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IoT-Based Implementation of Field Area Network Using Smart Grid Communication Infrastructure

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Abstract: A power grid is a network that carries electrical energy from power plants to customer premises. One existing power grid is going through a massive and revolutionary transformation process. It is envisioned to achieve the true meaning of technology as "technology for all." Smart grid technology is an inventive and futuristic approach for improvement in existing power grids. Amalgamation of existing electrical infrastructure with information and communication network is an inevitable requirement of smart grid deployment and operation. The key characteristics of smart grid technology are full duplex communication, advanced metering infrastructure, integration of renewable and alternative energy resources, distribution automation and absolute monitoring, and control of the entire power grid. Smart grid communication infrastructure consists of heterogeneous and hierarchical communication networks. Various layers of smart grid deployment involve diverse sets of wired and wireless communication standards. Application of smart grids can be realized in the facets of energy utilization. Smart grid communication architecture can be used to explore intelligent agriculture applications for the proficient nurturing of various crops. The utilization, monitoring, and control of various renewable energy resources are the most prominent features of smart grid infrastructure for agriculture applications. This paper describes an implementation of an IoT-based wireless energy management system and the monitoring of weather parameters using a smart grid communication infrastructure. A graphical user interface and dedicated website was developed for real-time execution of the developed prototype. The prototype described in this paper covers a pervasive communication infrastructure for field area networks. The design was validated by testing the developed prototype. For practical implementation of the monitoring of the field area network, multiple sensors units were placed for data collection for better accuracy and the avoidance of estimation error. The developed design uses one sensor and tested it for IoT applications. The prototype was validated for local and wide area networks. Most of the present literature depicts a design of various systems using protocols such as IEEE 802.15.1 and IEEE 802.15.4, which either provide restricted access in terms of area or have lower data rates. The protocols used in developed system such as IEEE 802.11 and IEEE 802.3 provide ubiquitous coverage as well as high data rates. These are well-established and proven protocols for Internet applications and data communication but less explored for smart grid applications. The work depicted in this paper provides a solution for all three smart grid hierarchical networks such as home/field area networks, neighborhood area networks, and wide area networks using prototype development and testing. It lays a foundation for actual network design and implementation. The designed system can be extended for multiple sensor nodes for practical implementation in field area networks for better accuracy and in the case of node failure.

Keywords: IoT; prototype; smart grid; communication infrastructure; field area network; monitoring and control; wireless sensor network; IEEE 802.11; IEEE 802.3

1. Introduction

Smart grid technology is a revolutionary approach for improvement in existing power grids. It can be envisioned as "technology for all and everything." A smart grid is an automated and broadly distributed energy generation, transmission, and distribution network [1,2]. It is characterized by a full duplex network with a bidirectional flow of electricity and information. It is a closed loop system for monitoring and response. A smart grid network integrates an electrical distribution system with an information and communication network. Smart grid technology ensures a reliable, efficient, resilient, and advanced energy distribution system with an enormous amount of features. The integration of renewable energy resources will lead to reduced carbon footprint and emissions [1–4]. It can be defined in various ways as per its functional, technological, or beneficial aspects. As per the definition given by the U.S. Department of Energy, "a smart grid uses digital technology to improve the reliability, security, and efficiency (both economic and energy) of an electric system of large generation, through delivery systems to electricity consumers and a growing number of distributed-generation and storage resources [5]." The scope of the smart grid is from electrification to web of all things. The efficacy of smart grid can be envisioned for smart farming applications which forms a base for economy of any country.

Chaouchi et al. have discussed potential applications and challenges to IoT implementation [6]. IoT facilitates computation, coordination, and communication between various devices and network elements. Thus, the security and reliability of networks are critical issues to be addressed along with the design and implementation of IoT-based networks and applications. Burhan et al. have depicted various network elements, security, and solutions [7]. Kim et al. have proposed the use of visible light communication in IoT-based machine-to-machine and device-to-device communications [8]. Angrisani et al. [9] have proposed a message queuing telemetry transport (MQTT)-based energy optimization and monitoring solution for consumer awareness. IoT is an integration IP-based network comprised of heterogeneous devices and hierarchical networks. Interoperability between various communication protocols is a crucial requirement for an IoT-based network. Crioado et al. [10] have depicted an integration of cyber physical systems using an application program interface for IoT-based applications.

Karaagac et al. [11] have illustrated a case study of IoT-based automated warehouse using localization of integrated resources. A lightweight machine-to-machine protocol has been proposed for this application. Hernández-Rojas developed a virtual transducer data sheet for the development of web of things with self-registration and self-configuration capabilities [12].

Perahia et al. [13] discussed a multi Gbps wireless local area network based on the IEEE 802.11 standard for higher data rates in Gbps using a 60 GHz frequency band. Successful implementation of this standard could be a quantum leap toward IoT in smart grids. Kumar et al. discussed a mobile-based home automation system with IoT [14]. In that paper, the authors developed an Android-based system using the IEEE 802.15.1 standard. IoT is an unavoidable constituent of smart grid communication for the real-time monitoring and control of a complete network. Real-time measurements and information of various networks as well as commands are communicated using the Internet. Granjal et al. have reviewed various security issues for IoT [15].

Various papers provide review and analysis of the role of IoT in various areas and challenges in the implementation of IoT-based systems. This paper discusses the IoT-based implementation of a field area network using the IEEE 802.11 and IEEE 802.3 standards. This design illustrates a ubiquitous network coverage.

Crop production mainly depends upon the type of plants, the soil, and the meteorological conditions. An information and communication infrastructure has laid the foundation of "precision farming" or "precision agriculture." Precision farming is a technique to gain a higher yield by the complete monitoring and control of agricultural parameters. It is intended for complete monitoring and control of various parameters pertaining to soil, the environment, and the crop for better quality and yield. Wireless sensor networks can fulfill the sensing and measurement requirements of field area networks. Tiny sensor nodes placed at various locations can collect and communicate various parameters such as current, humidity, and temperature [16]. This data can be used for remote monitoring and the control of field area networks. Moreover, the excess energy can be sold back to utilities for waivers in billing or revenue generation. Monitoring of soil conditions and weather parameters can be used to make decisions that can result into higher yield. This paper describes an experimental investigation of smart farming using a smart grid communication infrastructure.

2. Hierarchy-Based Smart Grid Communication Infrastructure for Smart Farming Applications

Smart grid is an integration of electrical as well as information and communication technology to make the power grid more reliable, flexible, efficient, and robust. It is an intelligent power grid with an integration of various alternative and renewable energy resources using automated monitoring, data acquisition, and control and emerging communication technologies [16–20]. The application of a diverse set of communication standards requires analysis and optimization depending upon requirements [21–28]. These requirements can be decided on the basis of the area of coverage, the application bandwidth requirement, etc. It can be categorized as FAN, NAN, or WAN for agriculture applications. Various sensors for the measurement of different parameters such as humidity, temperature, current, flow, etc. can be deployed for the monitoring and control of the agriculture field. An automatic irrigation system can be implemented using a communication infrastructure. Smart farming can result in a higher agricultural yield. Figure 1 illustrates the communication infrastructure of a smart grid technology for smart farming using different hierarchical network layers.

Figure 1. Hierarchy-based smart grid communication infrastructure for smart farming applications.

A smart grid communication network for intelligent agriculture applications can be designed on the basis of the following hierarchical layers.

2.1. Field Area Network

A field area network is applicable for agriculture automation. As shown in Figure 2, it consists of various sensor nodes, a smart meter, renewable energy resources and data acquisition, and a control system for complete monitoring and the control of a smart farm. Smart meters receive commands from the central power grid and control various appliances based on the received commands. Smart farming necessitates various information such as weather conditions, temperature, soil humidity and fertility, source, and load conditions for the operation of various ancillaries, metering data, the time of day usage, auxiliary power, etc. Wireless sensor networks are used for sensing, measurement, and communication of these parameters. A communication backbone can facilitate a complete automation of pumping, harvesting, spraying, and fertilizer spreading. Smart farming includes sensing, measurement, data acquisition, monitoring, control, and the remote access of field area network parameters. A system for remote monitoring and the control of a plug-in hybrid electric vehicle (PHEV) can also be designed for smart farming electric vehicles. A PHEV consists of a gasoline or diesel engine with an electric motor and a rechargeable battery that can be recharged from an electrical power outlet [16]. A field area network is connected to the cloud for web-based monitoring and the control of various parameters. Seamless remote data acquisition can create an interactive system between researchers, experts, and various stakeholders. Precision farming is based on site-specific conditions. The field area network ranges for the coverage area of a few meters. IEEE 802.15.1 (Bluetooth), IEEE 802.15.4 (Zigbee), IEEE 802.3 (Ethernet), IEEE 802.11 (WLAN/Wi-Fi), and narrowband power line communication (PLC) standards, among others, can be used for field area networks [26–31].

Figure 2. Field area network.

2.2. Neighborhood Area Network (NAN)

The neighborhood area network (NAN) communicates information collected by smart meters to the central controller. The NANs may contain a few hundred smart meters set up in HANs. Smart meters are connected with different gateways through NANs. The coverage area of NANs is around 1–10 square miles [31–37]. The requirement of data rates for NAN is around 10–1000 Kbps [38–40]. WLAN, cellular technologies, and PLC can be used for neighborhood area networks.

2.3. Wide Area Network (WAN)

The wide area network (WAN) unites various NANs. Data are collected by various collection points and are sent to a central controller. The area covered by the WAN is around thousands of square miles. The data rates required by WAN are around 10–100 Mbps [39]. A wide area necessitates a large bandwidth for the management of a smart grid network. WAN is appropriate for supervisory control and data acquisition (SCADA) systems for monitoring, control, data acquisition, and the management of a smart power grid [39–42]. IEEE 802.16 (Wimax) and cellular technologies, such as LTE, 3G, 4G, 5G, EDGE, and GPRS are appropriate adoptions for wide area network applications. Geographic information systems (GIS), remote sensing, and the Global Positioning System (GPS) can be used for the field-specific management of smart farming parameters. WAN is applicable for the IoT applications [39–42]. IoT facilitates "machine-to-machine" or "device-to-device" communication. The web of things can benefit smart farming in terms of contemporary techniques for higher crop production.

3. Related Work

3.1. Web-Based Smart Energy System

The developed prototype is intended for the remote wireless monitoring and control of a smart microgrid system situated in a field area network. The HTML webpage was designed for the monitoring and control of various energy sources. The prototype uses IEEE 802.11 and IEEE 802.3 standards for monitoring and control. An ethernet shield is used for communication between Arduino Uno and the user interface. A graphical user interface (GUI) is developed for the monitoring and control of the smart power system. The data is received at an interval of 2 s. The system works successfully in the range of around 50 m in the wireless local area network. The designed prototype was tested using all three energy sources. Sequential priorities were assigned to sources. Initially the system works on a grid. The load will then be shifted to solar and battery power based on the value of the threshold current. The prototype represents a direct current (DC) microgrid. It can operate in both grid-connected and island mode.

The prototype was tested for a local area network using the WPA-PSK security mode. A maximum of 254 devices can be connected and regulated in the network. Other encryption options such as the wired equivalent protocol (WEP), the wireless fidelity protected access temporal key integrity protocol (WPA-TKIP), and WPA2 are also available. Further extension can be achieved by using different network devices such as switches and routers.

A serial terminal program CoolTerm has been used to capture real-time data. Various farming machineries can be operated on any of the three energy sources based on their load serving capabilities. Figure 3 shows the design of the remote wireless monitoring and control of a smart power system. Figure 4 shows flow charts of the monitoring and control of the developed prototype. The user can monitor the data and control an entire system by entering the predefined commands on the local network webpage, as shown in Figure 5. Figure 6 shows the IoT-based monitoring and control of the developed prototype. The address of the website developed for the designed system is "**smartfield.dlinkddns.com**". When the prototype is functioning on the local network, the port can be forwarded for a WAN application. The designed prototype was tested on the developed website.

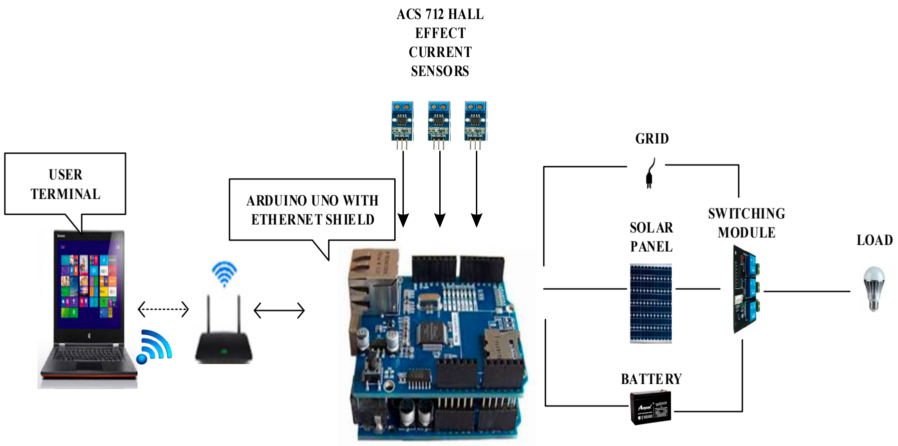
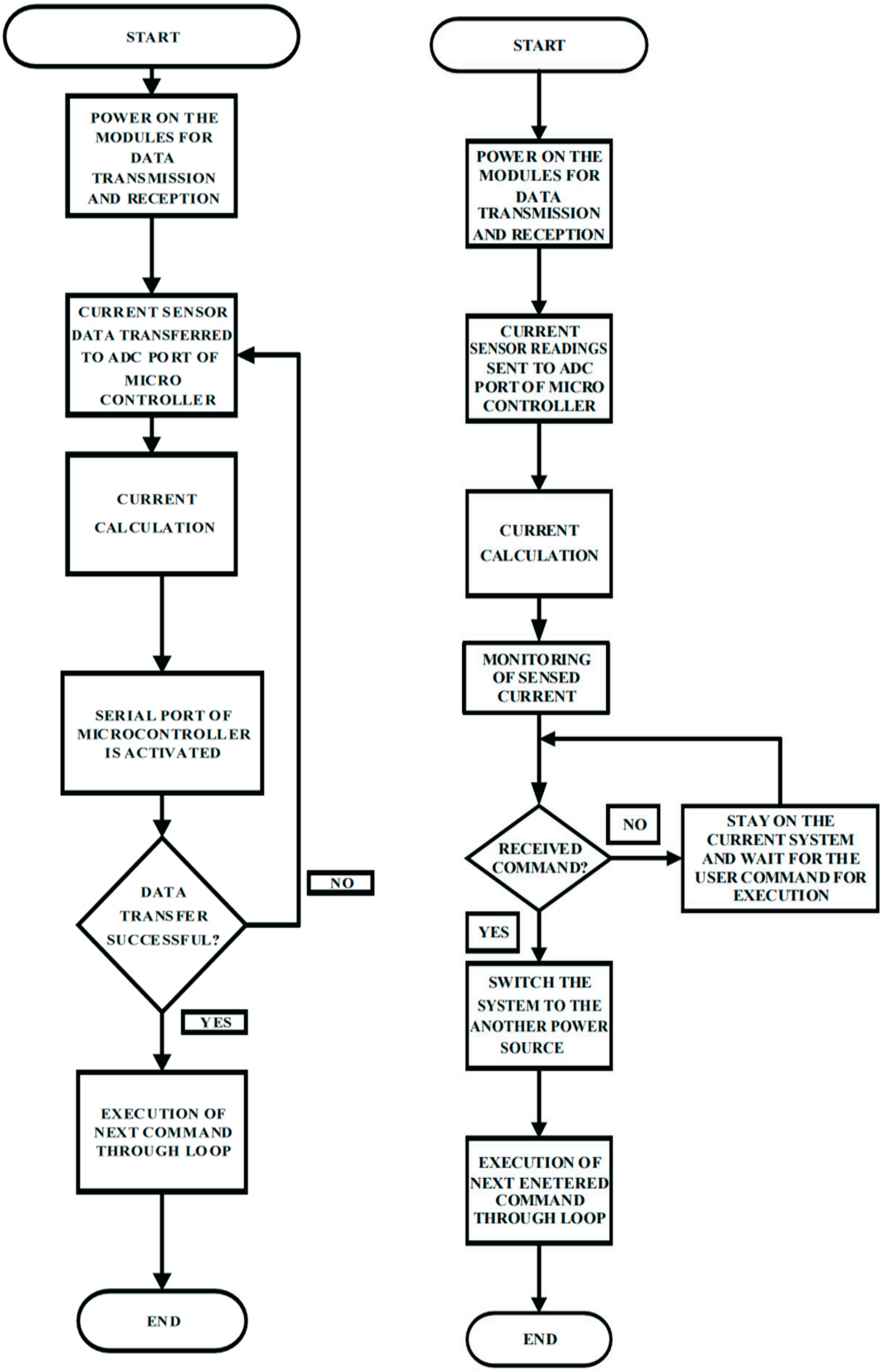


Figure 3. Design of a smart power system.



(**a**) (**b**)

Figure 4. Flow charts for the (**a**) energy monitoring and (**b**) control of the prototype.

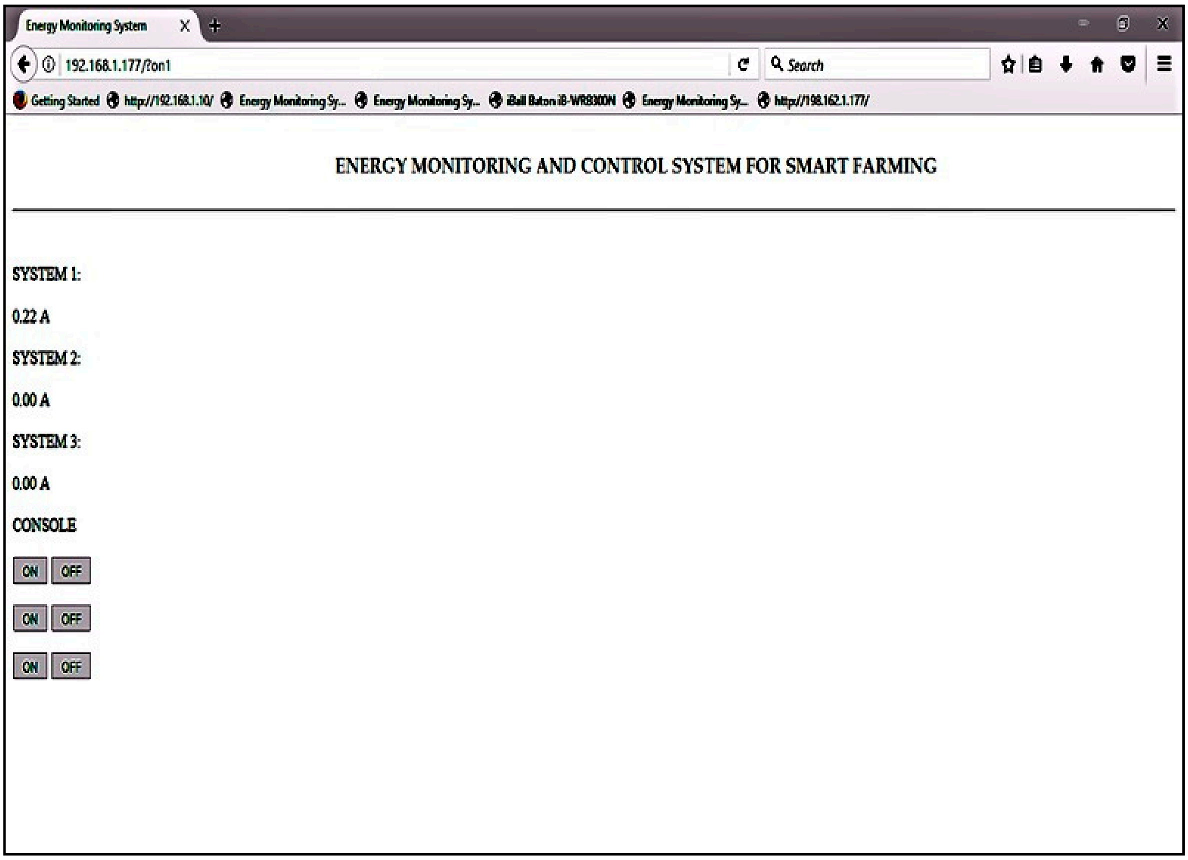


Figure 5. Snapshot of remote wireless monitoring and control of a smart power system through an HTML webpage.

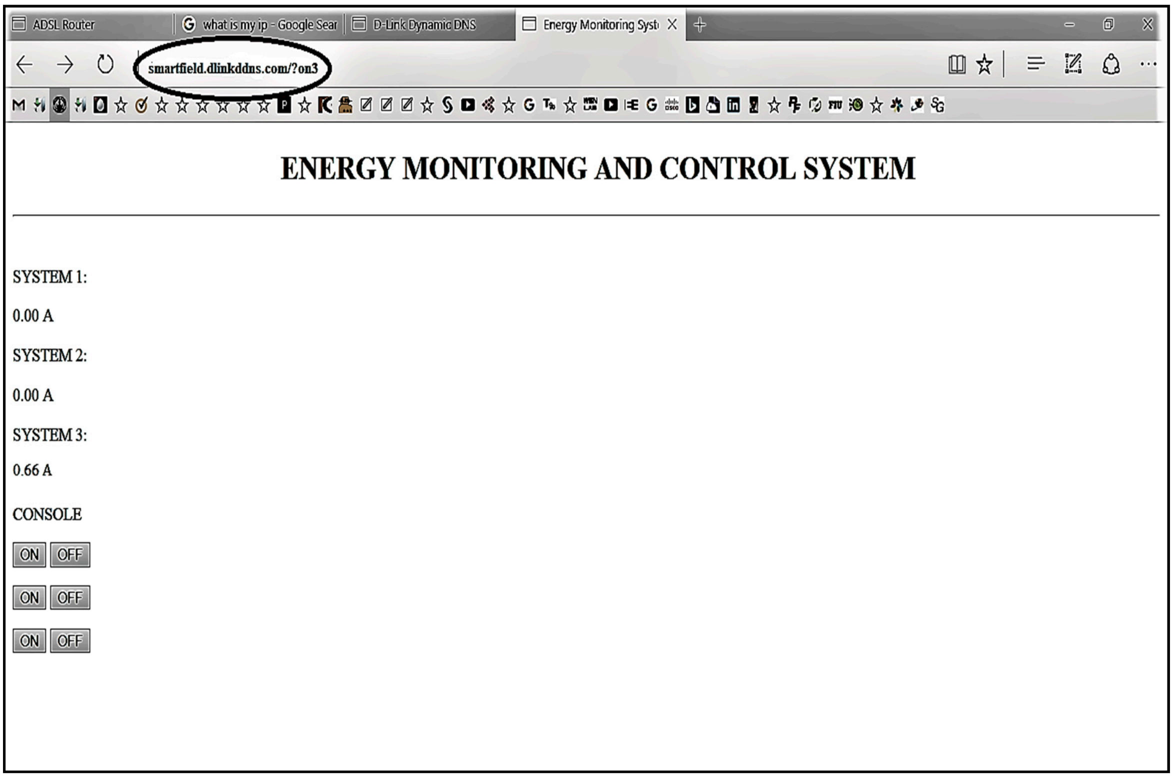


Figure 6. Snapshot of the remote wireless monitoring and control of a smart power system on the website.

3.2. Weather Monitoring System

The IoT-based prototype was developed for both local and wide area networks. The developed prototype is used for the measurement of weather parameters such as temperature and humidity. These parameters are essential for crop cultivation. The DHT11 sensor is used for the sensing and measurement of temperature and humidity. It uses a thermistor and a capacitive humidity sensor for sensing. These data are directly fed to Pin 2 of Arduino Uno. Arduino Uno is programmed for a webserver application. An HTML webpage was designed for the monitoring of humidity and temperature. When the client enters an IP address of the server, humidity and temperature are displayed on a local network. The dynamic host configuration protocol enables a server to automatically assign an IP address to connected clients. The developed prototype was used for the monitoring of temperature and humidity in a local area network. An ethernet shield is used for the Arduino webserver application. The designed prototype includes temperature readings in both Celsius and Fahrenheit. Monitoring humidity and temperature can also be useful to switch an agricultural load to different energy sources depicted in the previous prototype. For example, if temperature is low and humidity is higher, then the solar photovoltaic system cannot serve the load and the system can be switched to the grid for smooth operation of farming machineries. The developed design uses IEEE 802.3 and IEEE 802.11 standards. Figure 7 shows the design of the weather monitoring system for field area networks. Figure 8 shows the flow chart of the weather monitoring system. Figures 9 and 10 show a snapshot of readings of the developed system in Celsius and Fahrenheit, respectively.

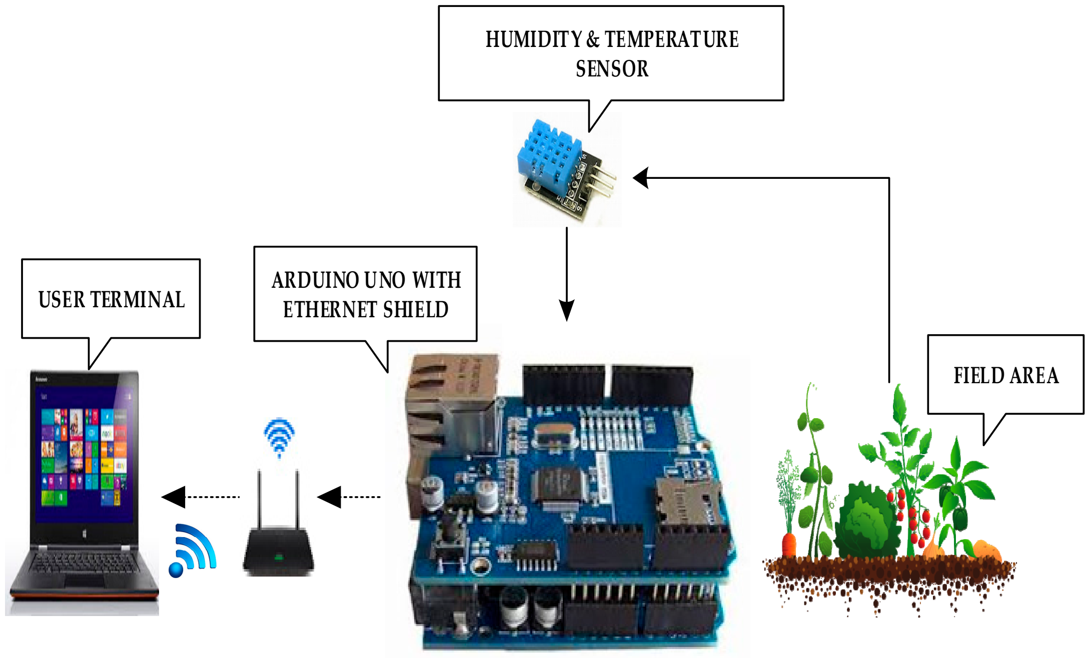


Figure 7. Design of the weather monitoring system for smart farming.

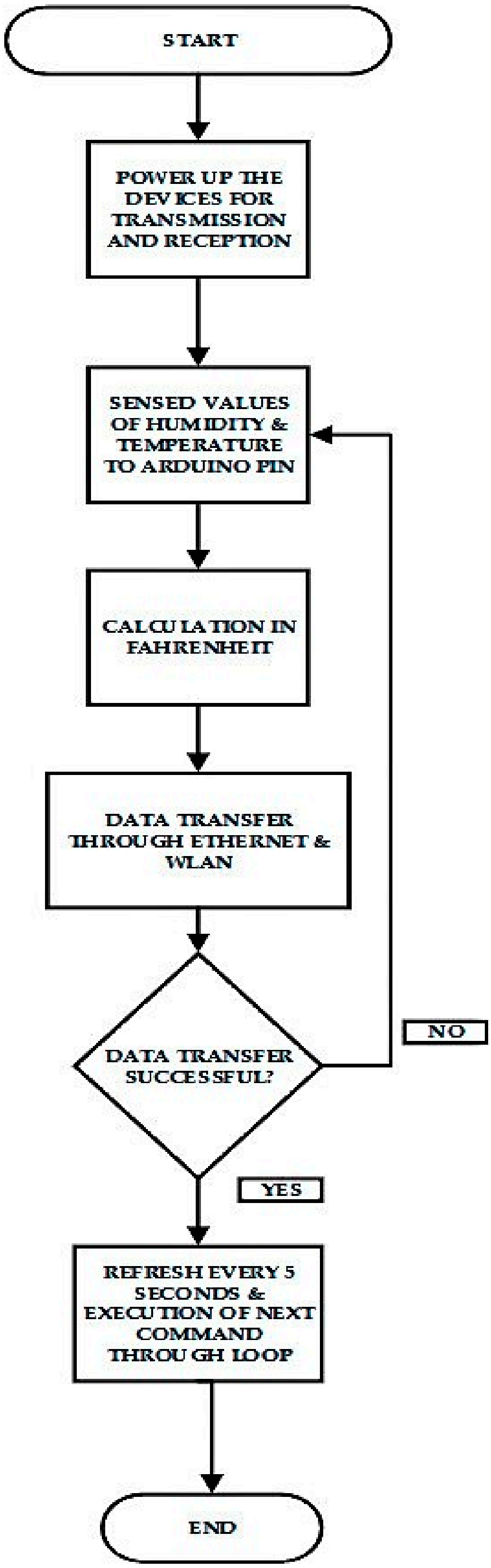


Figure 8. Flowchart of the weather monitoring system.

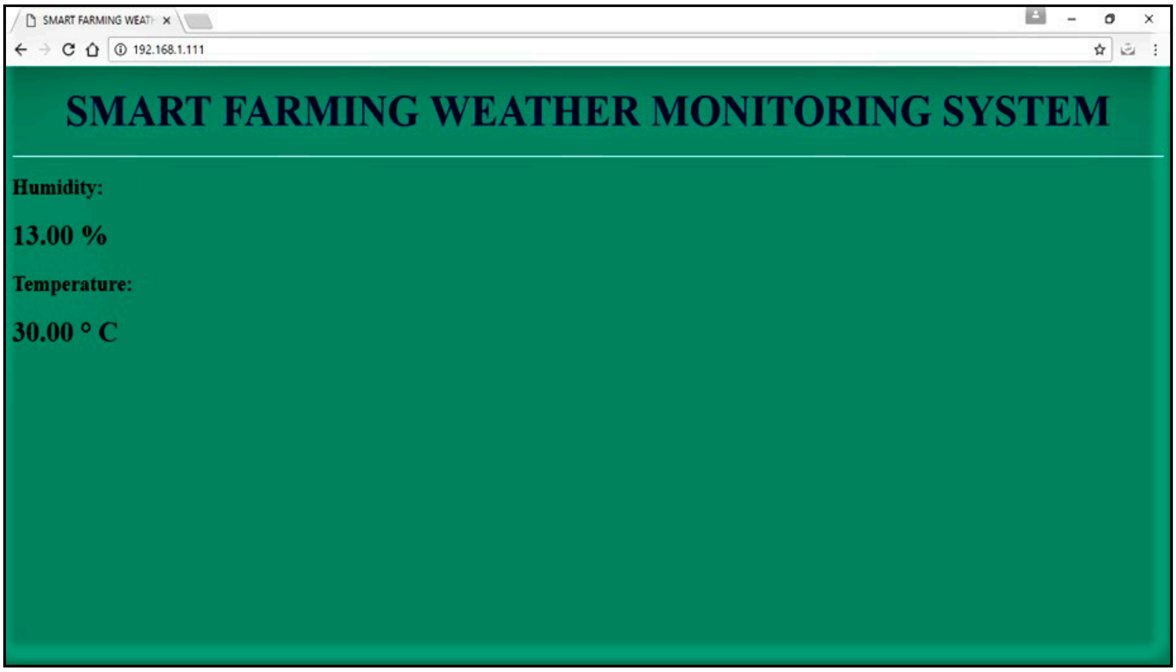


Figure 9. Snapshot of the weather monitoring system (temperature in Celsius).

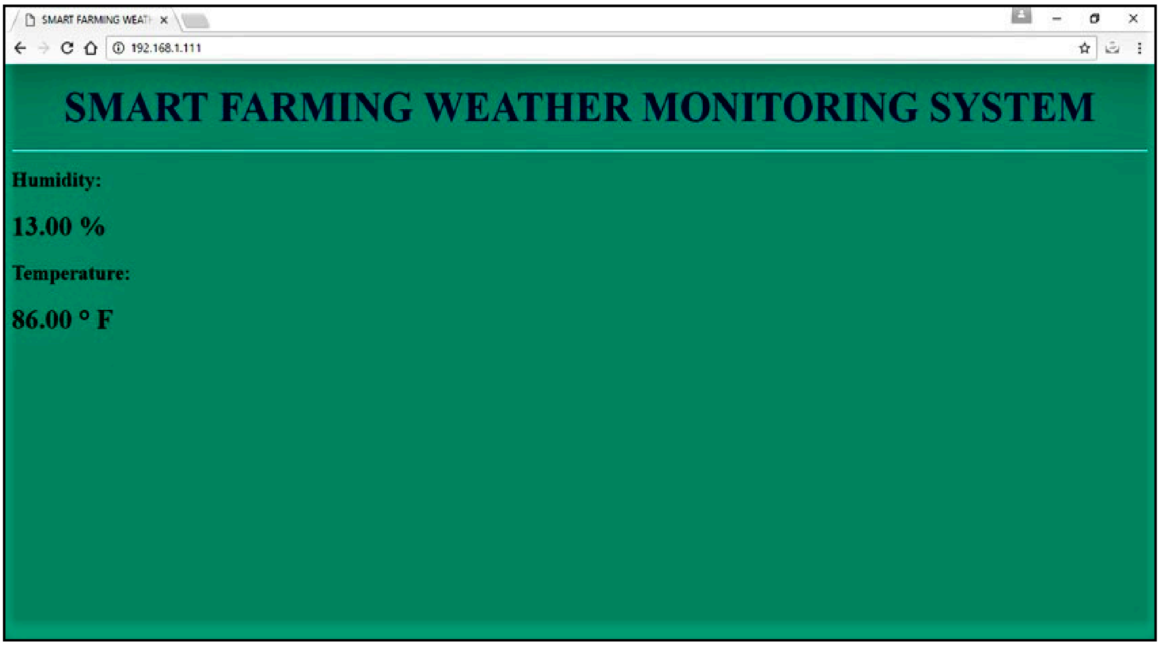


Figure 10. Snapshot of the weather monitoring system (temperature in Fahrenheit).

4. Conclusions

The true meaning of technology is accomplished only when it reaches the grassroots level and makes a difference in the lives of the community. The smart grid is the most revolutionary technology in the present era. The integration of information and communication technology with an existing passive power grid is a critical aspect of this revolution. It is an intelligent power grid with an integration of various alternative and renewable energy resources using automated monitoring, data acquisition, control, and emerging communication technologies. A smart grid is envisioned as a technology of empowerment and progress. The most crucial requirement of empowerment is energy. Energy is an essential commodity in the present era. A smart grid assures reliable and stable electricity and includes distinctive elements from tiny sensor nodes to the enormous web of things. This paper explores an application of smart grid technology in smart farming for improved crop production. The paper depicts an experimental investigation of smart farming application using smart grid information and communication infrastructure. Two prototypes are developed for the implementation of smart farming. The prototypes are developed for a local area network. The first prototype was designed for the remote seamless monitoring and control of a field area network using a wireless local area network as well as a wide area network. It describes an implementation of a smart microgrid for smart agriculture. The integration of renewable energy resources for green farming is also explored. Various agriculture machines can be considered as load and can be operated using various energy sources depending upon weather conditions and serving capabilities. The second prototype is developed for weather monitoring to facilitate higher crop production. Sharing best practices can enable farmers to understand and implement the methodologies for greater yield. It can be extended in future work to an IoT-based smart irrigation system based on various weather parameters. Future work can also include the use of multiple sensor nodes for data collection to avoid estimation errors and to improve the accuracy of the collected information. The developed prototypes can be used for smart energy and weather monitoring using a smart grid communication infrastructure. It is beneficial in terms of consumer participation. The use of renewable energy sources is beneficial in terms of the reduction of carbon emissions and the time of day billing cycle. Consumers can sell extra energy back to the grid to avail a reduction in billing. Applications of the smart grid are virtually limitless in various areas, as it can be anticipated as a technology for all and everything. An implementation of a farm management system can be considered and deployed for reliable electricity and an improved production of harvests.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

FAN	Field Area Network
NAN	Neighborhood Area Network
WAN	Wide Area Network
WSN	Wireless Sensor Network
MQTT	Message Queuing Telemetry Transport
PHEV	Plug-In Hybrid Electric Vehicle
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
PLC	Power Line Communication
SCADA	Supervisory Control and Data Acquisition
Wimax	Wireless Interoperability for Microwave Access
LTE	Long Term Evolution
EDGE	Enhanced Data Rate for GSM Evolution
GPRS	General Packet Radio Service
GIS	Geographic Information System
GPS	Global Positioning System
IoT	Internet of Things
HTML	Hypertext Markup Language
GUI	Graphical User Interface
DC	Direct Current
WPA-PSK	Wireless Fidelity Protected Access-Pre-shared Key
WEP	Wired Equivalent Protocol
WPA-TKIP	Wireless Fidelity Protected Access Temporal Key Integrity Protocol
WPA2	Wireless Fidelity Protected Access 2

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