Solar-Powered Smart Agricultural Monitoring System Using Internet of Things Devices

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***Abstract*—Advances in wireless communication technologies for monitoring and control systems have paved the way for a new method of farming known as smart farming. Smart farming can be achieved through the use of Precision Agriculture (PA) which involves using novel technology along with inch-scale devices to monitor crops and provide precise treatments when required. Smart PA is able to take traditional farming practices and apply technological advances from areas such as Wireless Sensor Networks (WSN) and the Internet of Things (IoT) to assist in increasing the output yield of a crop while improving efficiency and reducing the amount of stress placed on a farmer. In this paper, a solar-powered smart agricultural monitoring system with IoT devices is presented. Solar-powered prototype nodes were designed to measure environmental conditions in a field and report to a base station for data storage and further processing. Two prototypes were compared in identifying the advantages gained when using energy harvesting in a device. Using an experimental testbed, a proof of concept of how the system would function is presented. According to experimental results, using an energy harvesting device can provide an increased lifetime for a device by supplying power and recharging its battery.**

***Keywords*— Smart Monitoring; Precision Agriculture; Internet of Things; Wireless Sensor Network.**

I. Introduction

Modern advances in wireless technology have revolutionized the way farmers are able to interact with their crops and monitor their growth. By utilizing new technologies to monitor crops and by responding appropriately to their needs, advanced management concepts can be employed. One approach where technology is combined with traditional farming practices is known as Precision Agriculture (PA) [1], [2]. Through the use of PA in farming, greater accuracy and control of the growing of crops and the raising of livestock can be achieved. By using new technologies to aid in agriculture, farmers are able to increase efficiency and reduce costs since through controlling the many aspects of their farm management directly more precise remedies can be applied.

In traditional farming application, fields are managed without the use of modern technology. A greater amount of experience is required in order to maintain proper efficiency [3]. When using traditional techniques in farming, decisions such as planting, harvesting, and irrigating require the use of current weather conditions and historical data to determine the ideal process to achieve the optimal harvest [4]. In comparison, PA uses technologies such as sensors, actuators, Global Positioning System (GPS), robots, and data analyzing software to limit the amount of labour that farmers apply and increase the amount of care given to the crops when required.

One promising solution towards achieving PA is through the use of Internet of Things (IoT) devices for the monitoring of vegetation and livestock [5]. IoT devices are small, low power embedded electronics which possess the ability to transmit data across a network. This is often referred to as an IoT network, where devices communicate with each other to work together in achieving a common goal. For instance, with an IoT-based farming system, sensors can be deployed to collect environmental information on the soil moisture. The measured information can then be utilized in an automated irrigation system to appropriately water plants, preventing over and under-watering. An IoT system could also provide the additional benefit of providing farmers with the ability to monitor field conditions remotely and in real-time. Monitoring livestock can ensure that the animals are being appropriately fed and cared for, which is just as important as monitoring vegetation in a field. By using IoT devices, it can greatly decrease labour costs and increase the well-being of the animals. Using IoT devices, data regarding the location and health of the livestock can be obtained.

Another promising approach that helps in solving many of the problems that farmers face in today's society comes from the use of Wireless Sensor Networks (WSN) [6]. By using sensors to gather environmental information from areas in a field, a farmer can then focus on taking care of those areas that require special attention, improving overall efficiency [7]. One benefit that WSN give in agricultural monitoring is that sensor nodes can be customized to the crop being monitored. While one crop might be heavily reliant on a proper soil moisture, another might be greatly susceptible to the concentration of hydrogen ion (pH) levels in the soil. Another benefit of WSN is the scalability. Since sensor nodes can be easily added or removed from a system, overall costs can often be reduced as the monitoring needs can vary from season to season.

In addition, since a variety of crops are affected by similar environmental conditions such as temperature and humidity, a WSN can be generalized for many different agricultural applications. Indoor greenhouses and outdoor fields have very similar monitoring conditions, all of which need to be controlled to produce the greatest yield.

In this paper, we present a solar-powered smart agricultural monitoring system consisting of wireless IoT devices. In an attempt to assist agricultural production, the proposed network was capable of measuring the soil conditions, temperature,

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humidity, and charge left on the battery. Sensor nodes were configured with solar panels that were used to draw solar energy and recharge the battery. In order to determine how effective energy harvesting can be in a system, a comparison is presented between two identical sensor nodes where only one has the ability to harvest solar energy to charge its battery.

The main contributions of this work are as follows:

- A system comprising of prototype nodes was designed for smart agricultural applications with energy harvesting capabilities.
- Extensive experimentation was performed to demonstrate the advantages of energy harvesting in WSN for agricultural applications.
- A comparison using different battery power supplies is performed.

The rest of this paper is organized as follows: Section II reviews the related work on WSN in agricultural applications. In Section III, an overview of the designed system is described, followed by Section IV, with a description of the experimental setup. The experimental results are presented in Section V. Finally, Section VI concludes this work.

II. Related Work

Modern farming is a new and emerging concept used in increasing the output yield of a crop by employing advanced technologies to assist in traditional farming practices [8]. Concepts such as Precision Agriculture (PA), Internet of Things (IoT), and Wireless Sensor Networks (WSN) are all methods that are used with traditional framing to aid in the production of crops, increasing efficiency, and controlling of costs. In literature, a number of systems utilizing WSN have been proposed and tested in monitoring vegetation and crops for PA applications [8]–[16]. While some designs have focused on developing low-cost monitoring solutions [9], [10], others have focused on employing IEEE 802.15.4 to create Zigbee-based WSN capable of reducing total power consumption, increasing the network lifetime, and improving performance.

In [13], an attempt to increase the performance and runtime of a WSN for PA applications was presented. The performance was increased through altering the Media Access Control (MAC) parameters in a Zigbee network while increasing the sampling frequency of the sensor nodes. An increase in the sampling frequency could be achieved by reducing the overall number of nodes that were contained in the network. While a similar network lifetime was proven achievable, by reducing the number of sensor nodes, a reduction of data from spots in a field would be unknown. However, although a speedup in sampling frequency was obtained, most agricultural systems do not require quick response times as environmental conditions do not rapidly change in short periods of time.

In [12], in addition to a WSN, a drone equipped with infrared thermometers was used to enhance the monitoring capabilities of the network. Sensor nodes were able to measure the leaf temperatures of specific plants in the node's vicinity, while the drone was able to fly above the field and measure leaf temperatures above the crops. Experiments demonstrated that measurements which were taken by the drone deviated from the actual temperature when the drone was positioned above the crop. However, when the drone was closer to the area of interest it was able to obtain readings with a greater accuracy. In order for the data gathered between the drone and nodes to be accurate, time synchronization between the devices needed to take place continuously.

In [16], a unique application was presented where a WSN was used in the monitoring of microclimate conditions across a field instead of the crops directly. The system was designed to implement a two-level network, where nodes were capable of alternating between two operating frequencies in order to create the multiple networks. Nodes were separated into clusters which would transmit the data to the cluster leader that would then forward all the information to the destination node. Results demonstrated that the design consumed a very low amount of energy, capable of functioning for an entire season on a single battery charge.

In the systems presented in [8]–[10], WSN for use in PA applications were designed utilizing similar hardware and features. In the systems, similar hardware consisted of XBee modules, which were used in creating Zigbee networks for connectivity between the nodes. The systems were different in that the sensor nodes designed used unique sensing units for monitoring conditions. In [8], sensor nodes consisted of soil moisture, temperature, humidity, and light sensors. In [9] and [10], sensor nodes only possessed a soil moisture sensor. In all of the system designed, nodes did not contain any energy harvesting devices, and as such would only function for a certain period of time before the node's power supply would need to be replaced.

In this work, we build on top of these previously published works, and in addition take advantage of the components introduced in [17], [18] for the design of a wireless IoT network for PA monitoring with energy harvesting capabilities. Sensor and relay nodes were equipped with solar panels for energy harvesting in order to increase the total runtime of the network. Once sensor data was measured and delivered to the destination, timestamps were placed on the packets and stored, which can then be reviewed later to determine any possible actions that are needed to further care of the crops.

III. System Overview

The proposed system has a number of different hardware components and nodes that were selected for a PA monitoring application.

A. Hardware Components

There were five hardware components that were employed in the customization of the designed prototypes. The components used consisted of: an Arduino Uno, a Series 2 XBee with 2mW Wire Antenna, various sensors, a power converter, and a solar panel.

- *Arduino Uno:* In order to connect all the hardware components together, an Arduino Uno Rev3 microcontroller was used. The Arduino Uno was selected based on its low power consumption and ease of development in configuring all the components together [19]. Based on the ATmega328P, which contained six analog input pins, the Arduino Uno is capable of interfacing analog sensors to easily determine the input measurements.

- *Series 2 XBee with 2mW Wire Antenna:* To provide wireless communication capabilities between the nodes a Series 2 XBee with a 2mW Wire Antenna was selected [20]. The Series 2 XBees are low power radios which communicate on the Zigbee mesh network. Capable of connecting hundreds of nodes together and transmitting up to 120m in line-of-sight, Zigbee provides many benefits for use in a smart agricultural monitoring system.
- *Sensors:* To measure the different environmental conditions required in an agricultural monitoring system, two types of sensors were utilized:
  1) The Grove Soil Moisture Sensor is capable of measuring the moisture content in the soil [21]. This sensor was selected as it could accurately gauge the volumetric water content in the soil indirectly by making use of the electrical resistance between the two prods. This is beneficial in agricultural systems, since by knowing the moisture levels in the soil, fields would only need to be irrigated when required and could limit the growth and spreading of bacteria.
  2) The DHT22 temperature and humidity sensor is capable of measuring the environmental information with floating point accuracy, up to 0.3 degrees for temperature and 2% for relative humidity [22]. This sensor was selected as most crops will produce the greatest yield when the temperature and humidity are within an ideal range. These measurements become important in greenhouses as outdoor conditions can greatly influence those inside the greenhouse. The ability to control the conditions can greatly aid in the development of the plants themselves as most require certain temperature and humidity levels throughout the different stages of growth.
- *Power Converter:* A power converter was used in supplying power to the sensor node system [17], [18]. In addition to supplying power, the converter was also able to interface other types of power components such as an energy harvesting device which can be used to both supply power and recharge a Lithium Polymer (LiPo) battery. The battery used was a Grand Pro 3.7V 6600mAh LiPo. The power converter was configured to provide a constant 5V power output while the charge on the battery was above 3V. Once the power level dropped below 3V the power converter would stop functioning and would wait until the battery was sufficiently charged before supplying power again.
- *Solar Panel:* To provide energy harvesting capabilities to the system, a Star Solar D165X165 monocrystalline solar panel was utilized. Being only 170 x 170 x 2 mm, the solar panel was capable of providing an output of 6.0V at a peak of 3.65W. The small size makes it suitable for placement in a field where it would have minimal interference to any of the growing plants surrounding it.

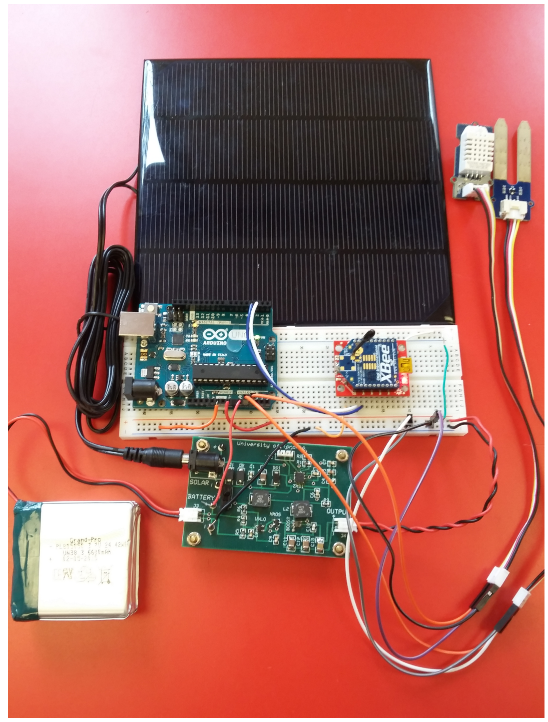


Fig. 1: Prototype sensor node with energy harvesting device.

B. System Nodes

The framework for the system comprised of three different types of nodes that made use of the hardware components listed. Four nodes were created in total with two customized to be sensor nodes, one as a relay, and one as the destination.

1) *Sensor Node:* The sensor nodes were designed to collect environmental information and forward the information to the relay which was the next node in the network that had the closest proximity to the destination. To achieve this, sensor nodes were equipped with all the hardware components that are listed above. In addition to collecting sensor data from the soil moisture, air temperature, and relative humidity, the nodes were also configured to measure the voltage charge left across the battery through the power converter. The power remaining on the battery was an important part of the system since if the charge is too low, that node could possibly stop responding. This could lead to unknown sensor values at that location. The designed wireless sensor node prototype with a solar panel to harvest solar energy can be seen in Fig. 1.
2) *Relay Node:* The relay node existed to forward information from the sensor nodes to the destination. This node was equipped with all the hardware components listed except for the sensor units as its function was to purely

Parameter	Value
Battery Power Supply	6600 mAh
Arduino Current Consumption	80 mA
Xbee Current Consumption	40 mA
Soil Moisture Current Consumption	35 mA
DHT22 Current Consumption	1.5 mA
Sampling Frequency	0.5 Hz
Tranmission Interval	2 s

TABLE I: Parameters corresponding to components used in sensor nodes.

forward any packets received to the destination. In a large field it might not be possible for the sensor nodes themselves to reach the destination, therefore, a relay was used in order to assist in conveying the information along. Since this node was also configured with a power converter and a solar panel, once it received a packet from a sensor node it would append its battery level to the end of the packet before forwarding it towards the destination. It was important that the relay node be fully functional at all times. If the operation of the relay were to stop, data from the sensor nodes would no longer be capable of reaching the destination. Hence, relay nodes are critical for the reliable delivery of information in a network.

3) *Destination Node:* The destination node was the final target where all information from the sensor nodes was collected. This node only consisted of an Arduino Uno and a Series 2 XBee antenna to collect the information. It was designed to be connected to a computer, receiving a fixed input voltage. Therefore, it did not require a power converter or a solar panel. Once the destination node received a packet, the packet was appended with a timestamp based on the clock of the computer. The packet was then saved into a database which could be viewed offline for further analysis.

IV. Experimental Setup

In order to evaluate the performance of the proposed system, a small two hop network was created. In total, four nodes were used to set up the network which consisted of two sensor nodes, one relay, and a single destination. The sensor nodes were customized to be identical in their hardware and operation. The difference between the nodes was that one was equipped with a solar panel for energy harvesting capabilities while the other was not. The parameters used in the setting up of the sensor nodes can be seen in Table I. It was determined that the battery supplied 6600 mAh while the other components used a significantly lower amount.

For the experiment, both of the sensor nodes communicated to the relay node, which then forwarded the information to the destination. The destination was connected to a computer to collect and record all information received with timestamps which could then be analyzed. To prevent the relay node from powering-down, the power converter was connected to a constant voltage input to continuously supply power to the battery. An outline of how the nodes communicate information throughout the network can be seen in Fig. 2.

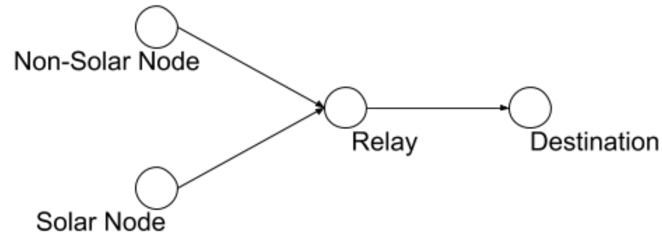


Fig. 2: Setup of sensor network system.

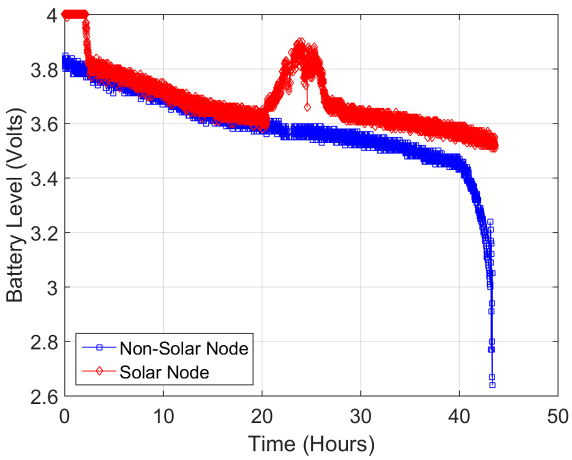
All of the nodes were placed in a controlled environment where all of the sensors were able to collect similar environmental data, therefore, would consume a similar amount of power. The testing area selected was a research lab on the third floor in the University of Guelph Engineering building. For testing purposes, sensor nodes were configured to sample the environmental conditions with a frequency of 0.5 Hz and a transmit interval of 2 seconds. This was done to ensure a large amount of data would be collected in a short period of time and for a greater amount of energy to be consumed for the duration of the tests. If the system were to be deployed in a field for data monitoring and collection purposes, the transmit time could be greatly reduced as changes in the environment do not occur frequently enough for such a rapid collection interval. To measure the soil moisture, sensors were placed in a potted plant. Sensor nodes were also placed in close proximities of each other to generate similar temperature and humidity readings. In order for the solar panel to generate a sufficient amount of energy to make a difference in the system, nodes were placed near a window where the sunlight was able to come into direct contact with the solar panel to charge the battery. Both batteries connected to the sensor nodes were charged to full capacity before the experiment was executed. Tests were performed until one of the nodes was no longer functional.

V. Experimental Results

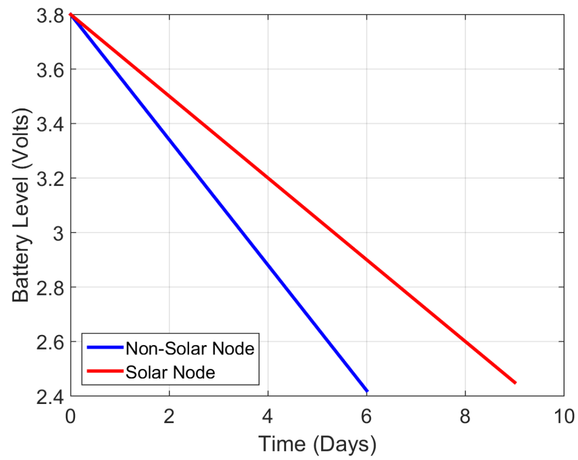
Based on the experimental results obtained, sensor data gathered was successfully transmitted to the destination. The information gathered by the sensors was correctly transmitted to the relay, whose remaining battery level was appended to the received packets, then forwarded to the destination to be timestamped. Results can be seen in Fig. 3 and Fig. 4. Due to a large amount of data that was gathered over the course of the experiment, only a small subset was plotted and is displayed.

A. Battery Level

Results for the energy levels left across the batteries for the sensor nodes can be seen in Fig. 3a. As expected as time passed, the voltage charge across the batteries dropped. Based on the results, tests were run for approximately 43 hours before the non-solar sensor node ceased to function. However, once the non-solar node ceased to function, the solar node still had plenty of charge remaining. It can be seen that the solar panel created a difference in the lifetime of the nodes. When



(a) Voltage levels remaining in batteries.



(b) Power level estimates for sensor nodes.

Fig. 3: Power results for the proposed system.

the experiment started, it can be seen that there was some sunlight in the room charging the battery, creating a steady power level across the solar node. Once the solar panel was no longer providing power, the battery started to be utilized and the measured charge across the battery dropped considerably. As time went on, both battery levels continuously dropped at similar rates. After 20 hours, the solar panel was able to charge the battery again, increasing the total possible lifetime of the node. Once the solar panel was no longer charging the battery, again the battery started to decrease at the same rate. However, there was a larger difference between the charge levels from the batteries.

B. Power Estimation

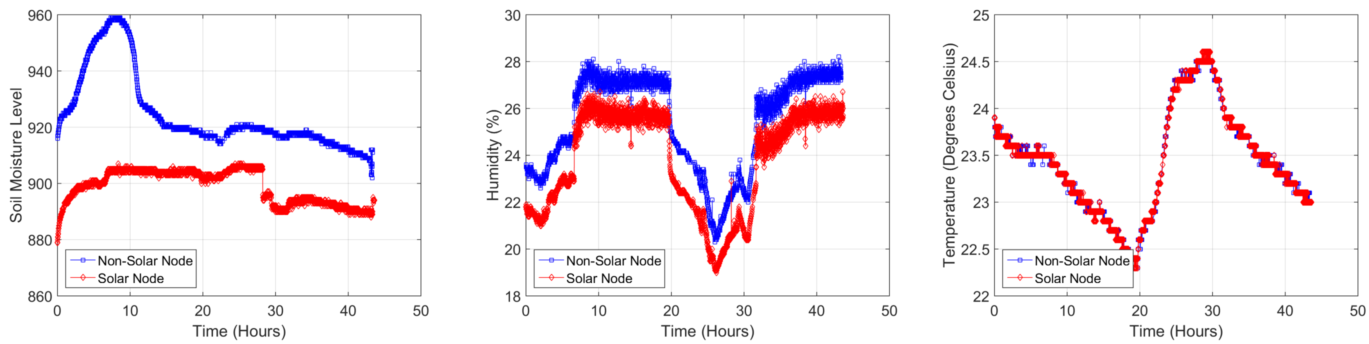
Using the results gathered for the battery power levels, estimates can be made for the total runtime of the nodes. Using the experiment power results in Fig. 3a, two important values can be gathered in order for estimates on the runtime of the nodes to be determined. The first being the fully charged starting voltage of the battery, 3.8V. The second value was the remaining charge on the battery after 24 hours had passed. For the two nodes, it was determined that the remaining voltage was 3.57V for the non-solar node and 3.65V for the solar node. Then, by calculating the difference in the starting voltage and measured after 24 hours, the voltage used in 24 hours could be determined. By assuming that the voltage decreases at a steady rate and that the solar panel receives the same amount of sunlight each day, the total runtime of the device could be determined. The results produced using the calculated values can be seen in Fig. 3b. Since the power converter is only able to provide power to the nodes while the battery voltage is above 3V, we can assume that once the voltage is below 3V, the node will cease to function. Based on the graphs produced, the non-solar node should have an expected runtime of 3.5 days, while the solar node should run for approximately 5.3 days.

Although the estimated runtime of the node is not similar to the actual runtime of the non-solar node, a couple of notes can be seen. Ideally, over time the power consumed is linear, however, once the power reached 3.4V in the non-solar node, the power level quickly dropped before the node ceased to function. The node also functioned for slightly longer than expected. Once the power dropped below 3V, the node was still transmitting. This could be attributed to the capacitors in the power converter, which were still powering the node and measuring the voltage on the battery before it was no longer able to function.

C. Sensor Readings

According to the experimental sensor results produced, the nodes were functioning properly in the gathering and transmitting of information. In Fig. 4a, the soil moisture readings for the two sensor nodes is shown. While both graphs may appear slightly different, the readings can greatly differ from one area to the other since the roots of the plant can draw water from deep in the ground and upward when needed. It can be seen in Fig. 4b and 4c that both nodes followed similar trends. This was as expected since both nodes were stationed in the same environment near each other, where any changes that occurred would have affected both nodes equally. Due to the points in the environment behaving differently it can be difficult to obtain sensor data that is similar across both of the nodes.

Knowing the information that the sensors produce is an important part of the system that can greatly affect battery life. Since sensors require power to function, the power consumed is greatly affected by the values read. In Fig. 4a, it can be seen that the non-solar node reads values greater than the solar node. While the power consumed by the sensor is minimal, the large difference between the two readings can cause one node to deplete its power supply much quicker than the other. Hence, can greatly affect the node's lifetime.



(a) Soil moisture.

(b) Humidity.

(c) Temperature.

Fig. 4: Preliminary sensor test results for the proposed system.

VI. Conclusions

In this paper, we presented a cost-efficient solar-powered smart agricultural system to enhance agricultural production by using sensor nodes with energy harvesting capabilities. The nodes were equipped with soil moisture, temperature, and humidity sensors along with a power converter. The power converter was capable of connecting a solar panel to the node in order to provide energy harvesting capabilities to recharge the battery and could obtain the remaining voltage level across the battery. Through the use of experiments in a controlled environment, we were able to demonstrate how using an energy harvesting device can greatly extend the lifetime of a node. In addition, the experimental results also demonstrated the possibilities of the system and how it was able to collect and transmit data through the network. Experimental results demonstrated how the proposed system could be used for agricultural applications. Overall, nodes that consisted of low-power microcontrollers, wireless antennas, batteries, a power converter, and an energy harvesting device could provide a reliable and robust solution for smart agriculture.

References

[1] M. Ponti, A. A. Chaves, F. R. Jorge, G. B. P. Costa, A. Colturato, and K. R. L. J. C. Branco, "Precision agriculture: Using low-cost systems to acquire low-altitude images," *IEEE Computer Graphics and Applications*, vol. 36, no. 4, pp. 14–20, July 2016.

[2] P. Abouzar, D. G. Michelson, and M. Hamdi, "Rssi-based distributed self-localization for wireless sensor networks used in precision agriculture," *IEEE Transactions on Wireless Communications*, vol. 15, no. 10, pp. 6638–6650, Oct. 2016.

[3] T. Wark, P. Corke, P. Sikka, L. Klingbeil, Y. Guo, C. Crossman, P. Valencia, D. Swain, and G. Bishop-Hurley, "Transforming agriculture through pervasive wireless sensor networks," *IEEE Pervasive Computing*, vol. 6, no. 2, pp. 50–57, April 2007.

[4] G. Ling and B. Bextine, *Precision Farming Increases Crop Yields*, 2017 (accessed March 29, 2018). [Online]. Available: https://www.scientificamerican.com/article/precision-farming/

[5] C. Brewster, I. Roussaki, N. Kalatzis, K. Doolin, and K. Ellis, "Iot in agriculture: Designing a europe-wide large-scale pilot," *IEEE Communications Magazine*, vol. 55, no. 9, pp. 26–33, 2017.

[6] Y. Kim, R. G. Evans, and W. M. Iversen, "Remote sensing and control of an irrigation system using a distributed wireless sensor network," *IEEE Transactions on Instrumentation and Measurement*, vol. 57, no. 7, pp. 1379–1387, July 2008.

[7] M. Srbinovska, C. Gavrovski, V. Dimcev, A. Krkoleva, and V. Borozan, "Environmental parameters monitoring in precision agriculture using wireless sensor networks," *Journal of cleaner production*, vol. 88, pp. 297–307, 2015.

[8] G. Sahitya, N. Balaji, C. D. Naidu, and S. Abinaya, "Designing a wireless sensor network for precision agriculture using zigbee," in *2017 IEEE 7th International Advance Computing Conference (IACC)*, Jan 2017, pp. 287–291.

[9] A. Mondal, I. S. Misra, and S. Bose, "Building a low cost solution using wireless sensor network for agriculture application," in *2017 International Conference on Innovations in Electronics, Signal Processing and Communication (IESC)*, April 2017, pp. 61–65.

[10] G. E. John, "A low cost wireless sensor network for precision agriculture," in *2016 Sixth International Symposium on Embedded Computing and System Design (ISED)*, Dec 2016, pp. 24–27.

[11] P. Durga, G. Narayanan, B. Gayathri, M. V. Ramesh, and P. Divya, "Modelling a smart agriculture system for multiple cropping using wireless sensor networks," in *2017 IEEE Global Humanitarian Technology Conference (GHTC)*, Oct 2017, pp. 1–7.

[12] T. Moribe, H. Okada, K. Kobayashl, and M. Katayama, "Combination of a wireless sensor network and drone using infrared thermometers for smart agriculture," in *2018 15th IEEE Annual Consumer Communications Networking Conference (CCNC)*, Jan 2018, pp. 1–2.

[13] C. T. Kone, A. Hafid, and M. Boushaba, "Performance management of ieee 802.15.4 wireless sensor network for precision agriculture," *IEEE Sensors Journal*, vol. 15, no. 10, pp. 5734–5747, Oct 2015.

[14] G. Sahitya, N. Balaji, and C. D. Naidu, "Wireless sensor network for smart agriculture," in *2016 2nd International Conference on Applied and Theoretical Computing and Communication Technology (iCATccT)*, July 2016, pp. 488–493.

[15] W. Yitong, S. Yunbo, and Y. Xiaoyu, "Design of multi-parameter wireless sensor network monitoring system in precision agriculture," in *2014 Fourth International Conference on Instrumentation and Measurement, Computer, Communication and Control*, Sept 2014, pp. 721–725.

[16] A. R. de la Concepcin, R. Stefanelli, and D. Trinchero, "Ad-hoc multilevel wireless sensor networks for distributed microclimatic diffused monitoring in precision agriculture," in *2015 IEEE Topical Conference on Wireless Sensors and Sensor Networks*, Jan 2015, pp. 14–16.

[17] P. Spachos and D. Hatzinakos, "Self-powered wireless sensor network for environmental monitoring," in *2015 IEEE Globecom Workshops (GC Wkshps)*, Dec 2015, pp. 1–6.

[18] A. Shaltout, P. Spachos, and S. Gregori, "Power management modelling of a photovoltaic system for a wireless sensor network," in *2016 IEEE International Workshop on Computer Aided Modelling and Design of Communication Links and Networks*, Oct. 2016, pp. 201–206.

[19] Arduino uno rev3. [Online]. Available: https://store.arduino.cc/usa/arduino-uno-rev3

[20] Xbee 2mw wire antenna - series 2. [Online]. Available: https://www.sparkfun.com/products/retired/10414

[21] Grove - moisture sensor. [Online]. Available: https://www.seeedstudio.com/Grove-Moisture-Sensor-p-955.html

[22] Grove - temperature&humidity sensor pro. [Online]. Available: https://www.seeedstudio.com/Grove-Temperature%26Humidity-Sensor-Pro-p-838.html