid is far away.

II. AUTOMATED IRRIGATION SYSTEM:

The automated irrigation system hereby reported, consisted of two components (Fig. 1), wireless sensor units (WSUs) and a wireless information unit (WIU), linked by radio transceivers that allowed the transfer of soil moisture and temperature data, implementing a WSN that uses ZigBee technology. The WIU has also a GPRS module to transmit the data to a web server via the public mobile network. The information can be remotely monitored online through a graphical application through Internet access devices. A. Wireless Sensor Unit A WSU is comprised of a RF transceiver, sensors, a microcontroller, and power sources. Several WSUs can be deployed in-field to configure a distributed sensor network for the automated irrigation system. Each unit is based on the microcontroller PIC24FJ64GB004 (Microchip Technologies, Chandler, AZ) that controls the radio modem XBee Pro S2 (Digi International, Eden Prairie, MN) and processes information from the soil-moisture sensor VH400 (Vegetronix, Sandy, UT), and the temperature sensor DS1822 (Maxim Integrated, San Jose, CA). These components are powered by rechargeable AA 2000-mAh Ni-MH Cycle Energy batteries (SONY, Australia). The charge is maintained by a photovoltaic panel MPT4.8-75 (Power Film Solar, Ames, IN) to achieve full energy autonomy. The microcontroller, radio modem, rechargeable batteries, and electronic components were encapsulated in a waterproof Polyvinyl chloride (PVC) container These components were selected to minimize the power consumption for the proposed application.

ARM7

The ARM7 family includes the ARM7TDMI, ARM7TDMI-S, ARM720T, and ARM7EJ-S processors. The ARM7TDMI core is the industry’s most widely used 32-bit embedded RISC microprocessor solution. Optimized for cost and power-sensitive applications, the ARM7TDMI solution provides the low power consumption, small size, and high performance needed in portable, embedded applications.

The ARM7EJ-S processor is a synthesizable core that provides all the benefits of the ARM7TDMI low power consumption, small size, and the thumb instruction set while also incorporating ARM’s latest DSP extensions and enabling acceleration of java-based applications. Compatible with the ARM9™, ARM9E™, and ARM10™ families, and Strong-Arm® architecture software written for the

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ARM7TDMI processor is 100% binary-compatible with other members of the ARM7 family and forwards-compatible with the ARM9, ARM9E, and ARM10 families, as well as products in Intel's Strong ARM and x scale architectures. This gives designers a choice of software-compatible processors with strong price-performance points. Support for the ARM architecture today includes:

- Operating systems such as Windows CE, Linux, palm and SYMBIAN OS.
- More than 40 real-time operating systems, including qnx, Wind River's vxworks and mentor graphics' vrtx.
- Co simulation tools from leading eda vendors
- A variety of software development tools.

GSM:

The SIM900 is a complete Quad-band GSM/GPRS solution in a SMT module which can be embedded in the customer applications. Featuring an industry-standard interface, the SIM900 delivers GSM/GPRS 850/900/1800/1900MHz performance for voice, SMS, Data, and Fax in a small form factor and with low power consumption. With a tiny configuration of 24mm x 24mm x 3 mm, SIM900 can fit almost all the space requirements in your M2M application, especially for slim and compact demand of design.

- SIM900 is designed with a very powerful single-chip processor integrating AMR926EJ-S core
- Quad - band GSM/GPRS module with a size of 24mmx24mmx3mm
- SMT type suit for customer application
- An embedded Powerful TCP/IP protocol stack
- Based upon mature and field-proven platform, backed up by our support service, from definition to design and production

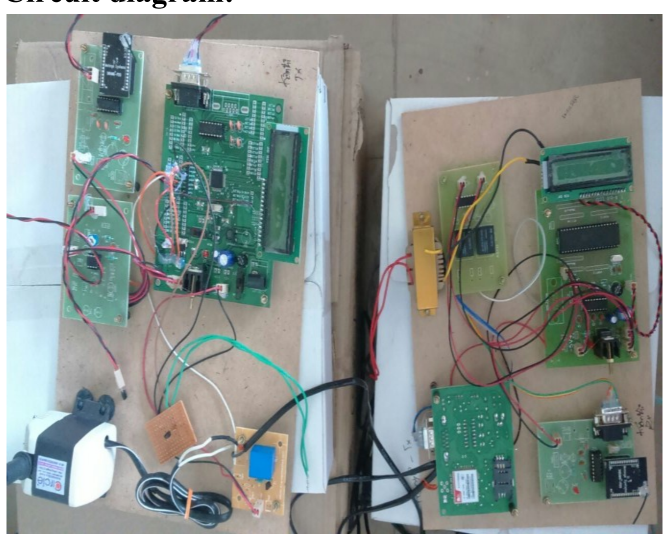
ZIGBEE:

ZigBee was designed to provide high data throughput in applications where the duty cycle is low and low power consumption is an important consideration. (Many devices that use ZigBee are powered by battery.) Because ZigBee is often used in industrial automation and physical plant operation, it is often associated with machine-to-machine (M2M) communication and the Internet of Things (IoT).

ZigBee is based on the Institute of Electrical and Electronics Engineers Standards Association's802.15 specification. It operates on the IEEE802.15.4 physical radio specification and in unlicensed radio frequency bands, including 2.4GHz, 900 MHz and 868 MHz. The specifications are maintained and updated by the ZigBee Alliance.

As of this writing, there are three ZigBee specifications: ZigBee, ZigBee IP and ZigBee RF4CE. ZigBee IP optimizes the standard for IPv6full mesh networks and ZigBee RF4CE optimizes the standard for partial mesh networks.

Circuit diagram:



CONCLUSION

The automated irrigation system implemented was found to be feasible and cost effective for optimizing water resources for agricultural production. This irrigation system allows cultivation in places with water scarcity thereby improving sustainability. The automated irrigation system developed proves that the use of water can be diminished for a given amount of fresh biomass production. The use of solar power in this irrigation system is pertinent and significantly important for organic crops and other agricultural products that are geographically isolated, where the investment in electric power supply would be expensive. The irrigation system can be adjusted to a variety of specific crop needs and requires minimum maintenance. The modular configuration of the automated irrigation system allows it to be scaled up for larger greenhouses or open fields. In addition, other applications such as temperature monitoring in compost production can be easily implemented. The Internet controlled duplex communication system provides a powerful decisionmaking device concept for adaptation to several cultivation scenarios. Furthermore, the Internet link allows the supervision through mobile telecommunication devices, such as a smartphone. Besides the monetary savings in water use, the importance of the preservation of this natural resource justify the use of this kind of irrigation systems.

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