Sensors & Transducers, Vol. 191, Issue 8, August 2015, pp. 120-125

Sensors & Transducers

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Self-Sustaining Weather Sensor Networks for Microgrid Stabilization

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Received: 24 June 2015 /Accepted: 30 July 2015 /Published: 31 August 2015

Abstract: In the Galvin Electricity Initiative, a microgrid is defined as a “small scale version of the central electricity system” [1]. Renewable energy sources, such as photovoltaic (PV), are intermittent, which raises concern when considering their integration on a large scale [2]. Through the creation of a self-sufficient, wireless weather sensor network, we present a step towards forming a method to track current weather conditions and predict future patterns. Each node in the network relays solar irradiance, barometric pressure, relative humidity and temperature to a server via a transceiver. Data is collected at approximately one sample per second and sent back to a server where it is stored into a relational database. Deployment on the University of Hawaii at Manoa campus has begun as a part of the Renewable Energy and Island Sustainability (REIS) initiative. *Copyright © 2015 IFSA Publishing, S. L.*

Keywords: Renewable energy, Sensor nodes, Wireless sensor network.

1. Introduction

Hawaii is highly dependent on the importation of energy. In 2012, 93 % of the energy Hawaii consumed was imported. In addition to this, a majority of electricity is generated from petroleum. In December 2014, 529 GWh of electricity were generated from petroleum, whereas only 102 GWh were created from renewable energy sources [3]. Due to Hawaii’s heavy reliance on imported oil, it has the highest electricity prices per kilowatt in the nation. In January 2015, residents of Hawaii paid an average of 33.34 cents per kWh, which is over 20 cents above the national average [4]. In the future, our reliance on fossil fuels could be problematic when these sources become depleted.

Using alternative energy sources, such as photovoltaic (PV), have become popular in Hawaii as the state now has the highest penetration of distributed solar PV in the country [9]. With large penetration of solar PV there is serious concern about the stability of the grid as PV energy generation is intermittent [2, 9]. Electric companies must account for underproduction when generation of energy is inadequate and overproduction when the consumption of energy is lower than the generation of it. The outdated grid in Hawaii has an unknown tolerance to intermittent renewable energy sources resulting in an inability to integrate a large number of these sources. To address this concern, it is imperative to form a method to track current weather and environmental conditions and predict future patterns.

Through the creation of a self-sufficient weather sensor network, we present a step towards being able to predict these future patterns. The sensor nodes will be deployed on roofs of buildings around the University of Hawaii at Manoa campus. This network will monitor and relay reliable weather data for at least two years. In order to create a sensor network, a sensor module with low power consumption has been designed and built [11]. Currently, the next generation of sensor modules is in development. It communicates in a mesh-network configuration (relays data between sensor modules) and is self powered by a 15,600 mAh lithium ion battery pack and a 5.6 W solar panel. Each node in the wireless weather sensor network will relay solar irradiance, barometric pressure, relative humidity and temperature to a server via an XBee transceiver.

Data is collected at approximately one sample per second (this rate can be varied); a total of up to 86,400 samples per day can be collected and sent back to a server where such data is stored into a relational database (PostgreSQL). Data can then be accessed directly through the database or by means of a web application, which allows users to choose which data intervals they wish to download.

This data will be used to study and analyze the behavior of renewable energy sources, specifically solar irradiance patterns, throughout the year. The analysis and weather patterns found can be used in the future to integrate PV in optimal places on the University of Hawaii at Manoa campus.

2. Module Overview

The sensor node is a low cost, low power, wireless module that collects weather data, including solar irradiance, temperature, humidity, and pressure. Data from each sensor is sent back to a server for storage and analysis. Several sensor nodes will eventually be deployed on rooftops of the University of Hawaii at Manoa campus to form an environmental sensor network that monitors environmental conditions both spatially and temporally throughout the campus. Fig. 1 shows the main components of the current sensor node.

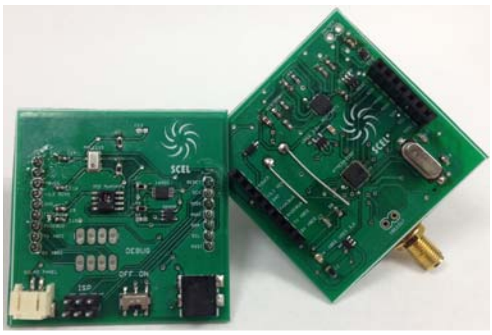

Fig. 1. Primary components of current sensor node: main board and sensor board.

2.1. Cost Breakdown

The cost of the current sensor node is $402.36. The removal of unnecessary components, use of a dedicated microcontroller as opposed to an Arduino and the miniaturization of the main PCB have reduced the cost of the sensor modules by over $100 from the last generation. Table 1 shows the cost breakdown for the module not including labor.

Table 1. Current Sensor Module Cost Breakdown

Description	Quantity	Unit Cost (USD)
XBee Pro 63 mW RPSMA - Series 2 B	1	44.95
Relative humidity/temperature sensor	1	9.89
Barometric Pressure Sensor	1	4.59
Pyronometer Apogee SP-110	1	169.00
Large 6 V 5.6 W Solar panel Solar panel - 3.4 Watt	1	49.95
Solar Panel Charging Chip	1	1.49
Lithium Ion Battery Pack 3.7 V 15,600 mAh	1	40.49
Housing	1	15.00
Mount	1	50.00
PCB	1	7.00
Cap, Res, switch and etc.		10.00
	Total	402.36

2.2. Sensors

The pyranometer (solar irradiance sensor) used in the sensor module is the Apogee SP-110 shown in Fig. 2. The pyranometer is self-powered, and has a sensitivity of 0.20 mV per Watt m^2 [5]. The current module has a 16 bit analog to digital convertor (ADC) with a 0.05 mV resolution to convert the analog solar irradiance signal to digital.

Fig. 2. Apogee SP-110.

The current module also has a Honeywell humidity and temperature sensor, model HIH6031, as shown in Fig. 3. The sensor has a humidity accuracy of ±4.5 % RH, and temperature accuracy of ±1 %. The sensor has a 14 bit ADC and uses I2C, a communication protocol, to send data to the microcontroller [6].

Fig. 3. Humidity and temperature sensor.

The barometer (pressure sensor) used in the current node design is the MPL115A2 from Freescale Semiconductor shown in Fig. 4. The sensor can measure from 50 kPa to 115 kPa with ±1 kPa accuracy [7].

Fig. 4. MPL115A2 barometer.

2.3. Power

In outdoor tests, the Lithium-ion battery in the previous sensor module design would discharge below the recommended 30 % of energy during the rainy season. The current module has a 3.7 V 15600 mA Li-ion battery, which is twice the battery capacity of the previous module. The battery is charged by a single 6 V 5.8 W solar panel. The solar panel has dimensions of 7×8.5 in^2. A MCP7381-2CAI/ML IC is used as the charger for the battery [8]. (Fig. 5).

Fig. 5. Battery for previous sensor module (left), and battery for current sensor module (right).

3. Housing

The first prototype of the housing for the current node is shown in Fig. 6. The housing was fabricated using a 3D printer and Acrylonitrile Butadiene Styrene (ABS), and its dimensions are 8.5×7×5 in^3. The housing consists of two pieces: the main box with the mount for the solar panel on top and the cover to seal the box and mount it to the tripod stand. Four screws on the side hold these two pieces together. There is an exposed area in the box for the sensor board. On the bottom cover for the housing, there is a custom mount joint where different types of stands can be used to mount the module. In this prototype of the housing, a camera tripod was used as the stand for the module shown in Fig. 7.

Fig. 6. Side and bottom view of Cranberry housing.

Fig. 7. Sensor module mounted to a camera tripod.

4. Network

Data is sent from an Arduino-based unit to the laboratory server over an XBee mesh network (extended IEEE802.15). The mesh network has self-healing and re-routing capability, remaining robust through an individual network failure. This allows for deployments over a large area, as long as there are enough nodes available to re-route data packets in case of a failure.

The installed XBee adapters are remotely configurable through an API provided by the XBee protocol. This includes features such as power control, sampling rate adjustment, and other parameters such as 128-bit AES encryption.

A master coordinator module controls the network. Each node is given a 16-bit address, resulting in the potential number of radios in a network to be 65,536. Each node, when configured as a router, can act as a bridge for any other nodes that are out of range of the coordinator.

In addition to relying on XBee transceivers to relay data back to the laboratory data store, the network can also adopt a hub-and-spoke network model, as shown in Fig. 8, with intermediary base stations providing coverage through Ethernet or WiFi. These intermediate base stations can be easily configured using any Linux-capable computing device. A successful remote deployment configuration has been accomplished using the Raspberry Pi computing platform.

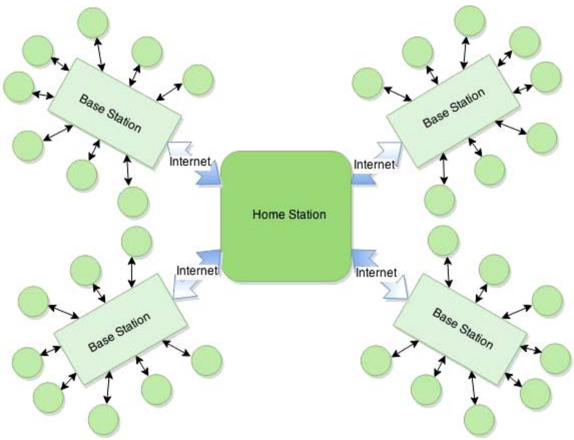

Fig. 8. Hub-and-spoke network model for long-distance data relaying.

4.1. Communication Firmware

XBee transceivers provide several functionalities that allow for network communications. Some of the functionalities are basic and need to be supplemented depending on the needs of the user. The ability to transfer a single message across multiple packets is one such feature.

If set up accordingly, the XBee transceiver in the module is capable of transmitting a message that exceeds its packet length limit. This is achieved by separating the message into multiple packets.

Due to its implementation, this feature becomes unusable in a large network, or a network with constant traffic. Communication firmware was developed so that the module could still fragment a single message into multiple packets. This implementation allows for greater flexibility in terms of data transfer.

If a message is fragmented and transmitted by an XBee transceiver, the receiving XBee will reconstruct the message. Since fragmentation is now handled by software on the module itself, reconstruction software was also developed to be run on the module.

5. Database

Collected data is stored in a high capacity Linux server running Redhat Enterprise 6.3 (Santiago) within a PostgreSQL database installation. This server allows for distributed access to be able to access data for remote analysis. Exploratory analysis can be performed by any group that has access to the server.

Since PostgreSQL is a well documented and open-source database installation, most modern programming languages have frameworks that support calls to a PostgreSQL database. Therefore, simple visualization scripts can be written in several languages within a reasonable amount of code. Fig. 9 is an example of a data visualization using a Python script.

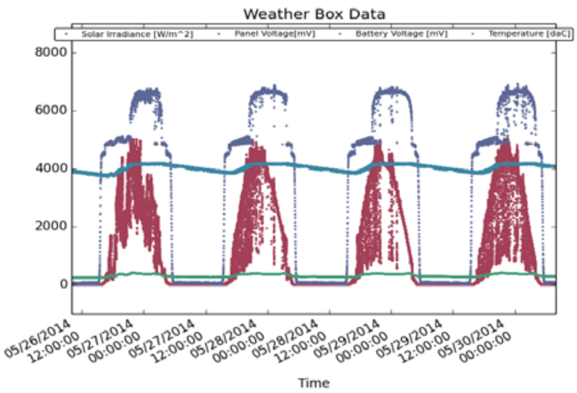

Fig. 9. Simple data visualization using Python.

To help facilitate data access and collaboration, a Representational State Transfer (REST) server was built to serve a simple data access Application Programming Interface (API). Likewise, a use-case for this REST server is a web-based on-demand visualization script written in Javascript, which is mobile friendly.

Easy access to on-demand visualization and analysis allows for quicker iteration and verification of experimental data obtained from hardware testing. A hardware stack is shown below in Fig. 10, describing the various technologies that are used in our database configuration.

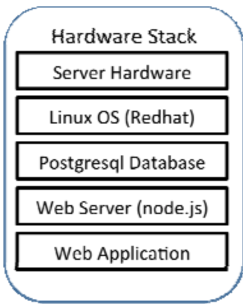

Fig. 10. Hardware stack of the technologies.

6. Data Analysis

We used a suite of online adaptive filtering algorithms; steepest descent (SD), least mean squares (LMS), normalized least mean squares (NLMS), and recursive least squares (RLS) for solar forecasting [10]. The data collected from the sensor nodes was used to perform one step prediction of solar irradiance with a 5-tap moving average filter. Fig. 11 shows the data used to test the algorithms. The algorithm uses root mean squared error (RMSE) as a performance criterion and considers the rate of convergence of the algorithms. Fig. 12 shows the RMSE curve after 1000 training iterations. Another set of data was used on the same system that was obtained from the training to do cross-validation. The results of cross-validation RMSEs are SD 67.7, LMS 71.1, NLMS 71.6 and RLS 67.7. The rate of convergence for the algorithms ranked from highest to lowest is RLS, NLMS, LMS. The MSE of the algorithms ranked from highest to lowest is RLS, LMS and NLMS.

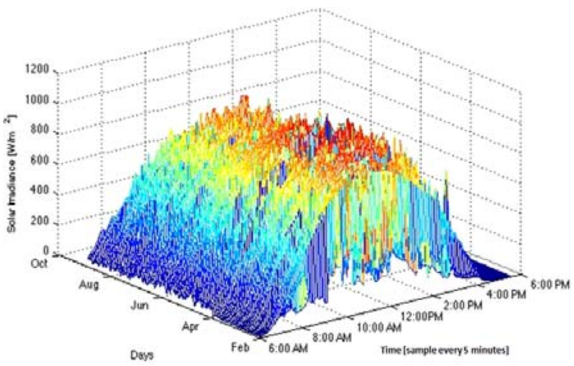

Fig. 11. Solar irradiance (SI) data before filter with moving average filter, and standard normalization.

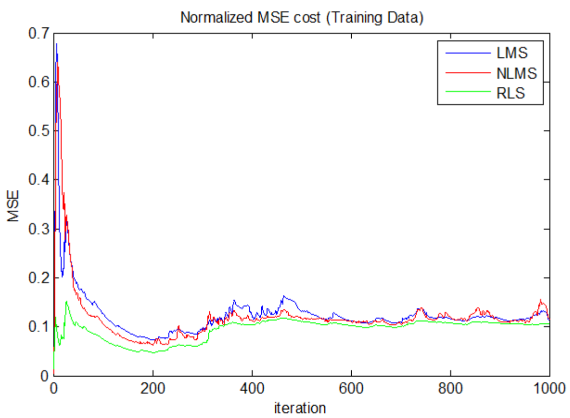

Fig. 12. Training cost - LMS 68.7, NLMS 69.2, RLS 65.8.

7. Future Directions

The current generation of weather sensor nodes came about by small, incremental design changes. Therefore, we hope to release our next generation of weather sensor nodes by continuing the trend.

The next generation of weather sensor nodes will be another iteration of the current generation, providing lower power use, greater programming flexibility and offering a greater range of sensors. This will be accomplished by adding additional hardware to support this capability.

In addition to hardware and firmware improvements, we hope to integrate additional data storage and sharing improvements into the server. These enhanced data sharing features will allow researchers to better collaborate and analyze data collected from the weather sensor network.

Acknowledgements

This project is supported in part by NSF grant ECCS-1310634. The authors would also like to acknowledge the Renewable Energy and Island Sustainability (REIS) program and the undergraduate and graduate students that are currently helping to develop and deploy future iterations of our weather sensor network.

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