HSENSE: a high performance framework for distributed weather sensor networks

J A Ortiz1, N G Santiago, J G Colom-Ustáriz
Department of Electrical and Computer Engineering, University of Puerto Rico, Mayagüez, Puerto Rico.

E-mails: jose.ortiz19@upr.edu, naydag.santiago@upr.edu, colom@ece.uprm.edu

Abstract. HSense is a framework designed for aggregating and monitoring weather sensor networks. It is implemented using the functional language Haskell to provide a modular and expandable interface and parallel data processing. HSense provides a building block in which researchers can integrate sensor networks and develop applications. It is specially developed for managing large quantities of distributed weather sensor data efficiently. This document summarizes the design and development of the HSense framework and a case study of the Puerto Rico Weather Radar Network at the University of Puerto Rico at Mayagüez.

1. Introduction
Distributed weather sensor networks are composed of multiple independent nodes used to measure weather parameters around their specific coverage area and at the same time maintain communication with each other. Vast data generated by these types of sensors is communicated, processed, and stored at common storing centers (called sinks) for further analysis. While several sensor network management methods exists, managing high quantities real-time data and develop applications for heterogeneous networks become a hurdle [1]. Most of weather sensor networks produce higher quantities of data and most applications are developed targeted to specific network architecture. However there is no framework for developing applications for high throughput generic sensor networks such as the one assumed in this article. The particularity of this problem of managing sensors like high performance weather radars entails the need of implementing a different alternative.

This work has the following objectives: first, to manage distributed weather sensor networks using high performance systems; second, to demonstrate the viability of using functional languages for managing sensors through the use of parallel processing. Finally, the third objective is to create a scalable and modular framework for managing weather sensors, capable of expanding and integrating heterogeneous systems.

 Evaluations of current methods of managing sensor networks are presented and a proposal for an improved way of managing while adding capabilities of processing and storing sensor data. Modern approaches of manipulating data are implemented, several of these detailed in the subsequent sections. HSense framework introduces various emergent technologies into the field of distributed sensor networks (DSN). Web protocols are introduced to communicate between the

1To whom any correspondence should be addressed.
sensor nodes, distributed databases for chaining different database networks, and a functional language that provides built in high performance capabilities with high concurrency and highly modular design patterns.

A case study of the framework designed is provided. It uses the Puerto Rico Weather Network courtesy of the University of Puerto Rico at Mayagüez. As the Puerto Rico network contains several different weather sensors, it became an ideal candidate for experimenting with alternative ways of managing sensors. Moreover, due to the large quantities of data that maintains the network, several highly parallel algorithms and distributed databases are tested. The ability to aggregate data from heterogeneous weather sensor networks will create a whole new range of applications involving weather data and capable of complementing current weather technology prediction systems.

2. The HSense Framework

The HSense framework design focus aims to offer a set of libraries for managing and processing weather sensor networks. It is intended to provide a set of organized common steps that a researcher can follow to manage their own sensors and share its data with web users. The HSense framework has the following features:

- **Sensor Management** – capable of maintaining status of current connected sensors to the network with a notification system in case of sensor failure.
- **Parallel Processing Capability** – built-in support for highly parallel processing algorithms.
- **Basic Sensor Data Visualization** – provide tools for basic sensor visualization such as plots and graphics.
- **Web Interface** – a web-based interface to access the framework resources.
- **Standalone Interface** – an interface that allows researchers to use the HSense basic algorithms to manage sensor and process their data.
- **API Interface** – an Application Programming Interface to allow developers to take advantage of framework sensor data.

![Figure 1: HSense Internals – Block Diagram of HSense framework and its interfaces](image)

HSense is built using the Haskell functional programming language. Haskell provides built-in features like high concurrency and parallel capabilities while improving the code maintenance through modules. HSense contains a Haskell-based concurrent server with several modules for task division. As shown in the figure 1, each module manages their task independently while the
main communication modules assign the tasks. The following sections describe the independent modules.

2.1. Sensor Management Module
The sensor management module permits real time monitoring of all the connected sensors. This allows the system to make decisions based on the sensor status. Moreover, it lets the network owner to stop sensors at will or validate if the sensor needs maintenance. Sensor management is a complex task by itself; HSense provides basic information and statistics for sensors and networks connected to the system. A simple knowledge engine will provide notifications to researchers about the sensors’ states. The console is capable of being accessed online and manipulates features of the HSense based systems.

2.2. Communications Module
The communication module (see figure 2) is based on the web technologies REST and JSON. Representational State Transfer (REST) is a style of software architecture, which simplifies the way of creating web services [2]. It allows simple HTTP address to require data or push data; this simplicity permits the integration of any web server as a possible node of a network. The JSON protocol, based on the Javascript programming language, is a common vessel for transporting information through the Internet. Contrary to XML (previous common protocol for transporting data on web), JSON protocol is easier for human reading and simpler; therefore it has become standard in current Internet companies. JSON packets can travel inside firewalls and out to the Internet thanks to the use of port 80 for communication; this provides an advantage for the integration of intranet sensors.

![Figure 2. Communication – JSON based communication between sensors.](image)

2.3 Processing Algorithms
The “PROCESSING ALGORITHM MODULE” contains algorithms for manipulating data. This data received from the sensors is processed in parallel and the results are stored in a database. This module also contains templates to allow the user to add algorithms to the platform. Adding an algorithm is as simple as dropping the code in a folder and the system will recompile and add it to the other available algorithms. Some processing algorithms that are being demonstrated are reflectivity calculations for rain, rain rate estimation, and plan position indicators (PPI) from weather radars.

These algorithms can be applied to large datasets of information from the database. This allows the user to generate reports or create studies based on the dates and times, which is critical when analyzing weather events. All parallel algorithms should be applied to data parallel structures (meaning arrays or arrays of arrays); this will ensure the most efficient parallelization. To ensure compatibility, all algorithms will use NetCDF file format as data entity [3].
NetCDF bindings created especially for HSense take advantages of the Haskell language for parallel algorithms.

2.4. Visualization Module
The “VISUALIZATION MODULE” generates images based on processed data to helps researchers analyze the data visually. Visuals are based on, if available, previously processed data. Several web services will allow the retrieval of previous generated visual information. The visualization module also will provide data as required by the web server module. The plots in Figure 3 show a common visualization of a weather event.

![Figure 3. Weather Event Visualization – A plot of a beam of a weather radar and a PPI plot of the weather event](image)

2.5. HSense Interfaces
The frameworks provide three interfaces: a standalone interface, an API interface, and a web interface. The standalone interface allows researchers to use HSense as a library for manipulating and visualizing weather data. It provides features for opening and saving NetCDF files, visualize radar data, and compare information from a Matlab-like console environment. The API interface provides developers the ability to build applications based on the information contained in HSense. The web interface serves as a template application for using the HSense API. It uses most of the API calls available for the developers and delivers an interactive website to allow users visualize real time weather sensor data.

![Figure 4. Weather Portal - A website created using the HSense Framework for the PRWRN](image)

3. Puerto Rico Weather Radar Network: A Case Study
The Tropinet MRI and the CASA-ERC projects at the University of Puerto Rico Mayagüez (UPRM) were founded to create multiple weather radar networks in the west coast of Puerto Rico.
The CASA ERC Puerto Rico Testbed is a network of Off-the-Grid (OTG) weather radars to research lower atmosphere weather events [4]. The OTG is modified marine radar made capable to detect rain reflectivity. This CASA-ERC project aims for the development of low cost, low infrastructure weather radars capable of working with green energy.

The Tropinet MRI weather radar network provides state of the art radars to Puerto Rico west coast. The Tropinet weather radars are the only dual polarization Doppler weather radars in Puerto Rico [5]. Figure 4 shows the Tropinet Radar Network. Both networks provide important information to researchers about the weather conditions of the west coast of Puerto Rico. However, these networks lack a framework to integrate and manage their radar sensors. Given the development status of the Puerto Rico Weather Radar Network (PRWRN) was the perfect subject to test the capabilities of HSense managing weather sensors.

Based on the HSense framework API interface, we built a website for displaying current sensor data to users. It also permits researchers to access raw data for further analysis if needed, along with common visualization algorithms built for HSense. The Puerto Rico Weather Radar Network comprehends a distributed sensor network capable of integrate seamlessly using web technologies to any web based network. Due to the HSense framework, any other web capable network could share and connect to the sensors to create larger and more powerful networks.

4. Conclusions
In this article a design and development of HSense framework for managing distributed sensor networks is presented. We specified a design that used multiple technologies such as REST services, HTML5, and functional languages. This gave us the ability of developing a high performance framework for managing weather sensor networks. Functional languages such as Haskell helped in the development, incorporating parallelization, modularity, and concurrency. It was also showed parallel algorithms for processing weather data, NetCDF algorithms for data storage and visualization algorithms.

The HSense framework provides an Application Programming Interface (API) that permits the user to create applications that use the data of managed sensors. A template for managing sensors is provided which uses the HSense framework with an integrated web server for display sensor data. Finally a case study was developed using the template provided for managing the weather sensors of the Puerto Rico Weather Sensor Network, in which the capabilities of the framework were shown. Several tests were performed that showed that the platform is stable and capable of managing hundreds of sensors simultaneously.

There are several areas for the framework to improve. For example, it will be interesting to do testing with multiple remote sensor networks and with several databases. HSense provides an approach of management unique to high throughput weather sensors that will help researchers develop their own sensor networks, manage them, and make decisions based on the data stored.

5. References
[1] Mottola L and Pietro G 2011 Programming wireless sensor networks: Fundamental concepts and state of the art. ACM Comput. Surv. 43(3) 19:1-19:51
[2] He J, Zhang Y, Huang G and Cao J 2012 A smart web service based on the context of things ACM Trans. Internet Technol. 11(3) 13:1-13:23
[3] Rew R and Davis G 1990 NetCDF: an interface for scientific data access IEEE Comput. Graph. Appl. 10(4) 76 82
[4] Trabal J M, Colom-Ustariz J G, Cruz-Pol S L, Pablos-Vega G A, and McLaughlin D J 2012 Remote Sensing of Weather Hazards Using a Low-Cost and Minimal Infrastructure Off-the-Grid Weather Radar Network IEEE Trans. Geosci. Remote Senss. 99 1-15
[5] Trabal J M, Colom-Ustariz, Pablos-Vega J G, Ortiz J, Castellanos W, Cruz-Pol S, Leon L and Rodriguez-Solís R 2011 Low cost and minimal infrastructure Off-the-Grid XBand radar net-work development for the west coast of Puerto Rico IEEE Radar Conference (RADAR) pp. 1026 -1031