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Original Research Article

Photovoltaic, Internet-of-Things-Enabled Intelligent Agricultural Surveillance System

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Abstract: The implementation of wireless communication technologies for monitoring and control systems resulted in the first instance of "smart" farming. Precision agriculture (PA) is characterized by the employment of cutting-edge technology and equipment calibrated to the inch to precisely monitor and treat crops. Smart PA is able to assist farmers in increasing crop yields and simultaneously increasing efficiency and reducing stress by utilising wireless sensor networks (WSNs) and the Internet of Things (IoT). In this paper, an Internet of Things–enabled agricultural monitoring system is discussed. Data on the environment will be gathered in the field by solar-powered prototype nodes, and then transmitted to a central station for processing. Utilizing two nodes, it was determined whether or not it is advantageous to add energy harvesting into an electrical device. An experimental testbed demonstrates how the system might work in the future by capturing energy. Using a gadget that can harvest energy can lengthen the amount of time a device is able to run by supplying it with electricity, charging the battery, and increasing the battery's capacity.

Keywords: Precision Agriculture (PA), Surveillance, Internet of Things (IoT).

I. INTRODUCTION

Wireless technology has made it easier for farmers to communicate with their crops and monitor their progress. Modern technology can be used to develop advanced crop management systems that monitor and respond appropriately to their demands. Precision agriculture (PA) is a farming approach that integrates modern methods with tried-and-true methods of production [1, 2]. As a result of the application of IoT [3] in agriculture, farmers can get greater precision and control over the production of crops and livestock. Using innovative technologies to assist farmers in their farming operations can increase efficiency and reduce costs for farmers. By employing more precise solutions, farmers can exert direct control over a greater number of components of their farms, which is advantageous for the farmers.

Farming fields are traditionally handled without the use of modern technology in traditional farming applications [4]. To maintain the status quo and keep things operating efficiently, additional experience is essential. When deciding where to plant, when to harvest, and how much water to use, a farmer who practises conventional agriculture must consider both present and historical weather conditions [5]. Paternalistic agriculture aims to reduce the amount of labour farmers must employ while simultaneously raising the level of care given to crops when it is necessary. This is made feasible via a computer programme called PA, which employs multiple sensors and actuators in addition to GPS and robotics.

Use of the IoT devices to monitor plants and livestock [6, 7], which are currently being tried is an intriguing method to achieve PA. The IoT [23] devices are low-power embedded circuits that can communicate with other IoT devices across a network. Internet of Things networks, in which devices interact with each other and work together toward a common objective. In an Internet of Things-based farming system, sensors can be utilised to collect environmental data such as the soil's moisture level. The measured data can then be used to operate an automated irrigation system to adequately irrigate plants, minimising over-and underwatering. As an additional bonus, farmers may monitor their fields remotely and in real-time using an Internet of Things system. It was equally necessary to monitor the livestock as it was to monitor the crops in the field, and monitoring the livestock can reduce the likelihood of disease transmission between animals and humans. By using IoT devices, animal welfare can be dramatically improved while labour costs are reduced. Animals' location and health status can be provided by the IoT devices [8].

Wireless Sensor Networks (WSN) are used to assist farmers in various ways [9]. As a result, farmers can focus on certain fields, increasing their efficiency [10]. It is possible to adjust the sensor nodes of each crop to its individual requirements. Some varieties of crops require a specific pH level in their soil, while others require a specific degree of moisture. Scalability is a second characteristic of WSN. To achieve cost reductions, IoT devices are designed to be adaptable, allowing anyone to instantly add or remove them from a network [24]. Agriculture is one of the potential uses for a WSN because it operates in similar surroundings. Greenhouses are monitored to ensure that they are functioning at their maximum capacity.

II. RELATED WORK

For maximum crop yield, contemporary farming blends technical advances into traditional farming practises. PA, IoT [11], and WSN's have all been created to help farmers to increase yields, enhance efficiency, and reduce expenses. There are examples of built and proven WSN-based PA monitoring systems in the published literature [12]. Others have used IEEE 802.15.4 to develop Zigbee-based WSNs so that they use less power, live longer, and perform better.

In [12], a camera-equipped drone was also employed. Thermal imaging cameras were used to enhance the process of monitoring. Using the network, it is possible to accomplish specific tasks. There were environmental sensors capable of gathering data. The drone was given permission to fly above and collect data on selected plants in close proximity to the node's leaf temperature. The leaves have higher temperatures than the crops. These findings have been corroborated by scientific studies. According to the temperature at the time the drone was deployed above the crop, the drone's measurements were significantly out of whack. Nonetheless, when the drone was in close proximity to the target, it was feasible to take more data accuracy. People who use these devices need to make sure that drones, nodes, and time-synchronization between them are always running.

Microclimate conditions were monitored throughout an entire field using a WSN [3, 13], rather than physically monitoring [14]. For the purpose of constructing multiple networks, a two-tiered network with nodes that can switch between two operating frequencies was intended to be constructed. This was always the intention of the system. Clusters of nodes were formed, with each cluster relaying data to a cluster leader, who then sent the information to the next node in the chain. An entire season's worth of use was found to be possible with only a single battery charge based on the findings. When developing a WSN for PA applications, the same hardware and features were used in the systems disclosed [8-10], which were based on the same hardware and features. These two systems employ X-Bee modules to set up wireless Zigbee networks to connect the nodes. Sensor nodes were employed by the systems to monitor environmental variables, making them distinct from others [15]. In addition to the light level, sensors that detect the temperature, wetness, and humidity of the soil. On each of the two sensor nodes in [16, 17], just one dirt sensor was present. Nodes in the built systems have a limited length of time to work before their power supply must be replaced. Due to the lack of available energy harvesting technologies, this is the case.

III. PROPOSED MODEL

The hardware components and nodes that make up the proposed system were chosen expressly for their suitability as part of a PA monitoring system.

A. Devices

Customisation of the designed prototypes was accomplished through the use of six hardware components. Along with an Arduino Uno, DHT11 sensor, Soil Moisture sensor, Power Converter, Lithium-Ion Polymer (LiPo) battery and a solar panel were used.

1. Arduino Uno

Open-source electronics prototyping platform known as Arduino. The Arduino Uno, based on the ATmega328P microcontroller has 6 analog pins reads the analog values and 18 digital pins in which analog pins acts as both digital and analog pins. Arduino Uno has in-built ADC converters. This platform gives designers access software and hardware components efficiently. The Arduino programming language and the Arduino development environment are both utilised in the process of writing code for the microcontroller. For the purpose of connecting all of the components, an Arduino

Uno Rev3 board was utilised. Because of its low power consumption and simple programming interface, the Arduino Uno was selected as the board to use for this project.

2. *Series 2 X-Bee with 2 milliwatts of power over a wire antenna*

In order to facilitate wireless communication between the nodes, a Series 2 X-Bee equipped with a 2mW Wire Antenna was chosen as the appropriate device [20]. Low-power radios that connect with one another using Zigbee mesh networking are the Series 2 X-Bees. Because it can link dozens of nodes and transfer data up to 120 metres in line of sight, Zigbee is utilised in the intelligent agriculture monitoring system. In addition to this, there are several advantages to it.

3. *X-Bee Navigator USB*

A second X-Bee Series 2 module is connected to a computer and utilised for communication with the module with the help of an X-Bee Navigator USB. The X-Bee unit's serial and programming pins can be accessed with this module. The board can be configured by using the X-CTU software that is made available by Digi International Inc., and incoming data can be read by using this programme.

4. *Sensors*

Temperature and humidity sensors were the sorts of sensors that were utilised in the process of gathering data from an agricultural monitoring program in order to assess the myriad environmental factors that needed to be monitored.

i. The Grove Soil Moisture Sensor [21] is a device that measures the moisture content of the soil. This sensor was able to accurately estimate the volumetric water content of the soil by the electrical resistance that was present between its two rods. This was helpful in agriculture since it reduces the amount of irrigation needed, which in turn inhibits germination and spread.

ii. The DHT11 temperature and humidity sensor is capable of measuring ambient conditions to an accuracy of 0.3 degrees Celsius and 2 percent relative humidity [22]. This sensor was selected due to the fact that the majority of crops achieve their optimal levels of production when the temperature and humidity are optimal. These methods are crucial in greenhouses, because the outside environment can significantly affect the inside conditions. Controlling climate conditions is extremely beneficial for plant growth, as most plants require specific temperatures and humidity levels at particular stages.

5. Power Converter

Power Converter is the name of the converter that converts solar panel current into sensor node current [18, 19]. A lithium polymer ion (LiPo) battery could be charged using this module, in addition it having the ability to deliver energy. A Grand Pro 3.7V 6600mAh LiPo was used as the battery in this instance. As long as the battery was charged to a level higher than 3V, the power converter was programmed to output 5V. The power converter turned off as soon as the voltage dropped below 3V and waited for the battery to recharge while it was in standby mode.

6. Solar Panel

It was powered by a PV Logic Polycrystalline solar panel (STP010P). Despite its small size, the solar panel produced 22V at a maximum of 5W. Its modest size allows it to be placed in areas where it will cause the least amount of disruption to surrounding plants.

7. Lithium-Ion Polymer (LiPo)

Lithium-ion Polymer batteries are used to store the electricity from the solar panel for the time when there is no sun light. The electrolyte within the battery is gelled, it does not require a stiff casing to squeeze the electrodes together in order to function properly. This allows lithium-ion polymer batteries to be moulded into virtually any configuration that may be required by the application.

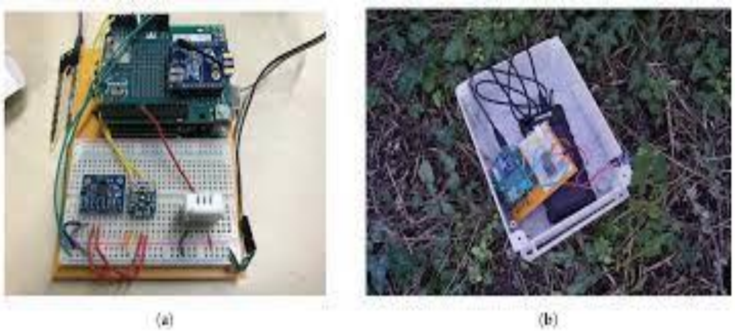


Fig 1: Prototype of sensor nodes with energy harvesting through solar panel

B. System Nodes

System nodes were of three types. Sensor, relay, and destination were nodes.

1. Sensor Node

The sensor nodes collect environmental data and sent it to the relay, which was the network node closest to the destination node. To achieve this objective, sensor nodes containing the aforementioned components were utilised. Sensor nodes capture soil moisture level, ambient temperature, and humidity level. The system also monitors the battery's remaining charge, low charge could cause the node to stop responding. Unidentified sensor readings may ensure. Fig 1 shows the prototype of a solar-powered wireless sensor node.

2. Relay Node

The data collected by the sensor nodes is transmitted to the relay node. Because it was completely responsible for delivering any incoming packets to their intended location, this node was equipped with all of the hardware described above with the exception of the sensors. Because the sensor nodes may not be able to reach the target in a wide region, a relay was deployed to transmit the data to the destination node. After receiving a packet from a sensor node, this node appended the current battery level of the sensor to the packet before sending it on to the location that was specified in the send command. During the expedition, it was imperative that the relay node function properly. In the event that the relay fails to function properly, the sensor nodes' collected data will be lost. As a consequence of this, relay nodes are absolutely necessary for the secure transport of data between networks.

Table I: Parameters of the sensor nodes

Parameter	Value
Power Source	6600mAh
Arduino Energy Usage	72mAh
X-bee Current Usage	38mAh
Soil water Current Usage	32mAh
DHT11 Current Usage	0.9mAh
Sample Frequency	0.5Hz
Transmission Interval	2s

3. Destination Node

The information gathered by the sensor nodes was brought together to the destination node. An Arduino Uno and an X-Bee Series 2 antenna were the components that made up this node. It was designed to establish a connection with a computer and take in a predetermined voltage input. This was accomplished without the use of a solar panel or power converter. When a packet was finally received, the internal clock of the computer was used to time stamp it. After that, the packet was saved in a database so that it could be analysed at a later time.

IV. EXPERIMENTAL SETUP

In order to examine the system's capabilities, a tiny, two-hop network was developed and tested. There are a total of four nodes in this network: two sensor nodes, one relay node, and one destination node. It was possible to accomplish both the physical and functional equivalency of the sensor nodes. The second node did not have a solar panel for energy collection, in contrast to the one that did have one. The parameters that are utilised to configure the sensor nodes are listed in Table I. As a consequence of this, the capacity of the battery was determined to be 6600mAh, although the capacities of the other components were significantly lower.

Both of the sensor nodes established connections with the relay node, which then transmitted the data to the appropriate receiver. Each piece of data that was received was recorded at its destination along with a timestamp, which made it possible for the computer that sent the data to

The database to analyse it later. In order to keep the relay node operational, The power converter was required to be connected to both a relay node and a source of constant voltage input. For an indefinite period of time. Fig 2 is a network diagram showing how nodes communicate. As a result of the regulated environment, it was anticipated that each node would utilise the same volume of electrical power. In order to conduct tests, sensor nodes were installed so that they could take readings of their surroundings at a rate of 0.5 Hz and send data to destination once every two seconds. This was done to ensure that a lot of data was obtained quickly and that a lot of energy was consumed throughout the testing. This is due to the fact that there are not enough significant shifts in the environment that occur out in the field to justify such a short period of time spent obtaining data. The amount of moisture in the soil was determined by sensors that were planted inside of a potted plant. Additionally, sensor nodes were positioned close enough to one another to provide comparable data on temperature and humidity. Nodes had to be positioned in close proximity to windows so that sunlight could directly hit the solar panel and cause it to charge the battery. This was done so that the solar panel would be able to produce enough energy to fully charge the battery. To ensure proper operation, both sensor node batteries were completely charged before to the experiment. Each node was tested until one node became unresponsive.

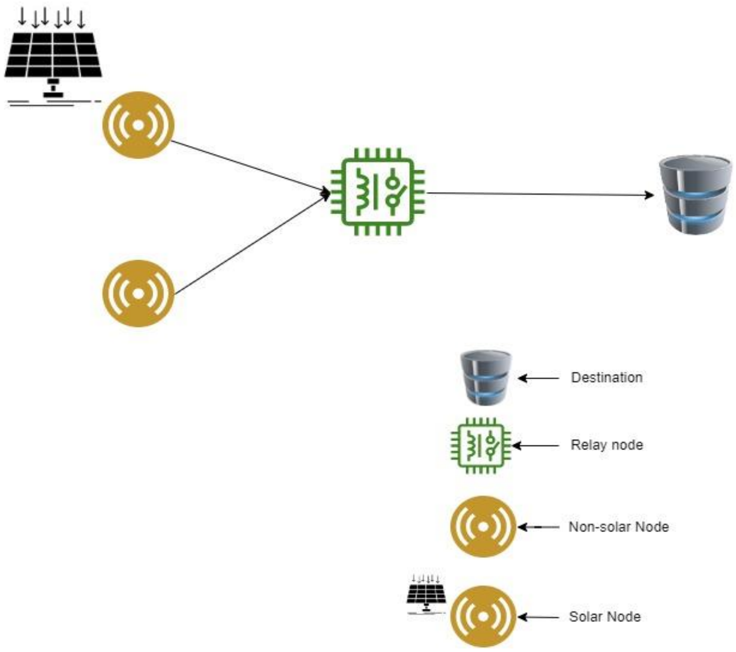


Fig 2: Sensor network deployment

V. EXPERIMENTAL RESULTS

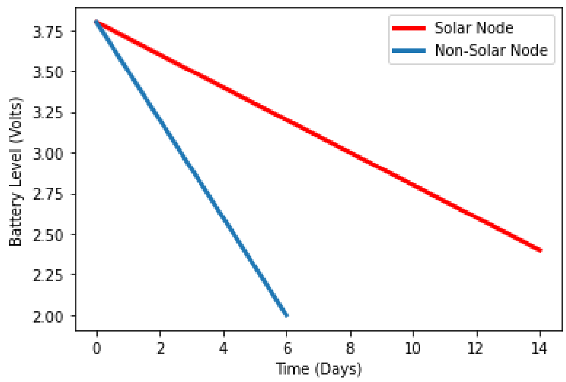
The experimental findings show that the sensor data was effectively delivered. After the relay received the packets, it added the relay's remaining battery level to each one before forwarding it to the destination, where, according to convention, the time stamp was positioned. Figures 3 and 4 show the results of the experiment. Due to the large amount of data obtained, only a subset was plotted and provided here for convenience.

A. Battery Level:

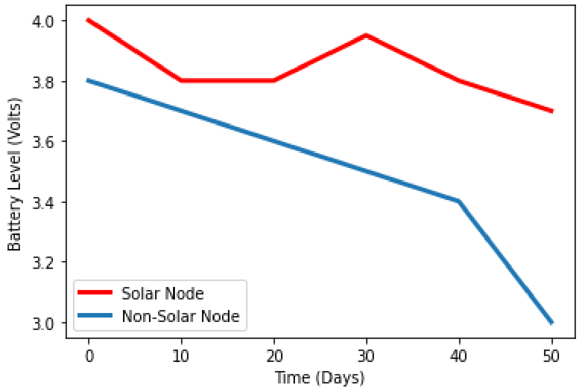
Figure 3a shows the results of the remaining energy levels in the sensor nodes batteries. As expected, the batteries voltage dropped with time. The non-solar sensor node failed after 43 hours of operation based on the data. The solar node had a significant amount of charge when the non-solar node suddenly stopped functioning. As can be seen, the solar panel had a significant impact on the node's lifespan. As can be seen in the Fig 1, sunlight was used to illuminate the area, which in turn served to charge the battery and keep the power level uniform over the solar node. When the solar panel could no longer produce electricity, the battery was used, which resulted in a considerable decrease in the measured charge of the battery. Each battery lost its charge at a rate that was nearly comparable to the other. Because of this, the node's predicted lifetime increased by 40 hours. After the solar panel stopped charging the battery, there was a continuing decline in the capacity of the battery. Despite this, there was a considerable difference between the states of charge of the batteries.

B. Power Estimation

The overall runtime of the nodes can be calculated using data collected of various battery levels. The experiment power results in Fig 3a can be used to collect two important quantities for calculating the node runtime. The first is the battery's full-charged starting voltage of 3.8V. The second value was the battery's charge after 24 hours. The non-solar node's residual voltage was 3.57V while the solar nodes was 3.65V. The 24-hour voltage can be determined by subtracting the starting voltage from the recorded value. If the voltage declines in a consistent manner and the solar panel receives the same amount of sunlight each day, then the device's runtime may be measured and estimated. The results with approximated values are presented in figure 3a. Take note that in order for the power converter to be able to supply power to nodes, the battery voltage must be more than 3V. The non-solar node is expected to operate for approximately 3.5 days, whereas the solar node is expected to operate for approximately 7.3 days. It is possible to make some observations about the non-solar node's anticipated duration. When the non-solar node reached 3.4V, the power level rapidly fell until the node stopped working. In addition, the node's operation lasted significantly longer than predicted. Even after the voltage was reduced to 3V, the node's capacity to transport data remained unaffected. As the capacitors were still monitoring battery voltage and supplying power to the node when the power converter failed, it is possible that they were responsible for generating this issue.



(a) Power level estimates for sensor nodes

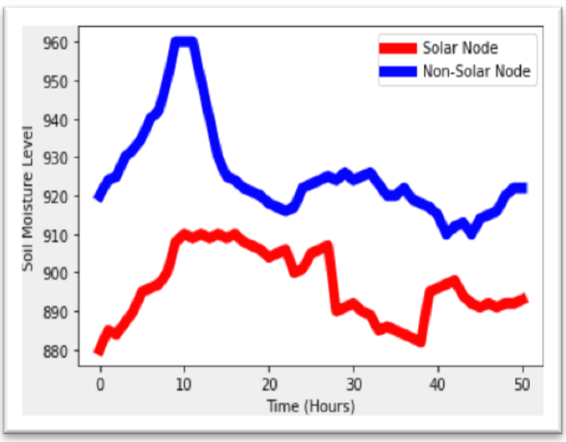


(b) Power level estimates for sensor nodes

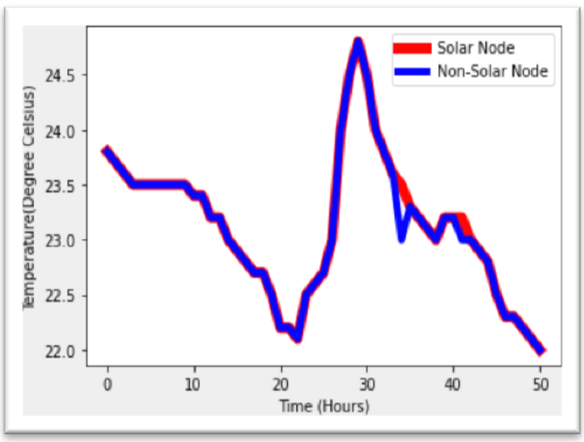
Fig 3: Power results for the proposed system

C. Sensor Readings

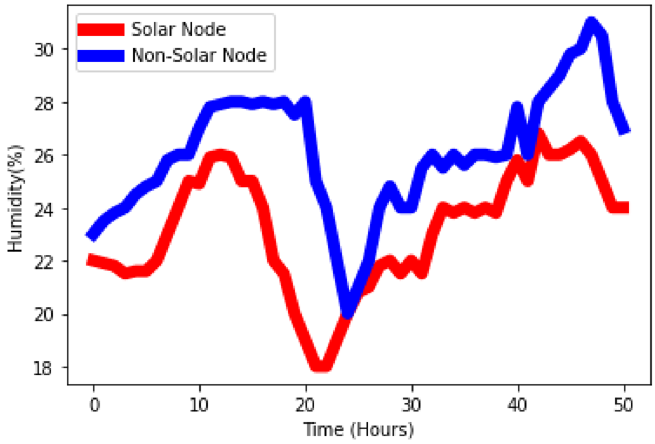
In accordance with the findings from the experimental sensors, the nodes did an adequate job of collecting and transmitting data. In Figure 4a, the two sensor nodes soil moisture values are equivalent. It is possible for measurements taken in different locations to vary substantially due to the fact that the plant's roots have the ability to draw water both downward from the soil and upward when it is necessary. In spite of the apparent differences, readings may vary greatly between places. As shown in Figures 4b and 4c, both nodes had similar values. Because both nodes were in the same environment, any modifications would have had the same effect on both, which was intended. It's challenging to get sensor data from both nodes since the environment behaves differently. It is essential to have a solid understanding of sensor data because it impacts battery life. Because electricity is required for sensors to function, the amount of power used is largely dependent on the values that are being read. As shown in Figure 4a, the non-solar node finds values that are higher than those found at the solar node. Despite the fact that the sensor only uses a little amount of power, one of the nodes may deplete its power supply far more quickly than the other. As a direct consequence of this, the lifetime of the node is shortened.



(a) Soil Moisture



(b) Temperature



(c) Humidity

Fig 4: Sensor test results for the proposed system

VI. CONCLUSION

In this paper, we proposed a solar-powered, low-cost, intelligent agricultural system that makes use of energy-harvesting sensor nodes to boost agricultural productivity and simultaneously reducing operational expenses. In addition to a power converter, the nodes of each sensors measure the temperature, humidity, and soil moisture. The power converter has the capability of connecting a solar panel to the node in order to collect energy for the purpose of recharging the battery and determining how much capacity it has left. Using controlled trials, we were able to show that energy harvesting devices may considerably extend node lifetime. The results also showed the system's capabilities, such as data collection and network transfer, as well as its limits. Based on the trial results, the proposed method may be employed in agriculture. Smart farming nodes with low-power microcontrollers, wireless antennas, batteries, a power converter, and an energy harvesting device could be reliable and robust.

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