Design and Implementation of a Smart Irrigation System for Improved Water-Energy Efficiency

Kizito Masaba, Amini Ntakirutimana and Taha Selim Ustun

School of Electrical and Computer Engineering, Carnegie Mellon University. PA, USA
kmasaba@andrew.cmu.edu

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Abstract

Although water, in some parts of the world is as abundant as the air that we breathe, it is still a precious resource in dry regions. Such regions must use it carefully and efficiently because of its scarcity. However, the irrigation systems are still wasteful as they unnecessarily flood the farms. This results into wastage of water and energy that is used for pumping the water. With the improvement of the technological infrastructure, effective management of water usage and power consumption of irrigation systems can be achieved. This can be done by enabling the irrigation system to identify specific areas to irrigate. This paper presents a smart irrigation system that uses environmental information to determine when and where irrigation is required.

The system is comprised of microcontroller, sensors and integration of water pumps with the decision making system. A truth table is developed to help the system determine the necessity to irrigate based on the collected environment information. The sensors narrow down the location that requires irrigation and the decision-making system activates sprinklers. In this fashion, water is given to dry locations of the field, already damp locations are not irrigated and this results efficient water use. Different parameters used, i.e. temperature, humidity and moisture, makes it possible to adjust the system according to the needs of a particular location.

1 Introduction

The rise in energy demand has outpaced power generation capacity due to the high increase in population and industries. This calls for management of demand to optimize the usage of the limited generated power. One of the areas where power is so essential is irrigation. There is always need to pump water to the water tanks and operate the irrigation system such as sprinklers. However, two scarce and valuable resources of irrigation, i.e. water and energy, are not efficiently utilized by the current irrigation systems. They do not have the means to determe where and when irrigation is required. Consequently, irrigation is sometimes performed when it is not necessary or delayed when required. This leads to water/energy waste and low-crop yield, respectively. These challenges can be mitigated if the irrigation system was able to determine precisely when and where to irrigate.

A lot of research has been done to address this. In [1], an approach for integrating precision agriculture and smart grid technologies is presented. This aims at balancing consumption and generation in the farmland, which increases the sustainability of energy supply. The coordination with the SmartGrid operator enables farmers to save on energy costs and support grid at peak hours [2]. However, there is need for minimizing the amount of energy and water that is used in the farm. Furthermore, the tools and equipment used in the implementation of this approach make it rather costly which compromises its feasibility.

The work in [3] proposes a central smart irrigation system that controls several farms. Each farm has a data collection node that is connected to a computer installed in the farmland. Communication is done through a TCP/IP protocol over internet and it limits its applicability. In [4], a cloud based control system for smart irrigation using wireless sensor networks is presented. The environmental parameters are collected by sensors and uploaded to the cloud for evaluation. The actuator network is controlled remotely from the cloud after evaluation of the sensor data. This system also requires internet connectivity. The work in [5] also addresses the challenge of power and water wastage in water constrained regions using an irrigation system that is based on the Internet of Things concept. The system collects environmental information and sends it to the farmer for easy decision making using internet, which limits its feasibility in developing regions. The operating costs are also quite high as it involves labor and internet costs.

The research done in [6] also proposes a monitoring and actuation system. It collects environmental parameters such as temperature, relative humidity and rainfall, as well as plant status like truck size and leaves' humidity. This is done using wireless devices that are spread over the land. The statistical data is sent to the central unit where the decision strategy is hosted. This control unit communicates with actuators that activate the water pumps for a specific period. The major difference with that system and the system proposed in this paper is the control units in the latter are decentralized. Each unit of implementation is self-sufficient.

In [7], the use of remote switching and monitoring of irrigation systems using smart phones to address the need for

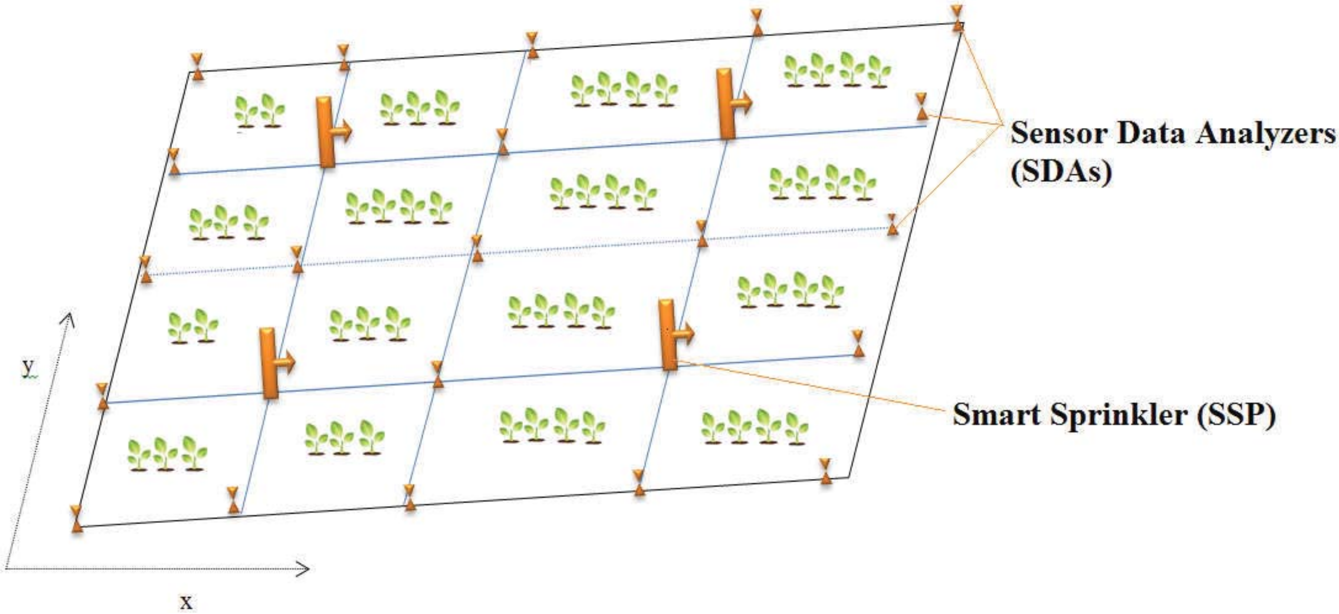

Figure 1: Illustration of the smart irrigation system in a garden

automatic control of water near the vegetable roots is presented. The data about soil moisture, temperature and humidity is collected and sent to the smart phone for the user to make the decision. Switching of the irrigation system is remotely done by the user sending a command to the irrigation controller. However, this is not an automated approach since it involves deployment of human workforce. Hence, it highly increases the operation costs especially for large smart farms. Also, it requires ownership of a smartphone and skills to use it, posing some challenges for developing world. Another smart system is proposed in [8].

It has a customized moisture sensor to collect moisture information and send it to a central server through Xbee communication. It enables farmers to monitor the moisture of the soil using a user-friendly interface. This ensures effective monitoring of the farm. However, automation of irrigation is important since it reduces on the operation costs of the smart farm. This has not been incorporated in the proposed solution.

In [9], a low power cost effective platform for use in irrigation is presented. It is called TinyOS. The OS has three essential layers that facilitate the development of smart irrigation applications. These layers include actuating, sensing and communication. This OS can be used to develop systems that can solve the challenge of power and water wastage in irrigation.

This paper presents an approach that decentralizes monitoring and decision making in farm irrigation. Each portion of land is made self-sufficient in terms of monitoring and decision making using sensors and Bluetooth communication. The sensors used are moisture, temperature and humidity sensors, which measure the most relevant environmental conditions required to determine the need for irrigation. The sensors communicate with the sprinkler whenever irrigation is required. The system is designed in such a way that sub irrigation systems are placed in different portions of land. Each sprinkler has a number of sensors that it controls. These sensors are positioned in different angles around the sprinkler as shown in figure 1. The decentralization of irrigation operations allows the use of short-range communication technology like Bluetooth, which increases the system's reliability in developing regions where internet connectivity is poor, and cuts the operation costs.

The rest of the paper is structured as follows. Section 2 presents the design and implementation of the proposed system, and Section 3 includes the conclusions and future work.

2 Design and Implementation of the Smart Irrigation System

The developed irrigation system is discussed under two subsections that are system design and implementation.

2.1 System Design

The smart irrigation system consists of an aggregated network of water sprinklers and sensors. To enable the communication, the sprinkler is controlled by a microcontroller through the servo motor. The microcontroller sets the angles between which the servo motor should rotate, which enables the sprinkler to irrigate only within those angles. The microcontroller communicates with the sensors by Bluetooth. In this research, the integrated system of microcontroller, servomotor and sprinkler, and Bluetooth is called Smart Sprinkler (SSP). The architecture of the SSP is shown in the Figure 2.

On the other hand, a microcontroller that collects the readings from each of them and evaluates the data to determine whether a given region requires irrigation manages the sensors. This setup is called the Sensor Data Analyzer (SDA) and its architecture is shown in Figure 3. The sensor information collected is from three sensors including moisture, temperature and humidity sensors. The moisture sensor gives moisture values between 0 and 900, the temperature gives value in Celsius and the humidity gives values in percentages. These individual sensor values are categorized into Low (L), Medium (M), Normal (N), and High (H). To increase the accuracy of the evaluation, the Medium category can further be broken down into Extremely Medium Low (ML), Medium Average (MA), and Medium High (MH) whenever it is necessary. The value is considered ML if it is tending towards Low, MA if it is tending towards neither Low nor High, and MH if it tends towards High. From these categories, a truth table was generated as shown in shown in Figure 4 to be used by the SDA during evaluation.

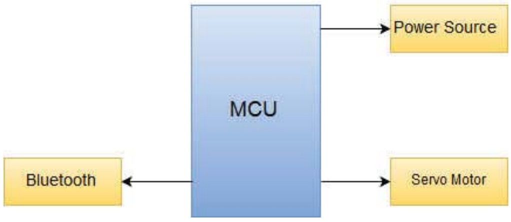

Figure 2: Smart Sprinkler (SSP) Architecture

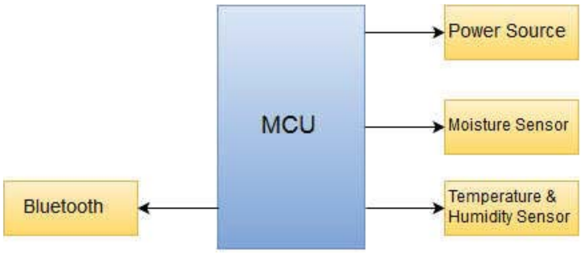

Figure 3: Sensor Data Analyzer (SDA) Architecture

As shown in the truth table, irrigation is not required when the temperature is Low and humidity is High, the state of moisture state. However, if the temperature is High and humidity is Low, irrigation is required even for Mild low Moisture values.

Sensor	Low	Medium	Normal and Above
Moisture	TRUE	TRUE	TRUE
Temperature	X		X
Humidity	X		X
Action	Irrigate		Don't Irrigate

Moisture	Medium Low				Medium Average				Medium High			
Temperature	H	H	L	L	H	H	L	L	H	H	L	L
Humidity	H	L	H	L	H	L	H	L	H	L	H	L
Is Irrigation REQUIRED?	T	T	F	T	T	T	F	F	F	T	F	F

Figure 4: Truth table for Sensor Data Evaluation

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When irrigation is required, the microcontroller sends a request to the SSP, which turns the sprinkler to irrigate around that region from where the request has come. Each SSP has several SDAs surrounding it depending on the resolution (i.e. Sensor distribution that is needed for accurate evaluation) that is appropriate for a given piece of land. Each SDA is placed at a specific angle and it is programmed in such a way that the angle in which it is placed is its identification. Hence, the SSP identifies the region to irrigate by checking the ID of the SDA that sent the request. The flowchart in figure 5 shows how the SPP operates when it receives a request from the SDA.

Date	Temp.(°C)	Humidity (%)	Moisture (kg w/kg)
19/04/2016	27	43	442
19/04/2016	27	42	443
20/04/2016	28	38	474
20/04/2016	27	38	484
21/04/2016	31	35	522
22/04/2016	31	36	601
23/04/2016	25	38	641
24/04/2016	26	37	689
25/04/2016	24	39	720
26/04/2016	28	39	723

Table 1: Sample sensor data collected by the SDA

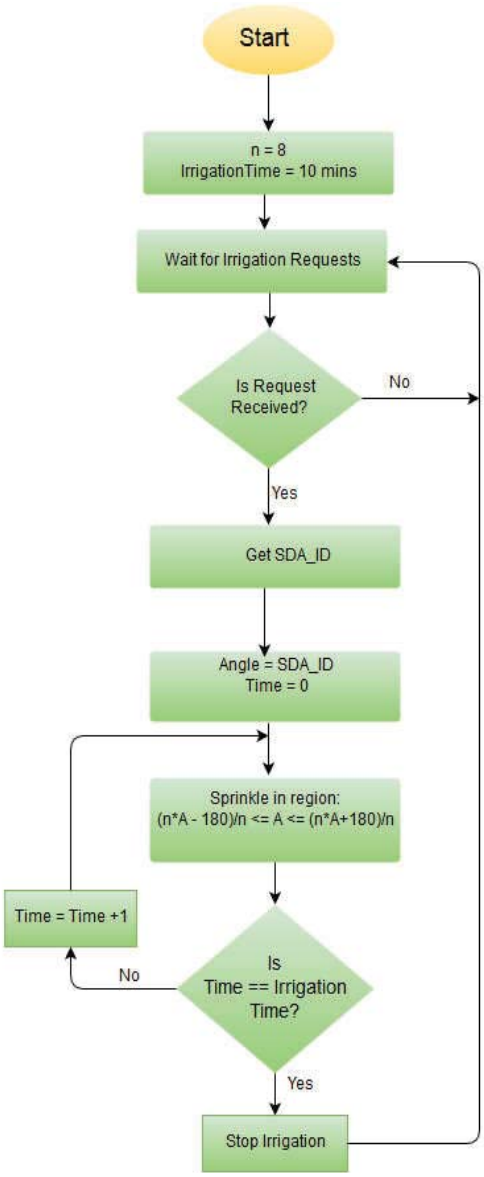

Figure 5: Flowchart showing operation of the SSP

The design in Figure 1 requires eight SDAs to realize accurate evaluation of the need for irrigation. As shown, the SSP is surrounded by eight SDAs placed 45 degrees away from each other. When the SSP receives a request from the SDA placed at angle A, the region that shall be irrigated is defined by the equation (1).

$$\left(\frac{nA-180}{n}\right) \leq A \leq \left(\frac{nA+180}{n}\right) \qquad (1)$$

where n is the number of SDAs connected to a given SSP, and A is the angle from which the request was received. For example, when an SDA positioned at 90 degrees sends an irrigation request to an SSP that is controlling eight SDAs, the SSP shall project the sprinkler to irrigate the area within 67.5^0 and 112.5^0 as shown below.

$$\left(\frac{(8*90)-180}{8}\right) \leq 90 \leq \left(\frac{(8*90)+180}{8}\right)$$
$$= 67.5^0 \leq 90 \leq 112.5^0$$

2.2 Implementation

The implementation was done with PIC 16F877 on LAB X1 programmer kit using MikroC. The diagram in figure 6 shows the lab setup of a single SDA. The SSP is identical to the SDA, except that it does not have sensors. At specified intervals, the sensor information from each sensor is collected and evaluated. The request is only sent to the SSP if irrigation is required. Some of the sensor information collected is shown in table 1.This data was collected from sensors that were placed in beakers filled with moist soil. As shown in the table, the temperature and humidity values were changing with the environment conditions and the moisture dropped with time as the soil dried up.

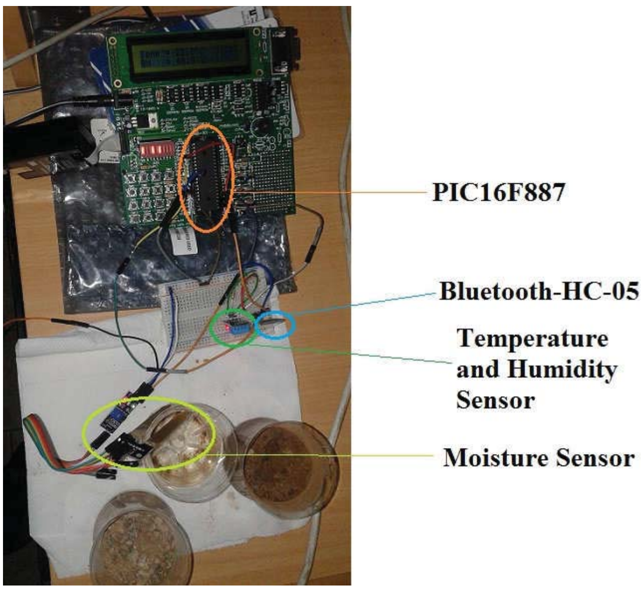

Figure 6: Lab Setup of the SDA

4 Conclusions and Futurework

The necessity to maximize the usage of water and the ever-increasing demand for energy call for proper management of consumption of these two resources. Irrigation is one of the areas where water and energy wastage is prevalent due to the use of systems that are not smart enough to determine the time and amount of irrigation required. This research presents a smart irrigation system that makes decisions on where and when to irrigate within the area it covers. The Sensor Data Analyzer (SDA), using a truth table, determines the need for irrigation. The truth table is generated basing on environmental conditions including temperature, moisture and humidity. The Smart Sprinkler (SSP) controls the sprinkler such that it sprinkles only in the region where irrigation has been requested for by the SDA. Several such smart irrigation systems can be placed in a farm field and each area remains self-sufficient. This kind of decentralization reduces the complexity of the irrigation system making it more manageable.

Plants need more than just water to grow well. So other than just managing irrigation, this system can be enhanced such that even data about soil nutrients is captured and used to determine the nutrients required in specific regions of the land. This is the major point of focus in the future work.

Acknowledgements

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