A Wired Sensing Suite for Data Center Climate Monitoring

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Development Objectives

Design a scalable, cost-effective system for monitoring the efficacy of cooling systems in data center settings. Specific goals for this iteration of the project include:

- Minimize size of sensor component (PCB) for minimal footprint in data center
- Minimize cost of components, cost of fabrication, and cost of assembly of sensor board
- Investigate increased sensing capabilities (humidity, vibration, etc.)
- Architect system to include multiple controlled sensor subsystems
- Prepare system for deployment in Princeton High Performance Computing Research Center (HPCRC)
- Build full-featured web client for managing a deployed instance of system

Background and Prior Work

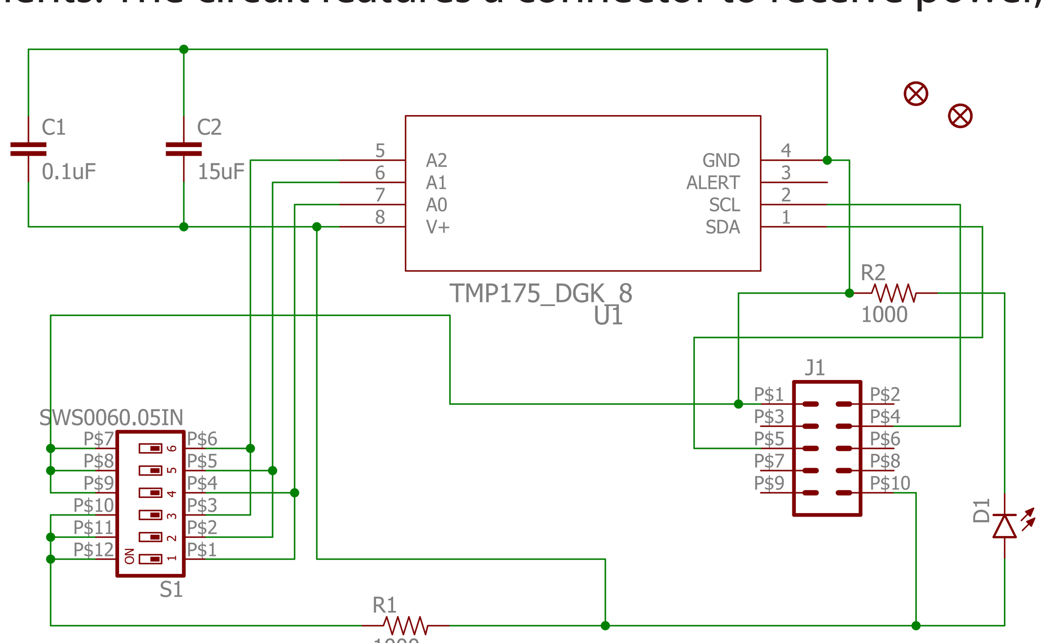
As cloud computing and mobile computation shift workloads from personal devices to large data centers, the cost of cooling these massive rooms of servers has increased dramatically. Cooling costs in modern data centers can hit 40-45% of total power consumption [3,4]. In the US, this cooling costs $1.4B/year in electricity, and $3.6B/year worldwide. The expense and importance of sophisticated cooling strategies demanded by cultural changes regarding computation necessitates a need to monitor the efficacy of these systems to ensure reliable and consistent cooling across the space of a data center.

This project began in 2014 as an independent work project. The accomplishments of that and a following IW project were a functional design for the wired sensor subsystem (i.e. a design for the temperature sensor board itself, plus a single controller directly connected to a number of sensor boards — up to 54). Further work in Summer 2015 led to the creation of a basic web portal to access the sensor data conveniently, along with some work recreating the preexisting designs.

This senior thesis aims to build upon the work of those projects to accomplish the objectives listed in the previous section. Particularly, this iteration is focused on bringing the project into a state that can be mass-produced easily and cheaply.

Design: Sensor Board Circuit

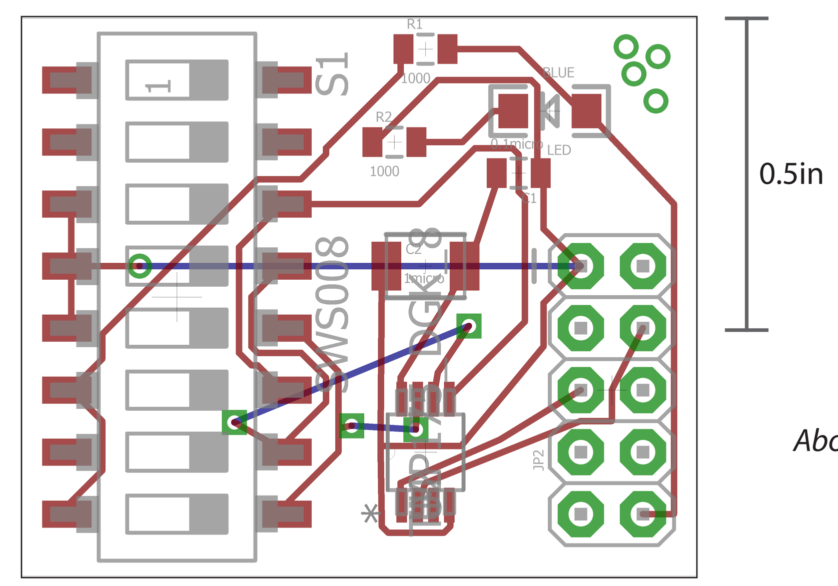
The circuit on the sensor board was originally designed by [2] and has been modified since. Some changes were made to decoupling capacitors, but the general concepts remain the same as the original design. The boards use a Texas Instruments TMP175 sensor to obtain measurements. The circuit features a connector to receive power, ground, and SDA/SCL for I²C communication from the BeagleBone controller. 6 DIP switches are used to configure the I²C address of the sensor, which uses 3 pins, each employing trinary logic, for up to 27 different addresses — and consequently, up to 27 sensors per I²C bus.

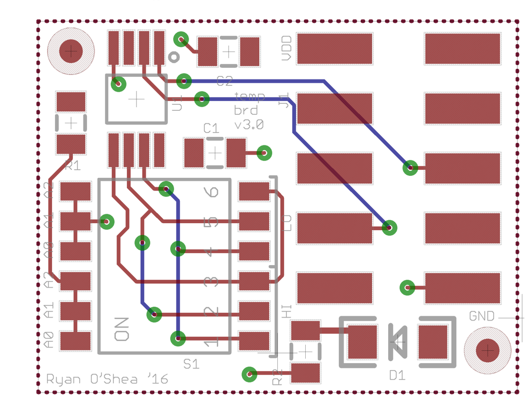


Design: Sensor Board Layout

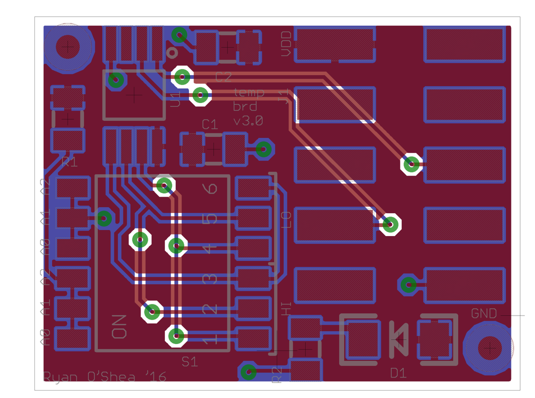
The primary focus of this first semester's efforts was redesigning the sensor board itself. Miniaturization, cost reduction, and design-for-manufacture were the largest concerns addressed in this third revision of the board design.

Old design: 1.1" × 0.9" (1 in²) **New design: 0.8" × 0.65" (0.52 in²)**



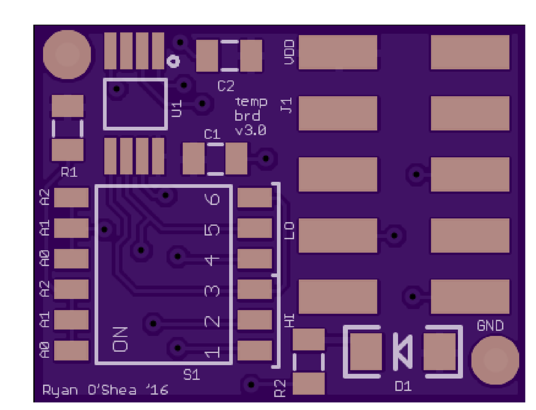


Above: copper pours hidden; Below: with copper pours



- Large DIP switch component
- Thru-hole component
- Non-45° traces
- Wasted space

Below: preview of fabricated PCB



New PCB features:

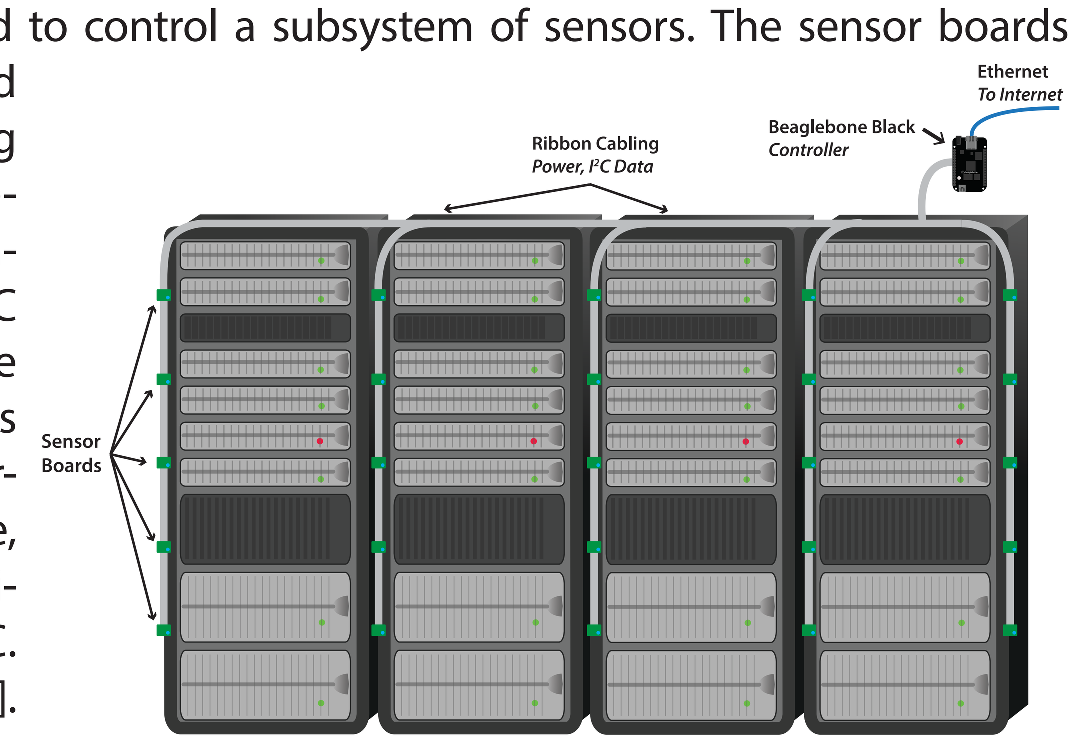
- 47% smaller area
- Exclusively surface-mount components for inexpensive and automated assembly
- Much smaller DIP switches (other component size reductions were prohibitively expensive)
- Ground & power fills for better electrical characteristics
- Better traces; better decoupling capacitor placement

Design-related Costs Per Board (rough estimate for quantity of 500):

Old design: $1.62 (fab) + $3.07 (assembly) = **$4.69**/board
New design: $1.29 (fab) + $2.02 (assembly) = **$3.31**/board (30% cheaper)
Note: This ignores unrelated costs (tooling/NRE, stencils, similar parts prices). Actual price per board is higher.

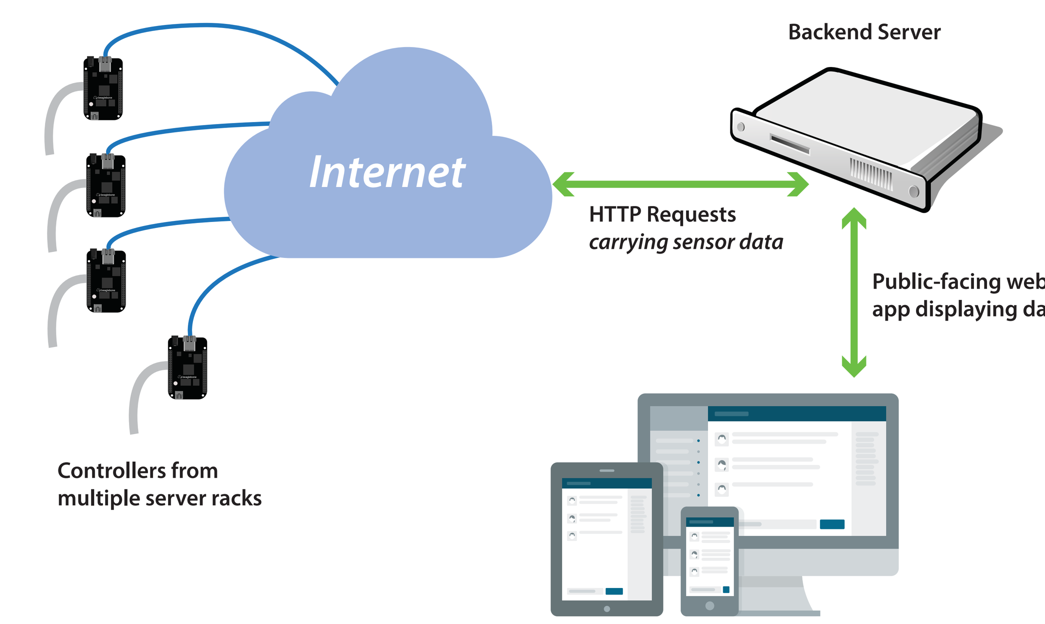
Design: Sensor-Controller Subsystem

For each set of server cabinets upon which the sensors should be mounted, one BeagleBone Black is used to control a subsystem of sensors. The sensor boards themselves are connected via ribbon cable delivering power from the BeagleBone controller and communicate with it via an I²C bus carried by the same cable. The BeagleBone is connected to the Internet via an ethernet cable, access to which is readily available in the HPCRC. This design was done in [1].



Design: Top-level System & Client Interface

A top-level system is used to manage multiple instances of sensor-controller subsystems, each of which consists of one server cabinet and its corresponding sensors and groups. The higher-level architecture is needed to manage many of these systems working in tandem, and its design has been articulated (and is diagrammed below, but has not yet been implemented. As each subsystem's BeagleBone controller is connected to the Internet (and hosts an Apache server which can be queried), a separate server will be used to communicate with each of the subsystems in a given facility and to gather temperature data from them on a regular basis. That server will then serve a client web application from which users can view the environmental data, gain insights regarding the status of the data center's climate, and manage their installation of the system.



Second Term Goals

While the design for a temperature-only version of the sensor board is complete, there is much yet to be accomplished before the system can be used in a production environment. Possible milestones for the next semester of work include:

- Explore feasibility of incorporating additional sensors on the sensor board, barring concerns regarding price and board area, including possibly making use of an I²C bridge to allow for more devices per bus
- Modify BeagleBone controller code for system robustness over long timeframes
- Possibly develop a small housing for the sensor boards to protect the electronics
- Build public-facing web app to display sensor data and provide more valuable insights to data center operators, manage sensor subsystems, and handle multiple instances of the sensor suite
- Produce an instance of the system affordably and deploy it in the Princeton HPCRC and gather feedback from that experiment
- Ready project for commercial use or further development; perform power usage analysis

References

[1] P. de Groot, "Data Center Instrumentation Project: Final Report," Princeton University, May 2015.
[2] R. Subramanian, "Design of an Instrumentation Circuit for Datacenter Temperature Measurements," Princeton University, 2014.
[3] J. B. Marcinichen, J. A. Olivier, and J. R. Thome, "On-chip two-phase cooling of datacenters: Cooling system and energy recovery evaluation," Applied Thermal Engineering, vol. 41, pp. 36–51, Aug. 2012.
[4] R. Azimi, X. Zhan, and S. Reda, "Thermal-aware Layout Planning for Heterogeneous Datacenters," in Proceedings of the 2014 International Symposium on Low Power Electronics and Design, New York, NY, USA, 2014, pp. 245–250.
[5] G. F. Davies, G. G. Maidment, and R. M. Tozer, "Using data centres for combined heating and cooling: An investigation for London," Applied Thermal Engineering, vol. 94, pp. 296–304, Feb. 2016.