Self-Sustaining Meteorological Wireless Sensor Networks

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ABSTRACT

Existing electrical grid infrastructure designs cannot reliably handle large intermittent power production fluctuations. Providing an autonomous, self-powered, and easily deployable meteorological sensor network can provide the tools to help mitigate this issue. With proper data at a high enough spatial and temporal resolution, it can be possible to model and predict weather patterns in areas containing a high penetration of solar photovoltaic installations. When coupled with a battery or another energy storage technology, this predictive capability can lessen the effects of the peak load on a system and provide the consumer with feedback on when to conserve. Through utilizing rapid prototyping techniques, specifically in-house 3D printing and open-source technologies, a sensor module connected in a self-contained wireless network is reported. Parameters analyzed include temperature, pressure, humidity and solar irradiance. The modules are inexpensive, portable, and self-powered. Data is transferred on a self-contained radio mesh network.

Keywords: Meteorology, wireless sensor network, self-sustaining sensor module

1 INTRODUCTION

As of the third quarter of 2012, solar power is accounting for 5.9 GW of energy production in the United States with an annual increase in utilization by an estimated 70% [1]. However, solar energy has an intermittent supply characteristic; not only is the production interrupted by the daily setting of the sun, but cloud cover is not finely predictable. With plans in place to rely more heavily on solar, the large variance in available solar energy will be felt more strongly by power network operators and consumers.

Since most of the energy production in the United States is currently derived from coal, oil, and nuclear sources, integrating renewable energy into the existing infrastructure presents new challenges. If an industrial district in a city has a high density of solar arrays powering a significant portion of the facilities, for example, at the end of the day, these facilities will be dependent on conventional electricity sources through the night. A more acute problem is intermittent cloud cover during peak hours of the day. If a large array in the MW range is overcast by clouds, the conventional power plant needs to compensate for the loss in local power production. In the extreme case, another turbine may need to be started to take up the extra load which is a heavy burden for power plants. The environmental effects on power consumption and renewable energy production need to be predicted.

In order to reliably model, predict, and control a power grid installation, a large amount of data is required. This data needs to contain a large number of observations both in time and at as many useful locations across the power system and in the local operating environment as possible. In other words, in order to imbue the grid with smart sensing capability, a second network of significant complexity must be overlaid across it. This network design presents a complex problem. The network will be subject to environmental degradation, dropped packets, and changes in topology. These threats to the integrity of the network increase with the size of the network.

In order to mitigate these threats, the sensing network must efficiently send traffic, be robust against network device failures, and be resistant to the environment. In other words, the network should be made up of inexpensive, simple, distributed devices that cooperate to deliver data over a large area for an extended period.

Interoperability is also a strong requirement. While pure environmental sensing applications have the luxury of choosing their devices, sensing networks for grid applications must be agnostic to local appliances and metering systems.

2 MODULE OVERVIEW

The sensing module is a small, low cost, low power, wireless module intended for mass field deployment. Information from each sensor can be sent via nodes along the mesh to a centralized computer for data collection and analysis. Each sensor module monitors temperature, barometric pressure, and humidity. The sensor also includes a GPS module for location and time stamping of data.

2.1 Sensors

Table 1: Sensors Included in Respective Modules

3D-Printed Device Housing	Lasercut Device Housing
Pressure – BMP085	Pressure – BMP085
Temperature – DS18B20	Temperature and Humidity – SHT11
Humidity – SHT11	GPS – MTK3339
GPS – MTK3339	Solar Irradiance – SP215
Current/voltage – INA219B	

All of the sensors (Table 1) are digital, and are calibrated by the manufacturer. Pressure, solar irradiance, and power sensors communicate via I^2C protocol. Humidity and GPS communicate via a 2-wire TTL. The temperature sensor communicates via the Maxim 1-Wire protocol.

The pressure sensor has the range of 300 – 1100 hPa with a resolution of 0.03 hPa [2]. The humidity sensor measures relative humidity from 0 – 100% with an accuracy of 3.5% and a resolution of 0.03% [3]. The temperature sensor has a range of -55ºC - 125ºC with an accuracy of +/-0.5ºC (at -10ºC - 85ºC) and a resolution of 0.05ºC [4]. The GPS module can track up to 22 satellites and updates at a rate between 1Hz and 10Hz with a -165dBm sensitivity [5]. The current/voltage sensor is capable of measuring a voltage of -26V – 26V with a maximum current of +/- 3.2A. The 12 bit ADC allows for a resolution of 0.8mA [6].

2.2 Power

The module is powered by a 3.4W 6V solar panel. Output current from the solar panel passes through a current sensor and battery charging circuit that tracks the peak power point of the solar panel and charges an installed battery when feasible. The installed battery is a 4.2V, 6600mAh lithium ion polymer battery, which supplies power when sufficient solar power is not available. It is calculated that the battery should last a maximum of 44 hours without any sunlight from full charge.

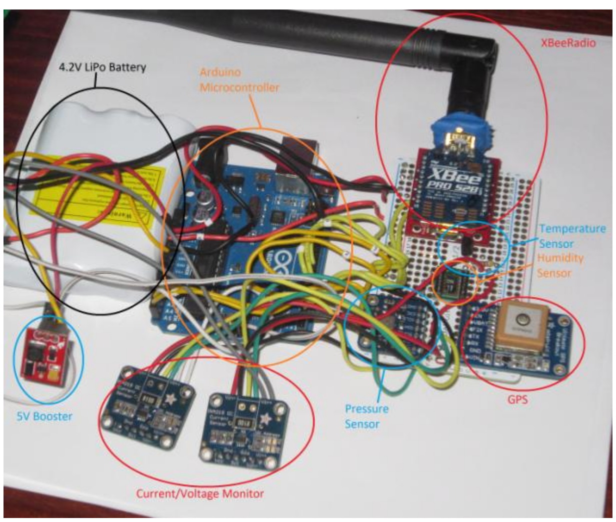

Figure 1: Sensor module internal hardware.

2.3 Network

The wireless network is controlled by XBee radios using the ZigBee protocol (an extension of 802.15). The modules communicate in a mesh configuration, using Ad-Hoc On-Demand Distance Vector Routing (AODV). Radios within communication range of the central coordinator node relay any information from nodes further out in the network, using routes established on demand. This routing protocol allows network nodes to renegotiate routes periodically, granting a degree of resilience against device failures.

The initial field deployment consists of 10 nodes in a mesh network. A visual comparison of general network types is shown in Figure 2.

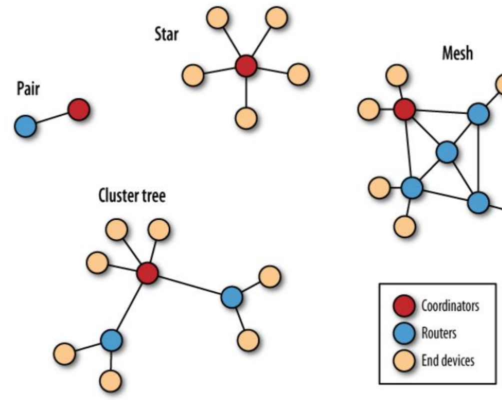

Figure 2: Various network configurations.

3 HOUSING

3.1 3D-Printed Device Housing

The housing was fabricated using a 3D-printer. The first version consisted of three compartments including individual spaces for the Arduino microcontroller (an Atmel AVR), sensor components, and the battery. The top plate of the housing is sized to accommodate one 3.4W 6V solar panel. Underneath, a tray allows for the placement of a ballast to prevent the module from being jostled in heavy winds.

Figure 3: 3D-printed module in the field.

3.2 Lasercut, Passively Ventilated External Sensor Housing

The lasercut housing is comprised of four main sections: the base, the ventilated compartment, the body, and the lid.

This housing design, fabricated primarily from lasercut plexiglass pieces, features a stacked electronics configuration in which electronics are fitted in layers on top of each other to allow for greater height and thus, improved antenna range. The ventilated compartment that houses the temperature, humidity, and pressure sensors seeks to allow natural air flow for more accurate sensor data readings. Furthermore, the lasercut housing lid design supports two 3.4W 6V solar panels as well as a silicon-cell solar irradiance sensor to accommodate improved power capacity and more accurate solar irradiance measurements.

Figure 4: Laser-cut module in the field.

3.3 Measurement Comparison

Two graphs (of data ranging over March 7, 2013) illustrate comparative findings (Figures 5 and 6).

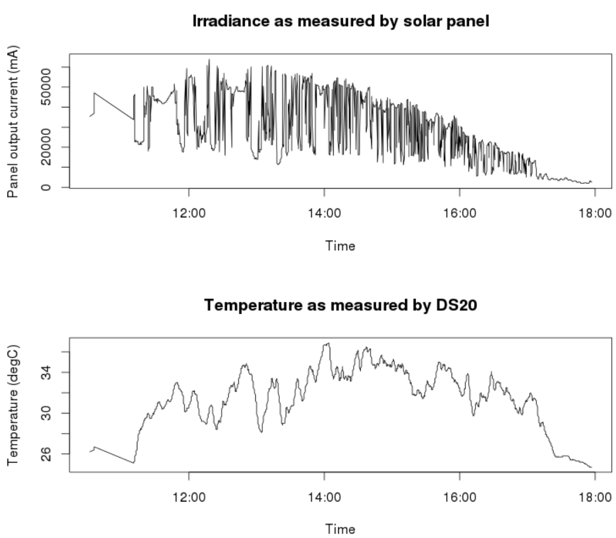

Figure 5: Solar irradiance and temperature measured by solar panel and specialized temperature-only sensor (respectively)

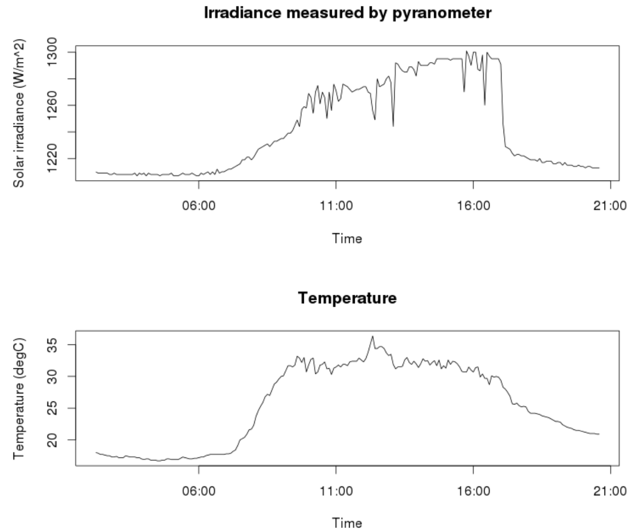

Figure 6: Solar irradiance and temperature as measured by solar irradiance sensor and integrated temperature/pressure sensor (respectively)

The two enclosures were used as candidate test beds for slightly different components. Notably, the 3D-printed housing has a smaller profile, and does not have a solar irradiance sensor installed, instead relying on solar panel current to gauge solar irradiance. The laser-cut housing has two solar panels, and uses the integrated temperature/pressure sensor to give measurements of temperature.

As seen from Figure 5, the solar panel response is noisier than that of the solar irradiance sensor due to its narrow sensitivity and primarily nonlinear characteristic. It does not make a good substitute for a solar irradiance sensor, even in a narrow band. However, the increased sensitivity of the specialized temperature sensor (DS20) provides a more detailed plot of temperature throughout the day.

Most importantly, the measurements on the single-panel enclosure are cut off until 9am, well after sunrise. This is due to the inability of a single 3.4W panel to sufficiently charge the battery to capacity. Given that the largest consumer of power on the sensor node is the XBee wireless adapter, this indicates that either better use of XBee dynamic power control or a larger panel area is warranted.

4 NETWORK

Data is sent from the Arduino unit to the laboratory data store over a ZigBee mesh network (extended IEEE802.15). Due to the mesh network's self-healing capability, the network is robust against single device outages. The installed XBee adapters are remotely configurable (through the provided API), including power control (hibernation and cyclic sleep), sampling rate adjustment, and numerous other parameters such as 128-bit AES encryption.

The current XBee adapters communicate in the ISM (2.4 GHz) band using direct sequence spread spectrum, which allows a higher data rate and interference resistance at the expense of range. The maximum rated range is 3200 m in ideal conditions with a clear line of sight. Current draw at full power is approximately 300 mA. This is at the high end of the unit's current daily power budget, making judicious use of the cyclic sleep function a requirement. The cyclic sleep function allows a user to set the number of times a node is polled for a route, grants the ability to offer or not offer guaranteed traffic in a given period, and allows adjustment of the route poll rate. These settings allow fine control of network traffic. Coupled with hibernation state settings, device power consumption can be freely adjusted at any time [7].

5 DATABASE

Captured data is stored on a high-capacity Linux server installation within the laboratory in a PostgreSQL database. This allows distributed access through SSH sessions to large chunks of data for analysis both in the lab and around campus. Other parallel research projects make extensive use of the shared data. Exploratory analysis is being conducted on the initial data collected during the device testing period, and higher-complexity models can be run on the server as well as locally on user machines. A simple visualization routine written in a few lines of R can query the database and produce graphs like the one below. Likewise, an XML-RPC client written in Java for Android allows administrators to check the status of data the server.

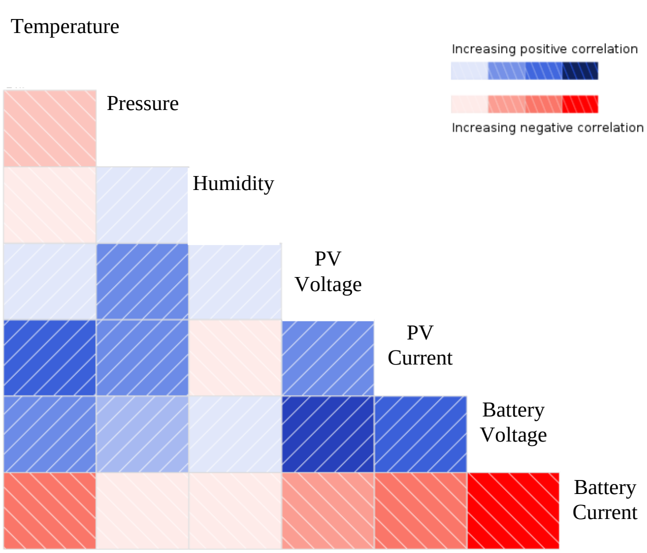

Figure 7: Data correlations on 3/7/2013

A slightly more detailed examination of the sensor data reveals possible correlations between environmental conditions and energy inputs (Figure 7).

6 FUTURE

The next version of the module's circuitry will consolidate all of the sensors onto a more closely connected and organized substrate. Temperature and humidity sensors will be placed in a well-ventilated compartment, reducing the greenhouse effect inside the housing. Conversely, barometric pressure, GPS and current sensing modules will be placed in order to avoid exposure to the elements. Ultimately, the entire circuitry, minus the temperature, irradiance, and humidity sensors will be consolidated onto one board organized around the Atmel AVR microcontroller.

7 REFERENCES

[1] Solar Energy Industries Association "Solar Market Insight Report 2012 Q3," *Solar Energy Industries Association*, SEIA, 2012 [Online]. Available: http://www.seia.org [Accessed: March 2, 2012]

[2] Bosch "BMP085 Digital Pressure Sensor" BMP085 Datasheet, July 2008.

[3] Sensirion "SHT1x/SHT7x Humidity & Temperature Sensor" SHT11 Datasheet, 2001 [Revised Mar. 2003].

[4] Maxim "DS18B20 Programmable Resolution 1-Wire Digital Thermometer" DS18B20 Datasheet, 2008

[5] GlobalTop Technology Inc. "FGPMMOPA6H GPS Standalone Module Data Sheet" FGPMMOPA6H Datasheet, 2011.

[6] Texas Instruments, "Zero-Drift, Bi-Directional Current/Power Monitor with I2C Interface," INA219, INA219 datasheet, Aug. 2008, [Revised Sept. 2011]

[7] R. Faludi "Building Wireless Sensor Networks" Sebastopol, CA: O'Reilly Media, Inc., 2011.