IoT Sensor Network Approach for Smart Farming: An Application in Food, Energy and Water System

Yemeserach Mekonnen, Lamar Burton, Arif Sarwat, Shekhar Bhansali
Department of Electrical and Computer Engineering, Florida International University, Miami, FL
Email: {ymeko001, lburt004, asarwat, Sbhansa}@fiu.edu

***Abstract*—As the global population soars from today's 7.3 billion to an estimated 10 billion by 2050, the demand for Food, Energy and Water (FEW) is expected to more than double. Such an increase in population and consequently, in the demand for FEW resources will undoubtedly be a great challenge for humankind. A challenge that will be exacerbated by the need for humankind to meet the greater demand for resources with a smaller ecological footprint. This paper is proposing a system developed to optimize the use of water, energy, fertilizers for agricultural crops as a solution to this great challenge. It is an automated smart irrigation system that uses real time data from wireless sensor networks to schedule an irrigation. The test-bed consists of a wireless network monitoring soil moisture, temperature, solar radiation, humidity, and fertilizer sensors embedded in the root area of the crops and around the test-bed. Wireless sensor data transmission and acquisition is managed by an Access Point (AP) using ZigBee protocol. An algorithm was established based on threshold values of temperature and soil moisture automated into a programmable micro-controller to control irrigation time. The system's energy demand is completely supplied by a solar Photo-voltaic (PV) panel supplemented with an energy storage unit. The experimental data obtained from this prototype will be modeled and optimized to investigate food production profile as a function of energy and water consumption. It will also attempt to understand the effect of extreme weather conditions on food production. This holistic approach will explore the nexus between water and energy resources, and crop yield for several essential crops in an attempt to design a more sustainable method to meet the forecasted surge in demand.**

***Index Terms*—Smart Farming, SmartAg, IoT, interdependent systems, FEW**

I. Introduction

Currently, almost 70% of the global fresh water is being used for agriculture [1]. The demand for water is expected to increase to 55% by 2050 [2]. Similarly, 30% of total global energy consumption is spent on producing, transporting and distributing food as well as in the application of pumping, extracting, treating and transporting water [3], [4]. Global energy consumption is projected to increase to 80% by 2050 [2], [4], [5]. As the demand for food soars to 60% by 2050, food security along with water and energy supply pose key issues in the availability, accessibility and utilization of these resources. Increased population growth, economic development and urbanization are the driving factors in the demand for food, energy and water resources more than ever [6]. The solution to solve the food requirement has to be more innovative.

This research was supported in part by the U.S. National Science Foundation under CAREER-0952977.

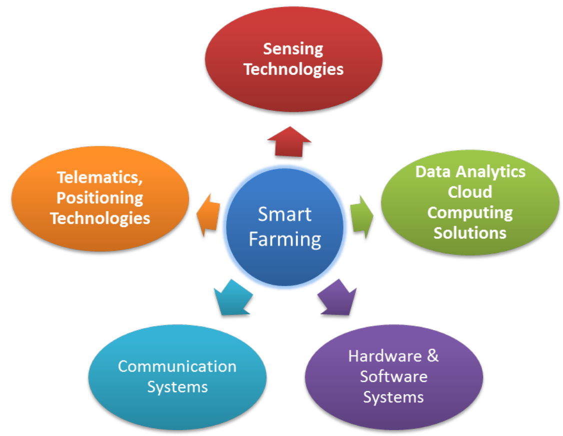

Fig. 1: Drivers of smart farming technology

Smart agriculture or precision farming is a recent concept that came out of the Internet of Things (IoT) applications [7]. The growing IoT landscape can almost be applied to different sectors and the agriculture field has been the recent one [8]. The combination of IoT along with predictive data analytics in agriculture can equip farmers with critical information on soil and environmental parameters to take actions.

The driving factor behind smart agriculture has been the demand for more food production to increase yields, optimize interdependent resources of energy, water and land and impact of urbanization [3], [6]. With advances in technology, there is more push by global stakeholders like the Food and Agriculture Organization (FAO) for farmers to use innovative tools and digital technologies [1], [3], [5]. The agricultural sector is faced with challenges connected to limited availability of arable land, water and energy, global climate change, and labor supply [6].

The IoT framework can be used to understand the interdependency of energy, water and food resources through wireless sensor networks (WSN) for each sub-systems [9]. With real-time data, farmers can predict their yield, optimize water utilization through smart irrigation control and precisely know when to harvest thereby reducing energy and labor input.

Although, smart agriculture is a recent phenomena with the saturation of digital technologies, there is a great body of work in IoT enabled farming [10]- [19]. Several works have been done in smart irrigation as part of smart farming model to optimize water utilization. The design and implantation of novel wireless mobile robot is demonstrated in [7] to monitor environmental parameters suitable for optimal crop yield. The use of distributed WSN of soil-moisture and temperature to automate irrigation system has been implemented in [10], [11]. Remote sensing and the use of distributed WSN for a site-specific irrigation scheme is implemented in [12] based on soil property map. The key components in smart agriculture; data sensing, communications, storage and processing are integral in achieving robust predictive capabilities [16]. Once data has been collected, it has to be analyzed using different algorithms to get predictive capabilities. In [17] prediction models based on linear regression, neural networks and Support Vector Machines (SVM) are proposed from WSN data. Machine learning algorithms like Artificial Neural Network (ANN) are often used in the data analytics to manage the bid data [18] side of smart farming [19].

The objective of this paper is to design and deploy a WSN for monitoring energy, water and crop development to further develop a nexus model based on real-time data. The scope of this paper is to describe the overall system description and deployment outlining the future proposed work.

This paper is organized as follows: Section II presents background work and major industry players in the IoT application of smart farming system. Section III describes the overall system design and implementation. Section IV presents the future work.

II. Smart Farm Test Bed

The smart farm test bed hereby reported consists of distributed WSN, off-grid PV panel, smart irrigation and data infrastructure. The purpose of the project is to develop an optimized smart solar-powered farm systems that maximize vegetation yield, minimize energy consumption, environmental effect through real-time monitoring from sensor data. The design requirements are to optimize input of fertilizers and pesticides, energy consumption using an off-grid PV and battery backup system and water consumption. The optimization function for this problem statement will be further investigated in the future work.

The end goal is to build a circular system where energy, water, weather, and crop data will be collected to develop a nexus computational model. The conventional way of thinking about the challenges of FEW systems had focused on “peace-meal approach” where decisions are made in one of the nexus areas without making an allowance for the consequences on the other areas [6]. The nexus approach provide decision makers with better information through optimization of synergies and trade-offs. One of the objectives of the nexus is the development of modeling tools to support integrated decision making. Big, precise and reliable data from all the three systems is required to address the computational challenge for FEW nexus. This creates the primary reason for designing intelligent agriculture infrastructure.

III. System Design and Implementation

The design of the smart farm prototype included field preparation which incorporated crop-line accommodation and soil preparation, along with solar panel footing foundation and pole placement. The farm consists of three 4x25 ft raised beds as shown in Fig.2

Fig. 2: Field preparation

A. Electrical System Units

The system’s energy demand is completely supplied by a PV panel supplemented with an energy storage unit. A 320W at peak power with V$_{mpp}$ of 37.2V PV panel with 16.3% module efficiency is used. The tilt angle is fixed at 26° same as the latitude of the location. The default tilt angle for a PV panel is set to the latitude of the location which will maximize annual energy production [20]. The PV panel is connected

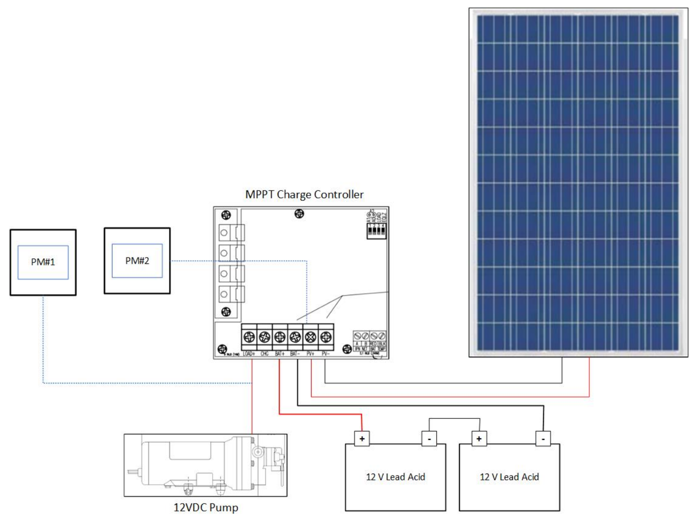

Fig. 3: Electrical System Unit

to a 20A 12V DC Maximum Power Point Tracking (MPPT) solar charge controller to prevent overcharging of the batteries. The MPPT charge controllers vary from the traditional PWM charge controller by allowing the solar panels to function at their optimum power output voltage thereby increasing their performance. The charge controller is installed between the PV and the batteries to automatically maintain the charge on the batteries using the bulk, acceptance and float charge cycles. In addition, the load for the system which comes mainly from the water pump is controlled by the MPPT. Two 12V, 250 Ah are connected in series to the MPPT. Power meters with RS485 serial communication capability from the generation and load side are connected. They have an RS485 serial communication capability for energy data acquisition. Energy data is acquired from the power meter through RS485 serial communication to Arduino and then sent to gateway through Zigbee protocol.

B. Wireless Sensor Unit

WSU are equipped with different types of sensors with the capability of measurement, acquisition and synchronization of data. The WSU used for this project is an Arduino based node with various radio options for connectivity. It has two

Fig. 4: WSU connected to a weather station

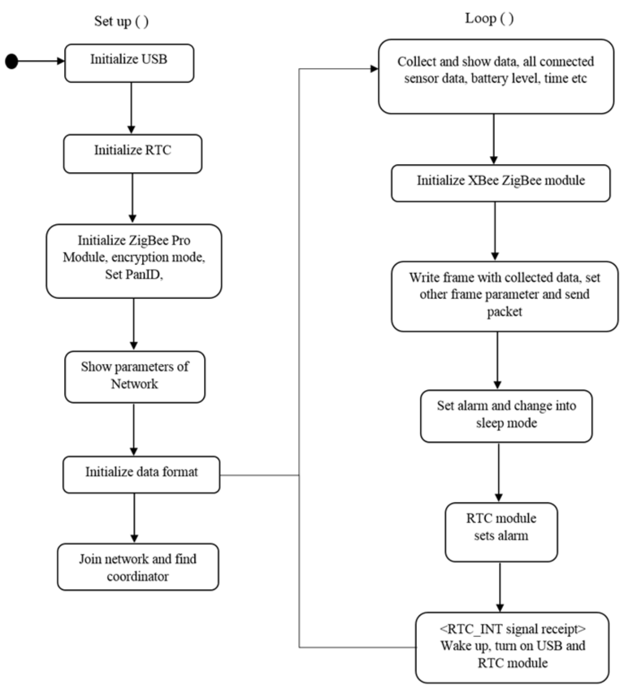

Fig. 5: WSU operational program flow chart

main component boards consisting of the sensor board and main functionality module board. Environmental and agriculture parameters are measured by the sensor board. Ambient temperature and humidity, atmospheric pressure, pluviometer, anemometer, solar radiation, soil temperature, soil moisture and leaf wetness data are collected every hour interval. The WSU device has been programmed to sense and transmit these data to a gateway router using XBee-Pro S2 module. All functionality such as sensing, data collection, communication and power is programmed in open source Integrated Development Environment (IDE). As part of the power saving mechanism, the micro-controller has real time clock (RTC) module that can be programmed to only wake the device at the time of measurement. The device is programmed to operate in deep sleep mode and wakes up every hour to collect and transmit sensor data. The device is powered by 6600 mAh rechargeable lithium ion battery. The charge on the battery is maintained by a 7 V-500mA solar panel for full energy autonomy.

C. Irrigation System Unit

A drip-irrigation system is implemented for irrigation scheme. Drip-irrigation is a method to water crops by dripping near plant roots through a network of pipes. It is the best option for irrigating crops by reducing water usage, improving productivity and is relatively cheaper. In addition, it requires low operating pressure thus reducing overall energy consumption. The system is fully automated that uses real time data from the WSU to schedule irrigation events. The control system integrates a switch regulator, 24 V DC water pump, 24 V DC solenoid valves, relays and Arduino. Soil moisture and temperature sensors are connected to the Arduino and the relays activate the solenoid valves and the pump at threshold value.

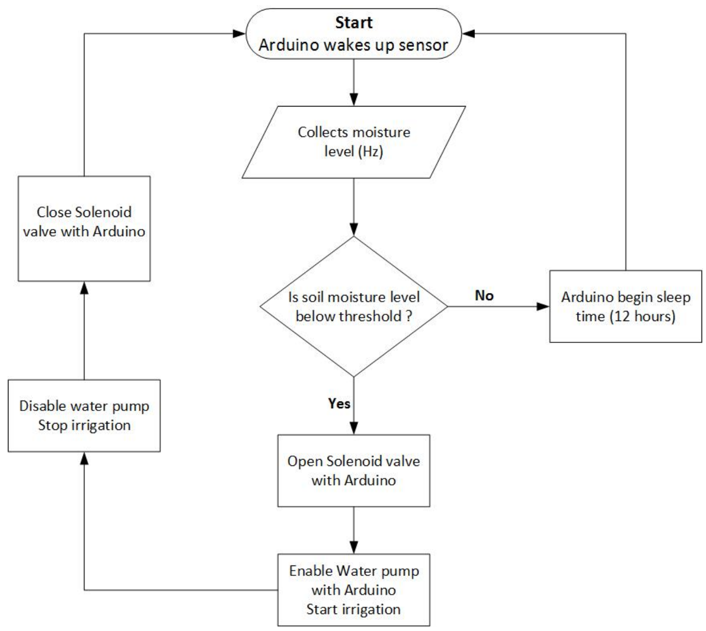

Fig. 6: Flow chart for control system algorithm

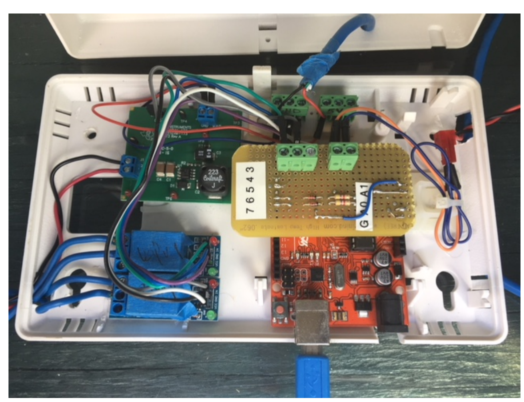

Fig. 7: The control unit for scheduling irrigation events

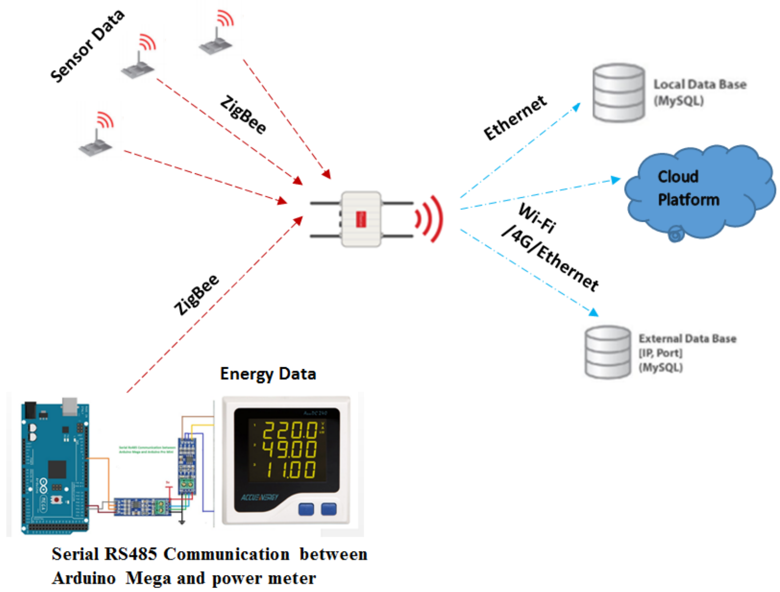

Fig. 8: Data transmission, reception and storage scheme of the system

IV. Data Infrastructure

Wireless sensor data transmission and acquisition is managed by IoT gateway router designed to connect to the WSN. The router can work as an RF-XBee interface, local and external database for WSU. For this project the WSU sends sensor data to gateway via ZigBee protocol. The gateway automatically stores the data on its local storage with an additional capability to synchronize to an external database or connect to a cloud platform. At the time of reception in the router, sensor data are timestamped, parsed and stored in local or synchronized to an external database. Energy data infrastructure is connected similar to the wireless sensor nodes. The protocol uses Max485 for serial communication between an Arduino Mega and the power meters. Arduino sends voltage, current and power data in frames to router with ZigBee protocol as shown in Fig.7.

V. Future Work

The experimental data obtained from this prototype will be modeled and optimized to investigate food production profile as a function of energy and water consumption. It will also attempt to understand the effect of extreme weather conditions on food production. Instead of the peace-meal approach, a holistic approach will be developed and explore the nexus between water and energy resources, and crop yield for several essential crops in an attempt to design a more sustainable method to meet forecasted surge in demand. The conventional way of thinking about these intertwined problems focus on "peace-meal approach" where decisions are made in one of the nexus areas of water, energy and food without making an allowance for the consequences on the other areas. In the future work, data collection from this smart farm will be crucial in analyzing the gap between the water, energy and crop data will be used to model the interdependency of these systems.

VI. Conclusion

The abundance of vast amount of data and the ability of analyzing data to make decisions have quickly become part of any sector with the advent of IoT technologies. Agriculture is one of the sectors with smart farming that relies on machine to machine communication to get precise and reliable data. This paper presents the design and implementation of smart farm prototype to further investigate and model the energy, water and food nexus in the future. In this paper, the overall system design, implementation and functionality is explained. The test-bed consists of distributed WSN that monitors different agricultural and environmental parameters. Wireless sensor data transmission and acquisition is managed by IoT gateway router through ZigBee protocol. An algorithm was established based on threshold values of temperature and soil moisture to automated into a programmable micro-controller to control irrigation time.

References

[1] FAO, "Walking the Nexus Talk: Assessing the Water-Energy-Food Nexus in the Context of the Sustainable Energy for All Initiative." Food and Agriculture Organization of the United Nations, Rome, 2014

[2] IRENA "Renewable Energy in the Water, Energy and Food Nexus", January2015

[3] FAO, "The Water-Energy-Food Nexus- A new Approach in Support of Food Security and Sustainable Agriculture", Food and Agriculture Organization of the United Nations, Rome, 2014

[4] International Energy Agency, "World Energy Outlook 2012", IEA, Vienna, 2012

[5] FAO, "Energy Smart Food for People and Climate", Food and Agriculture Organization, 2011

[6] H. Hoff, "Understanding the Nexus:Background paper for the Bonn2011 Nexus conference", Bonn2011 conf. The Water, Energy and Food Security Nexus, 19-18 Nov. 2011

[7] K.L. Krishna, et al. "Internet of Things Application for Implementation of Smart Agriculture System," IEEE, I-SMAC 2017, pp.54-59.

[8] A.I.Sarwat et al., "Toward a Smart City of Interdependent Critical Infrastructure Networks, " Sustainable Interdependent Networks (2018)21-45

[9] Beecham Research, "Enabling The Smart Agriculture Revolution: The Future of Farming Through the IoT Perspective, " Libelium 2016.

[10] J. Gutierrez, et al., "Automated Irrigation System Using a Wireless Sensor Network and GPRS Module," IEEE Trans. on Instrumentation and Measurement, 63(1), January 2014. pp. 166- 176.

[11] A. Rau et al., "IoT Based Smart Irrigation and Nutrient Detection with Disease Analysis," IEEE Region 10 Symposium (TENSYMP), 2017

[12] Y. Kim, R.G. Evans, & W.M. Iversen, "Remote Sensing and Control of an Irrigation System Using a Distributed Wireless Sensor Network," IEEE Trans. on Instrumentation & measurement Society, 57(7), (2008)1379-1387.

[13] L. Burton, Y. Mekonnen, et al., "Exploring Wireless Sensor Network Technology In Sustainable Okra Garden: A Comparative Analysis of Okra Grown in Different Fertilizer Treatments," In 14th International Conference on Precision Agriculture, arXiv:1808.07381 (2018).

[14] J.G. Jauey, et al., "Smartphone Irrigation Sensor," IEEE Sensors Journal , 15(9), (2015)5122-5127

[15] J. D. Lea-Cox, "Using Wireless Sensor Networks for Precision Irrigation Scheduling, Problems, Perspectives and Challenges of Agricultural Water Management," InTech, 2012

[16] S. Ivanov, K. Bhargava, W. Donnelly, "Precision Farming: Sensor Analytics," IEEE Intelligent Systems, 2015

[17] S. Rodriguez, T. Gualotuna & C. Grilo, "A System for the Monitoring and Predicting of Data in Precision Agriculture in a Rose Greenhouse Based on Wireless Sensor Networks," Procedia Computer Science 121 (2017) 3060-313.

[18] S.Wolfert, et al., "Big Data in Smart Farming - A review," Agricultural Systems 153(2017) 69-80.

[19] A. Irmak, et al.,"Artificial Neural Network Model as a Data Analysis Tool in Precision Farming," Transaction of the ASABE, 49(6) (2006) 2027-2037

[20] USDA, "Design of Small Photvoltaic (PV) Solar-Powered Water Pump Systems," USDA NRCS Technical Note No.28, PO, Oregon, October 2010