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Automation of drip irrigation systems using energy-efficient wireless sensor and actuator network (WSAN)

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Abstract
This research paper states the design and implementation of wireless sensor and actuator network for the specific task of automating drip irrigation systems in urban gardens. The designed wireless sensor and actuator network consists of coordinator device and end-devices. Each end-device is equipped with soil moisture level sensor and actuator. End-devices measure the soil moisture level and based on the measured value open or close the dripping actuator. Furthermore, end-devices transmit the measured values to coordinator wirelessly through radio-module in every hour. Coordinator device collect data from every end-device with the use of radio-module and send it to user interface through Wi-Fi module. Wireless communication between coordinator and end-devices are executed by ZigBee wireless technology. Each end-device is powered up by three AA-size back-up batteries.

Keywords: automation, wireless sensor and actuator network, drip irrigation, ZigBee

Introduction

Gardening has very significant role in making profit and source of nutrition for many people in the world. Over the past years, establishment of gardens in urban areas, such as rooftop gardens and vertical gardens, are being popular and making the urban buildings attractive and the air fresh. However, the gardens require continuous attention in order to keep their quality. For example, irrigation of plants should be precisely performed in order to increase the yield or freshness. Generally, this issue is solved by automating the irrigation system, but we proposed the automation of irrigation system along with monitoring some garden parameters with use of WSAN. Furthermore, we designed energy efficient power section for our proposed irrigation system. There are many automated irrigation systems has been developed implemented utilizing WSAN standards.

In this paper [1], authors designed and implemented cost efficient and automated irrigation system using wireless sensor network. The communication between wireless nodes is implemented by the Chipson CC2420 radio module which operates in 2.4 GHz. This low power radio module can achieve maximum 50meters indoor and 120meters outdoor range. Each node includes TelosB mote and adequate sensors and actuators. In order to maximize the node life-time, authors added energy harvesting module using solar panel. Another paper [2] presents automatic irrigation system using Arduino and GSM. The designed system employs DHT 11 sensor to measure the humidity and the irrigation is executed based on the measured humidity level. The proposed irrigation system is suitable for spray irrigation method. It cannot be utilized for drip irrigation because the DHT11 sensor cannot measure the soil moisture level directly. The communication between the wireless nodes are performed by sending SMS on GSM module. Gardener also able to switch on or off the water pump by sending SMS, as well. Furthermore, solar cell charging unit was designed to extend back-up battery life time.

The design of wireless sensor network for the development of smart irrigation system is presented in this paper [3]. The designed wireless sensor network prototype consists of single master and multiple slave nodes. The master node monitors the operation of slave nodes and receive irrigation data from each slave nodes and store them. Besides, slave nodes control the water flow based on the level of soil moisture. Authors used ZigBee wireless technology as radio modules and AVR microcontrollers in their prototypes. The testing results showed that the designed system can work perfectly in the range of less than 1000 meters. The backup batteries are powered up by solar panels on the slaves nodes.

Our project focuses to design and implement low-cost, energy-efficient and fully automated irrigation system for urban gardens using wireless sensor and actuator network. As the drip irrigation is the most water saving and precise method of irrigation, we decided to automate drip irrigation type for our project. The main tasks of the work are designing and implementing hardware prototypes of irrigation control units. We propose to insert wireless nodes at every irrigated plants and those nodes control the water dripping through valves. Another important task of the work is to develop firmware for each wireless nodes. As the designing irrigation system is targeted for urban gardens, the communication range of 1000 meters is sufficient. The most important requirement is being energy efficient and having long battery-life.

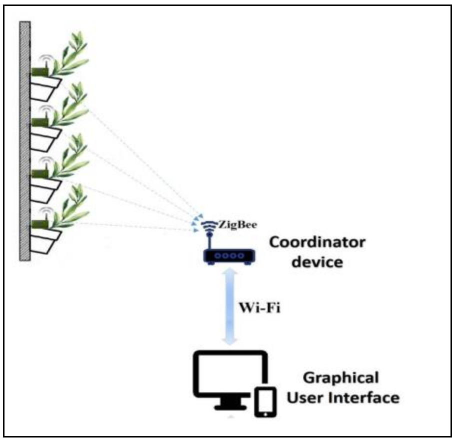

Fig 1: Deployed network architecture

System design and implementation

As the designing WSAN can be used in commercial purposes, it should be is simple and cost effective. Therefore, it is decided to use general master-slave architecture for our project, where the central coordinator device is master node and all the end-device are slave nodes. Generally, this architecture requires gateway in order to communicate master and multiple slave nodes simultaneously. However, gateway device is very expensive, therefore it is decided to employ scheduling method to communicate master and slave nodes. General layout of the proposed irrigation system architecture is described in Figure 1.

Designing and Implementing Master Node

The main functions of the master node is receiving data from slave nodes using ZigBee wireless technology, forward the received data to graphical user application of gardener using Wi-Fi module. The XBee S2C module is chosen as radio module to build wireless communication between the master and slave nodes, due to its very low power consumption (33 mA of transmit current and 28mA of receive current at 3.3V) and sufficiently long range (up to 1200 meters) [4]. XBee module uses ZigBee wireless standard. As the controller Atmega 328P microcontroller is selected because of its low power consumption (average current consumption is 5mA and 10μA in sleep mode). In order to forward the received data to gardener's application, master node employs ESP-01 Wi-Fi module owing to its low-cost and ease of use. The input voltage of the whole circuit is 12V and power section converts it into 5V and 3V by L7805 and MCP1700 voltage regulators. We designed the printed circuit boards (PCB) in Proteus Professional Software and Figure 2 shows the implemented PCB of master node.

Fig 2: Implemented Master Node PCB

Designing and Implementing Slave Nodes

The slave nodes are more complex than master node because of more functionality. The main functions of each slave node are

- Measuring soil moisture level
- Controlling the actuator based on the measured soil moisture value
- Transmit the measured value to master node wirelessly

Besides that, the slave node should have several years of battery life, therefore it is very necessary to choose every component carefully. We decided to select all the electronic parts that operate at 3.3V, because in that case no need to voltage conversion from one level to another and no energy wasting.

The microcontroller and radio module are the same with master nodes. Generally, main energy consuming part is actuator in those kind of applications. It selected very energy efficient and low power latching solenoid valve for our work. It operates at 3.3V and consumes 333mA. The latching duration is only 30ms. Usually, solenoid valves require applying continuous power to keep open state and when the power is disconnected it comes back to closed state immediately. The latching solenoid valve that we are using does not require constant application of power to keep a state. It requires only 333 mA at 3.3V during 30ms to change one state to another. Therefore, it is very efficient from energy usage point of view compared to typical non-latching solenoid valves. But, the latching solenoid valve requires control signal with reversible pole. We propose TC78H651 valve driver H-bridge to control the latching solenoid. It operates at 3.3V and consumes 0μA of quiescent current in standby mode [5]. The designed H-bridge is shown in Figure 3.

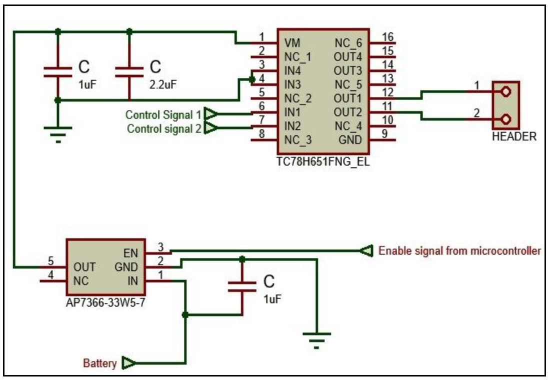

Fig 3: Designed H-bridge to control latching solenoid actuator

Furthermore, due to the limited source of energy, only three AA type batteries, the microcontroller and ZigBee module stay in sleep mode when no operation is required. As the brain of node, microcontroller disables or puts everything into sleep mode in order to achieve long battery life time.

When, microcontroller puts itself into sleep mode, only its internal watchdog timer works and wakes up the microcontroller after certain time of period. However, the maximum duration of this period is 8 seconds which not enough to be in sleep mode. In our work, the sleep duration should be 10 minutes. Therefore, it is decided that microcontroller goes back to sleep mode immediately after waking up until 10 minutes pass. Besides that, in every 1 hour slave node should transmit value of soil moisture level to coordinator device. The block diagram of the slave node is presented in Figure 4. The power section of slave node is designed simply. The input voltage of all the circuit is 4.5V from a battery. Therefore, we used low dropout voltage regulator MCP1700 to power up all the electronic components at 3.3V. We choose this voltage regulator because of its low cost, low quiescent current of 1.6μA and high output current of 250mA. The output current is sufficient to supply all the components except the solenoid actuator. The solenoid actuator consumes 333mA and therefore it is decided to employ another voltage regulator AP7366-33W5-7 for only the actuator. This fast transient voltage regulator outputs up to 600mA at fixed 3.3V. However, its quiescent current is 60µA that means it consumes this amount of current while not working continuously.

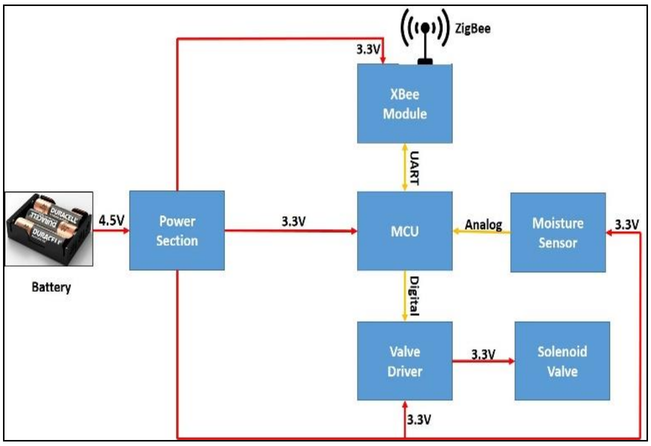

Fig 4: Slave node block diagram

This issue can be solved to disable the voltage regulator by microcontroller while the solenoid valve is not operating. In the disabled mode, the voltage regulator consumes 0.05µA [6] and that is acceptable.

The implemented PCB of slave node is presented in Figure 5, below.

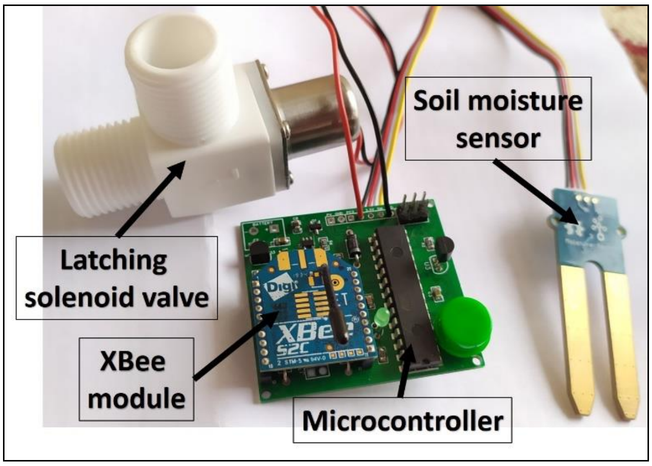

Fig 5: Implemented PCB of Slave Node

Results and discussion

The implemented system is tested in vertical structured flower beds (as shown in Fig. 1) in urban garden and the communication between master and slave nodes perfectly executed. Every slave node is energized by three AA-type, non-rechargeable alkaline batteries. In order to estimate the total energy capacity, AA-type alkaline battery from Duracell has been taken as a case study. One alkaline battery has nominal voltage of 1.5V, so three batteries in series provide 4.5V.

However, the voltage decreases over time as they are being utilized.

Since the designed slave node PCB integrates Low drop-out regulator and the XBee module operates at 3.3V, supply voltage is allowed to drop till 3.3V. This means the slave node allows each battery to discharge till 1.1V. Figure 6 presents the voltage drop of typical AA-size alkaline battery as it is discharged taking constant power [7].

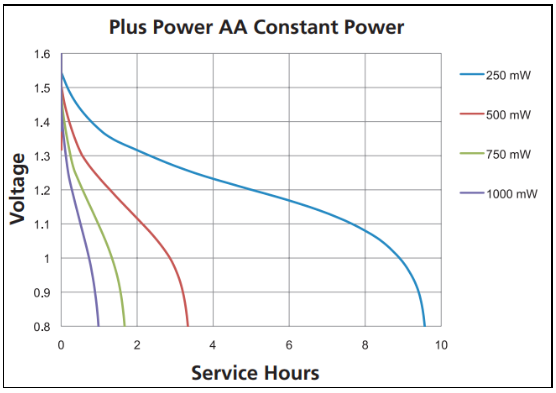

Fig 6: Constant power discharge [7]

The constant power curve of 250mW is considered in order to calculate the energy that can be consumed by slave node. Single battery can provide 250mW constant power during ≈7.8 hours, until the voltage decreases to 1.1V. Assuming the 20% of the available energy is lost for self-discharge, the initial energy that three batteries can provide is

$$E_{init} = 3 * 250mW * 7.8hours * \frac{20}{100} = 16848\ J$$

Assuming a number of daily actuations of latching solenoid valve is 4, and its overall efficiency is 80%, the total energy consumption to control an actuator per day is

$$E_{daily}^{valve} = 4 * E_{state_{change}} * \frac{100}{80} = 0.182\ \text{J/day}$$

Tests showed that XBee module consumed 183.1*10^{-3} Joules in an hour. Considering this cycle occurs 24 times in a day, XBee module spends 4.4 Joules from batteries.

Furthermore, microcontroller and voltage regulators consumed 12.62 Joules and 980*10^{-3} Joules per day, respectively.

The total daily energy consumption of each slave node is

$$E_{daily} = E_{valve} + E_{MCU} + E_{VRs} \approx \frac{18.2\ Joules}{day}$$

The initial available energy of 16848 Joules in batteries lasts 925 days, which means two and half years of battery life.

Conclusion

In this paper, automated drip irrigation system using energy-efficient, low power and low cost wireless sensor and actuator network has been presented. The implemented wireless nodes communicate using low power XBee radio modules. In short, this experimental work has shown the possibility of implementing more than years of battery life wireless sensor and actuator network which can be employed in automation of drip irrigation systems with the great impact. Besides, the implemented system is specifically targeted to urban gardens where the range of network is less than 1000 meters.

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