International Journal of Latest Research in Engineering and Technology (IJLRET)
ISSN: 2454-5031
www.ijlret.com || Volume 03 - Issue 09 || September 2017 || PP. 97-101

Optimizing Communications and Automation in Micro Farms

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Abstract: In the fast-paced growing society of the 21st century, the agricultural economy is slowly being left behind, however, the thirst for fresh, organic, cheap crops continues. The proposed system incorporates latest technologies, tools and designs, providing a platform for anyone to become a modern-day farmer with an easy, yet efficient, confine method of farming. The research intends to create an indoor farm with shelving unit of three-four shelves holding shallow bins of soil. Above the plants LEDs panels provides the lighting for the plants. Customized wireless network together with its own protocol using wireless technologies and different sensors for the temperature, humidity and other sensors have been developed, making indoor farming available to any user.

Keywords: Micro-Farming, IoT, nRF24L01, RaspberryPi, vertical farming,

I. Introduction

The increasing urban development leading to less and less arable land for growing crops and a significant rise in awareness of health risks in consuming Genetically Modified (GM) foods, urban citizens have less and less choices about the foods they consume [1][2]. Moreover, the built environments, especially high-rise buildings, usually lack space and resources for growing one's own crops. The decision to not venture into household farming is further backed up by the limited and conventional ways of farming, which are often inconvenient to fit within individuals' busy modern lifestyles. Furthermore, the global warming effect coupled with a rising global population, political conflicts and mass migrations, is adversely affecting agriculture in many developing countries that are primarily dependent on exporting of primary resources such as food [3][4]. Additionally, without the aid of smart agricultural systems, the traditional methods of farming may be inefficient in terms of the amount of resources used. For example, watering the plants much more than what is required not only wastes water, but also causes soil erosion and may even lead to salinization in dry, arid regions [5].

II. Related Works

With a significant increase rate of around 93.53% since 2008, published research papers on smart farms, which are mainly focused on farming management, soil carbon emissions and food security, undoubtedly proves the importance and demand for such a smart system [6]. Numerous related works previously conducted in this field have a pattern that extends some of the core features required for automation of farms. These include placement of additional sensors such as insect sensors [7] or carbon dioxide sensors [8], a mobile app [9], and an automated response [10] to the current situation, after undergoing a decision-making process, through actuators [11]. Furthermore, other changes are seen usually in the method of communication, for instance, one commonly used alongside Internet of Things (IoT) are Wireless Sensor Networks (WSN) [7][12]. Within such a network, sensors have nodes that send data wirelessly to a main port. Note that this does not use the Internet; instead, a transmitter-receiver relation is seen, and later on, the collected data is sent to servers using the Internet. Other solutions use Arduino board and a Wi-Fi module instead to redeem similar functionality [9].

III. Proposed Solution

In order to solve the issues stated previously, it is essential to be able to maintain and control an environment that is specifically suited and catered towards each crop's needs to ensure optimal harvest rates throughout the year. By implementing a smart 'Micro-Farming' system, which features an efficient use of space (vertical design) and time (more crops grown at a time), and real-time sensor readings, the user would be notified of the current conditions within the micro-farm. Meanwhile, the system will automatically adjust to bring about the set prime situation using a set of actuators, thus removing the need for the user to attend to the plants frequently. The solution incorporates a variety of sensors such as light, humidity, pH, and surrounding temperature to provide utmost detail. These sensors and actuators along with the crops are placed in an enclosed container that contains a Microcontroller Unit (MCU) and radio transceiver collectively known as a sensor node. Since in any particular use case there will be a variety of these enclosures, a wireless sensor network with a custom protocol and routing algorithm is also proposed. Data from these sensor nodes are passed to a local gateway, where it is stored in a robust database and analysed. The End-user is given control to the system through an app which apart from giving notifications also allows control of the system and its many nodes remotely.

A. Design Overview

The main exterior container is similar to a shelving unit or cabinet, whose width and length dimensions are fixed. Since several layers of interior containers designated as 'racks' can be stacked on top of another, the total floor surface area covered is significantly reduced, thus making it a practical solution. Each rack is removable, serves a specific purpose and is designed with separation of concern in mind. A certain rack holds the actual plants whilst another may contain LED lights or even an array of tiny drip pipes for irrigation of the plants. The end user is free to choose the arrangement of the racks and spaces between them as they see fit for the requirements of the plants they are growing. Each rack has distinct connectors at their sides for power supply of the different electrical components onboard the rack. This allows for easy management of cables on one side of the cabinet. At the very top of the cabinet is the water tank, whose water flow to each racks' soil layer via trickle drip irrigation is automatically controlled and adjusted as per the sensor readings using valves preceding each stemming pipe that are customizable as per the number of racks in a single shelf, using T-junctions. Such an irrigation method is seen to be most efficient as it prevents soil erosion, leaching of nutrients, and takes up less than half as much water as compared to a sprinkler system [13] since water is supplied directly towards the plants' roots.

B. Wireless Sensor Network (WSN)

In this design, a wireless sensor network is proposed for the micro-farm cabinets with principles similar to the WSN implemented in the paper by Sudhir G. Nikhade which has many advantages over traditional base station based systems, namely low cost and power consumption, compactness and ease of scalability and deployment [14]. However, a significant difference in this design is the use of different electrical components for the sensor nodes together with a custom protocol. Each Cabinet acts as a sensor node which communicates with six other parallel nodes and include a single local gateway acting as a coordinator node similar in fashion to a clustered star network. In this design, however the star network is extended to a tree network by using intermittent nodes as relay points or friend nodes that pass data from a distant node adjacent to the relay itself to the coordinator node. Each Cabinet contains an MSP430 LaunchPad by Texas Instruments connected to a radio transceiver. The MCU is connected to the different racks through varying means, which are discussed in detail in the sections below.

C. Local Gateway

The primary choices for the MCU of the local gateway are the Raspberry Pi and Arduino Uno as they are both flexible, open source platforms that are ideal given such an application. For the prototype, Raspberry Pi was selected because it has a lot more memory, much higher clock speed and has native Secure Digital (SD) card support albeit it is costlier and slightly larger in size. The native SD card support allows the Raspberry Pi to act as a server since it can store a much larger amount of sensor readings that can be used to make predictions and suggest improvements as future system developments. Note that the server will be the source of the data being displayed in the mobile application.

D. Transceiver

The Transceiver selected for this design is Nordic semiconductor nRF24L01+ which is an ultra-low power and data rate configurable RF Transceiver IC. It operates in the unlicensed ISM band and uses GFSK modulation instead of spread spectrum scheme to reduce power consumption. It is interfaced to both the MSP430 launchpad sensor node and Raspberry Pi gateway through SPI. Compared to a ZigBee XBee module, it is more cost-effective and has much lower power requirements such as 15mA compared to 50mA and a much higher data rate of 2 Mbps compared to 250Kbps [15]. The 2 Mbps high data rate transmission reduces packet loss, provides better lifetime and a significantly better channel avoidance [16]. This is because, data is sent and received at a much faster rate and the transceiver spends a lot of time in sleep mode. Similar to aCarrier-sense multiple access with collision avoidance(CSMA/CA), with further modifications.

Preamble (1 byte)	Address / Network ID (5 bytes)	Source ID (2 Bytes)	Payload (23 bytes)				CRC (1 byte)
			Packet Type (1 Byte)	Node Information (2 Bytes)	Rack Information (2 Bytes)	Sensor/Actuator Data (18 Bytes)	

Figure 1 - Data Packet Structure

E. Custom Protocol

The Data Packet Structure highlighting the syntax of the protocol is shown in Figure 1. The Preamble is a simple header which means data is about to be transmitted. The next section is about Destination Network ID followed by the Source Network ID. This is followed by the Packet Meta Data which includes the packet type field. The Different types of control syntax are summarized in Table 1.

TABLE 1 - The different types of control syntax

Packet Type	**Definition**
RTS	Request To Send
CTS	Confirm To Send
WTL	Wait Timeout Limit
DTS	Data To Send
DTA	DaTa Acknowledged
DTR	Data To Resend

Before sending any DTS packet, the node first sends an RTS packet to the local gateway and waits until it receives an acknowledgment CTS packet in order to perform a handshake. The gateway ensures only that node sends data by issuing a WTL record to every other node instructing those nodes to wait for specified amount of time until the previous transmission is completed. Once Handshaking is done, a DTS packet is sent which exclusively includes the node information, rack information and associated sensor data. Once the gateway receives the packet, it is verified using a Cyclic Redundancy Check (CRC) If the packet failed verification, a DTR packet is sent to the node to request the data to be resent otherwise DTA packet is Sent and the transmission ended.

F. Light Rack

With optimization of space kept as one of the main goals of the system, all of its components have to be carefully designed and integrated to maximize system performance whilst keeping costs, both in terms of power consumption and monetary equivalent, as low as possible.

In order to boost its efficiency and effectivity, each shelf has to be intricately designed to allow as much plants to grow within the same shelf without compensating the natural environment where each specie can photosynthesize at the highest rate. In other words, a specific type of lighting system should be used to ensure that power wasted due to unutilized wavelengths of light supplied be discarded, and further energy waste through heat be eliminated whilst not hindering plant growth through overheating given that distance between light racks and the plant racks would be less than usual in order to optimize space within the shelf. The positioning that maximizes the span of each LED for energy efficiency will be designed using DIAlux evo [17], a lighting design software by DIAL.

G. Sensor Rack

A sensor 'bundle', containing wired sensors that are connected to the local MCU, would be placed above every rack containing plants. Thus, the number of such bundles would vary from shelf to shelf depending on the number of automatically monitored plant layers it holds. The proposed product will utilize many sensors, namely-light, humidity, pH, soil moisture, and air temperature sensors. In cases where the whole shelf contains a single type of plant, a single sensor rack can also be used to save power.

Prioritizing optimum system performance and maintaining sustainable energy consumption, the sensors to be implemented within the system must provide high level of accuracy for ensuring that a favorable environment is achieved with little or no discrepancies and that they are able to do such functions with the least power consumption possible to ensure system sustainability. A summary of the sensors that meet such standards and are to be implemented within the system are given in **Error! Reference source not found.**.

A single shelf is expected to hold around 2-4 racks, depending on plant height. Hence, one sensor bundle containing light, pH, and soil moisture sensors would be placed for each rack. Due to common conditions that is expected to occur at different levels of the same shelf done by the effective ventilation design of the system, only one of the few sensor bundles used in a shelf would contain the DHT22 component, which is used to send humidity and temperature readings to the local MCU.

H. Irrigation Pipeline

The architecture designed includes a water tank above the shelf, connected to a mini solenoid valve, in order to control water supply electrically, backflow preventer, then a pressure regulator and lastly a filter, to remove sediments and any particles that can cause the pipes to clog, leading to bigger problems. From there, using regular pipes, tee and elbow pipe connectors a passage (Branching out) for waterflow is created. Note that these can be moved and placed where the user wishes.

Once the main pipe has been branched out for the cabinets, another mini solenoid valve will be connected to the pipes with emitters (Holes) placed across the sensor racks (Designed hollow), to water the plants. At the end of this line, end caps are placed as well.

IV. The System Overview

The outline in Figure 2 illustrates the proposed system whereby the flow of operations goes from the shelves to the Raspberry Pi unit and then to the user through the Internet, in the form of an app. Within a shelf, the plants, along with sensors and actuators, have been positioned in order to monitor current conditions and alter, whenever necessary. To be able to send the data for further analysis and receive efficient instructions on handling resources, an MSP430 LaunchPad unit along with an nRF24L01 transceiver/receiver is associated to every shelf. To put it into perspective, a shelf can be thought of as a sensor node within a wireless sensor network (WSN) that is trying to send data to a gateway.

On the other hand, the gateway, which is the Raspberry Pi board connected to another nRF24L01, is waiting to receive data. Once done, with the ability to quickly analyse and take decisions to optimize the farm, the instructions are sent again to the designated shelf through wireless communication.

V. Conclusions

Combining several concerns from the fields of biology, technology, and modern lifestyle, the Micro-Farming system is designed to allow efficient use of resources to give a desirable output. From ways to sustain the plants to configuring a new protocol for increased system capability, the design has been finalized through extensive research.

The components, ranging from every sensor to the main MCU, had been chosen as the project focuses on decreasing costs, both in terms of power consumption and initial investment costs. In particular, optimizing wireless communication further increases efficiency since it is generally low-cost and removes the need to add on the continuously increasing Wi-Fi network traffic.

Vertical farming in general enables much higher rates of harvest given that plant space is increased by stacking these in layers. Therefore, integrating automation and live monitoring through an easily available app further enhances user-friendliness and convenience.

On the other hand, further development in this area of research can be seen exploring options of, for example, mesh/tree networks being utilized instead of the proposed star network for communication between the shelves. Concepts to improve methods of changing humidity or air temperature can also be further considered, especially focusing on reducing power consumption and cost.

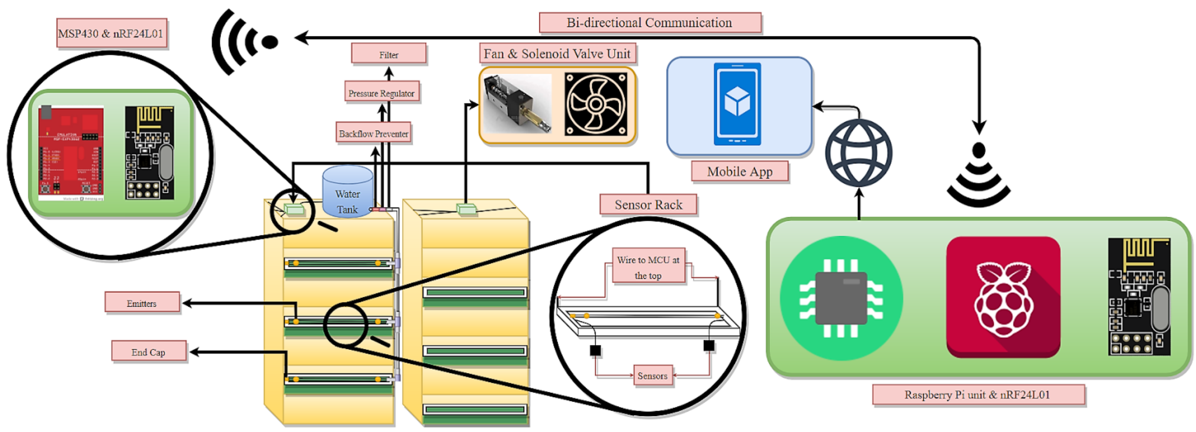

Figure 2 - System Outline (Solenoid Valve Unit Image [33])

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