Temperature Sensor Network for Thermostat Control

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Objective

Traditional thermostats collect temperature from one location. This may be insufficient in a place such as a multi-room apartment where different rooms, or different corners of the same room do not get heated/cooled evenly. While some modern HVAC systems can check for these imbalances, it's not practical for older buildings to replace existing systems. Also, replacing the whole HVAC system could be very costly. Regardless, incidents such as forgetting to close a door or window may cause dramatic disparities in temperature - hiking heating/cooling bills if not warned early.

We seek to build a scalable temperature aggregation system as a cheaper add-on (than replacing with newest zoning HVAC) to older HVAC systems to collect and interpret temperature data across multiple rooms in any internal environment. The design would require temperature sensors, wifi chips, and MCUs integrated on PCBs, and a central hub that gathers all the sensor data. The user can monitor temperature across rooms and receive alerts through a phone app in real time. The system will also attempt to regulate the internal temperature through two methods: adjusting the thermostats temperature and opening/closing air-vents.

Background

There exists zoning products [1][2] that can convert traditional single zone HVAC into multizone. However, most of these products require complicated installations and modifications to the wiring in an apartment. Besides, the number of zones that can be divided is fixed to the zone controller installed, i.e. if the user originally installed a two zone system but wants to expand it to four zones, he/she has to purchase and reinstall a new controller. Our system has two key differences to address these problems. Firstly, all of the temperature sensors are powered by batteries and communicate wirelessly, which eliminates the need to lay new wires. The only component powered externally will be the central hub, but it can be plugged into any wall outlets. Secondly, because all the communications are carried via wifi, our system is easily scalable: we can slice/combine zones by removing/adding new sensors and set them up using the software for the central hub.

High-level requirements

- Room temperature sensor modules must collect and communicate temperature data to a central hub.
- The central hub must be able to collect and store incoming temperature data for analysis.

- The central hub should coordinate actions based on live-analysis with the goal of maintaining a comfortable, consistent home temperature.

Block Diagram

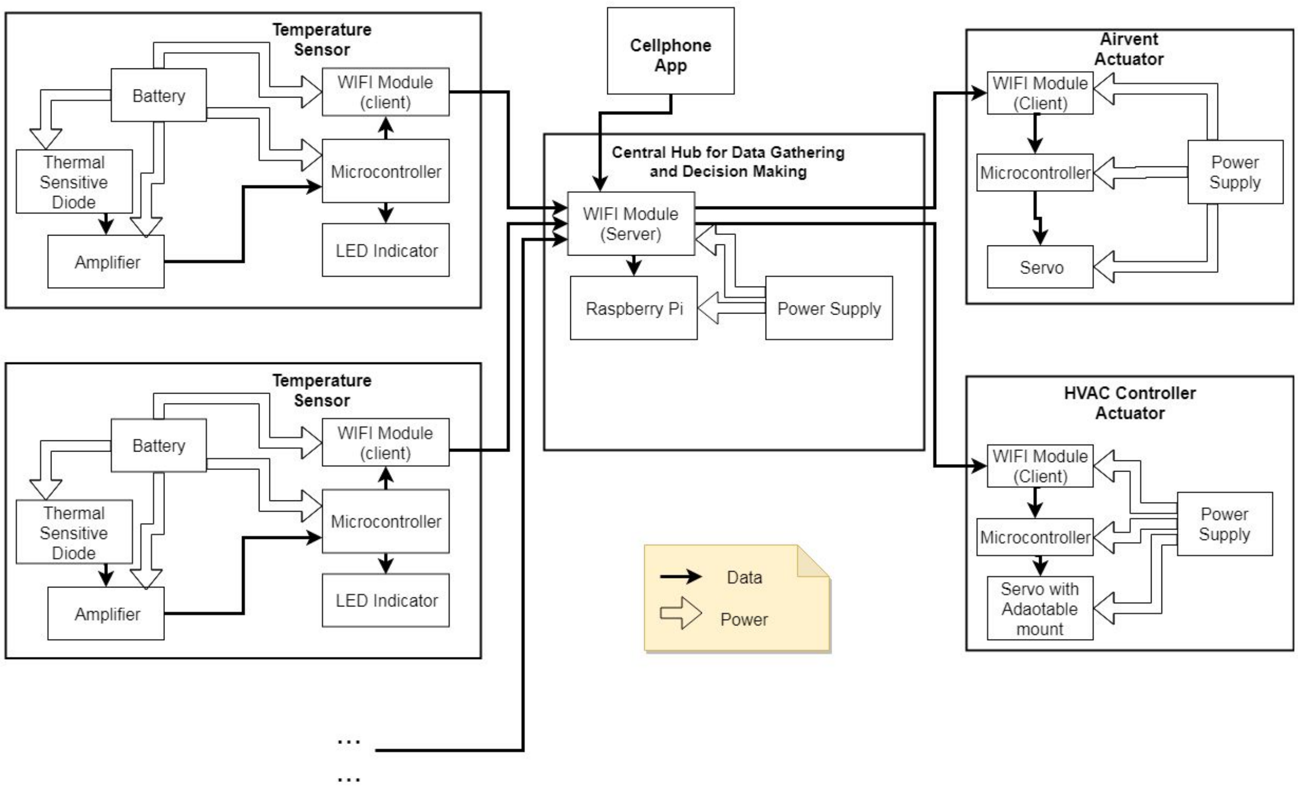

Figure 1: High Level Block Diagram

Physical Design

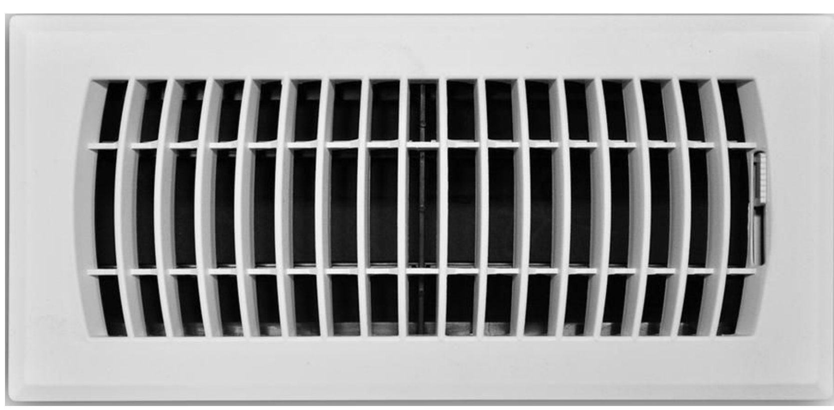

Figure 2: Sample Air Vent with Open/Close Slider

The automated floor-register air-vent will involve modifying an existing commercial floor register which includes a manual open/close slider, such as the one displayed above which contains a slider located at the far-edge of its vents. The modification will require us to attach and configure a stepper motor to drag the slider up and down, depending on the central hub's requested action.

Potential Reach Goal: One-fits-all clamp-on HVAC controller actuator case

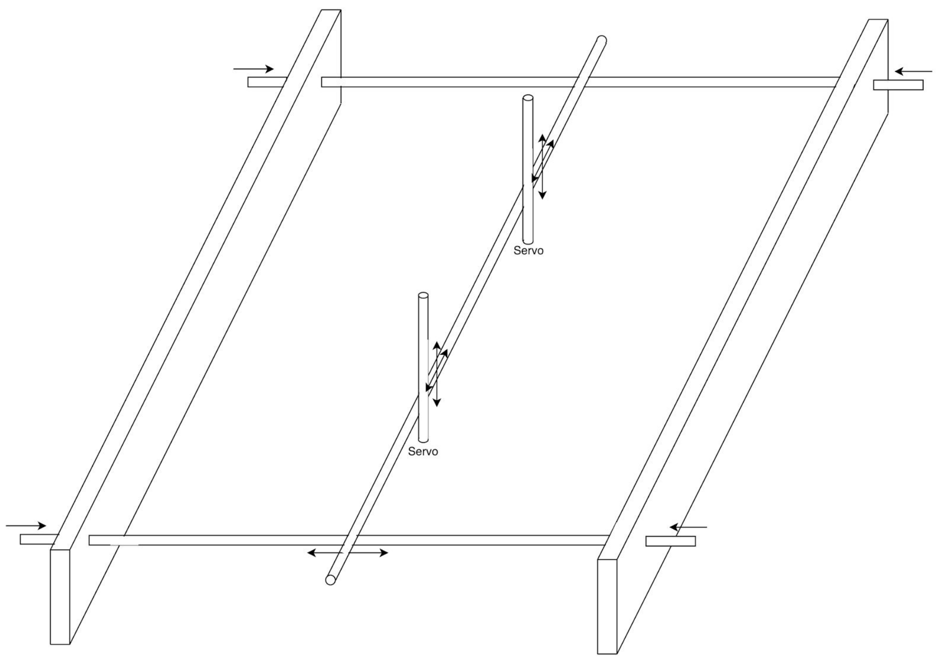

Figure 3: Idea for Mechanical Design for One-Fits-All HVAC controller actuator

We also plan to create a mechanical thermostat clamp out of several adjustable rods such that we can orient the up/down actuators into their correct positions. The thermostat clamp must be simple, but as adjustable as possible to accommodate a wide range of thermostats. Since the height of a thermostat is unknown, it's best to be conservatively large in the ridgid dimension. A simple design would consist of 2 narrow boards, each covered on on side with a strip of rubber to better grip the thermostat. These board will then be held on either side of the thermostat using threaded rods with wing-nuts. Two shorter rods will be fixed on the threaded rods between the two boards. These rods are adjustable up and down the rods, and hold a third adjustable rod which harnesses the actuators. These actuators can be adjusted up and down the rod into their necessary location. Components used to adjust and fix perpendicular rods together will require 3D printing, as commercial alternatives aren't easily acquired.

Functional Overview

Temperature Sensor Module

The temperature sensor modules measure the temperature in different rooms, then send data to the central hub. It will be implemented on a PCB that contains:

1. A pair of AA batteries connected to the component with a battery holder
2. An LED indicator light (HLMP-3507) to signify when a temperature reading is being sent out
3. A microprocessor (Atmega328) to coordinate logic between components
4. A wifi module [3] (ESP8266 in client mode) which is used to communicate with the Central Hub.
5. A thermal sensitive diode (LMT01LPG) for temperature reading.

Central Hub for Data Gathering and Decision Making

The central hub gathers temperature data sent from sensor modules distributed in different rooms, process the data, present the data to users and send commands to actuators to manipulate temperature. It contains the following components:

1. A wifi module (ESP8266 in server mode) that communicates with the sensors and actuators
2. A Raspberry Pi that processes the data and hosts a website so that users can check temperature on their phones.

The raspberry pi's software usage can be split into the following dockerized components:

1. A NoSQL data storage instance (MongoDB) to store and retrieve temperature data from wifi module
2. A web-server instance (Flask) to analyze temperature data, display alerts, and display historical temperature data across rooms

Air Vent Actuator Module

The air vent actuator is built into standard air vents with rotating sliders and controls the temperature by opening and closing the air vent. It contains:

1. A wifi module (ESP8266 in client mode) that receives commands from the central hub
2. Servo motors that rotates sliders based on received commands
3. Power supply that converts wall voltage (110V - 220V) to 3V-5V DC

HVAC Controller Actuator Module

The HVAC controller actuator is meant to be clamped onto an existing thermostat to manipulate its set temperature. It contains:

1. A wifi module (ESP8266 in client mode) that receives commands from the central bug
2. Two servo motors which are set-up to activate the "increase" and "decrease" temperature buttons on the thermostat.

3. Power supply that converts wall voltage (110V - 220V) to 3V-5V DC

Block Requirement

Component	**Requirement**	**Verification**
Temperature Sensor	● The components temperature read is accurate up to 0.5 ˚C within the range of temperatures 10˚C to 30˚C.	● Expose the sensor to a fixed air temperature environment, compare the readings against a known accurate thermometer, and ensure temperature disparity in the range 10˚C to 30˚C satisfiesı the requirement over an extended period of time.
Temperature Sensor: Battery	● The temperature sensor's battery should last up to a week on a single charge. [4] ● Voltage 4V-5V, Current >= 200mA	● Monitor a battery with simulated usage and ensure it stays charged over the course of 7 days.
Temperature Sensor: LED Indicator	● The LED indicator should signify the power state and signal activity of the system.	● The indicator should blink periodically whenever a reading is sent to the central hub
Temperature Sensor: Wifi Module Client	● The temperature sensor's wifi module should communicate temperature readings once every 60+/-15 seconds.	● We will kick of the system and monitor signal frequency over a period of 10 minutes, ensuring about 10 signals were sent at a period of about 60 seconds.
Central Hub: Wifi Module Server	● The wifi module should listen and cache new temperature readings from all clients. ● The central hub should communicate cached messages with the Raspberry Pi for data storage	● We will periodically send signals to the central hub and confirm it received and cached them. ● Confirm that cached messages are received by the Raspberry Pi
Central Hub: Power Supply	● Less than 10W±5% power consumption (5V±2.5%, 2A±2.5%)	● Run the central hub at full load, measure the power output of the DC power supply using multimeter, and ensure the peak power consumption is below 10.5W

Raspberry Pi: Data Storage	● The central hub should accurately receive communicated messages from the Wifi Module Server for data storage in a dockerized database	● Confirm data sent by wifi module cache arrives to the RBP and is accurately stored by sending mock signals through the raspberry pi, and query internally to confirm the data was received.
Raspberry Pi: Web app	● Raspberry pi capable of hosting a web service and sending alerts to the user through email or text ● Raspberry pi should only send alerts when certain data thresholds are met (e.g. temperature difference between rooms is > 5˚F ● The website displays temperature visualization and alerts should update within 60 seconds of temperature reading delivery from wifi module.	● Set-up a mock alerts that should be viewable on the web app ● Simulate each threshold (and each with mock data, and confirm corresponding alerts were sent. ● Periodically send signals through wifi component to ensure the web app displays information within the 60 second time window.
Air-vent Actuator	● receives signals from Central Hub Wifi Module with instructions. ● Air-vent opens/closes vent upon order and maintains that state until a new signal is received.	● Send mock signals through the central hub, and confirm they were received by the air-vent actuator ● Simulate signal response for both opening and closing by sending mock signals to the actuator and confirming the correct action was taken
Thermostat Actuators	● receives signals from Central Hub Wifi Module with instructions. ● HVAC Controller increases/decreases upon order and maintains that state until a new signal is received.	● Send mock signals through the central hub, and confirm they were received by the HVAC Controller Actuator ● Simulate signal response for both increasing and decreasing temperature by sending mock signals to the actuator and confirming the correct action was taken.
Actuator Power Supply	● Converts wall power (110-220V, 50-60Hz) to 3V-5V DC Voltage	● Use digital multimeter to measure the output voltage

Risk Analysis

1. The main selling point of our system is that all communications are carried via wifi, but bookkeeping all of that data can be challenging, especially when there are large number of sensors connected to the network. Because the central hub cannot request data from the sensors, we need to make sure our communication protocol can handle the situation where multiple sensors send their data at once. The central hub must be capable of caching and queuing the data properly so it does not lose import information.
2. While we will use an aftermarket processor as the brain for our temperature sensor, we are designing the supporting circuit ourselves. Obviously the circuit has to function properly, but also be simple to lower the cost and minimize build time, while at the same time offer enough protection mechanisms so any component failure won't damage the rest of the circuit.
3. Our sensors are powered by batteries, therefore we have to make sure the sensor assemblies meet the power requirement such that they do not drain batteries too rapidly to render the system impractical.

Ethical and Safety Issues:

1. Legal: We could end up creating a product too similar to an existing one, violating ACM code of ethics 1.5 [5].
2. Security: if someone is capable of eavesdropping on our sensor data or hijacking our actuators, it could pose dangers to the user. Likewise, the sensor data could be aggregated and monetized without the user's knowledge. This would dishonor confidentiality and violate the ACM code of ethics 1.7 [5].
3. Safety: if our system is installed incorrectly or malfunctions (e.g. HVAC controller button is pressed too many times, or air vent cannot be opened), it may damage the HVAC system or disrupt the desirable temperature set by user, which could be dangerous while the users are asleep.

Solutions

1. Legal: Careful analysis of competitors, what their fundamental technology is and ensuring our products differ is crucial.
2. Security: we can securely communication by introducing application layer encoding using certain keys and a hash function.
3. Safety: We'll work to make our system fail-safe by exploring options such as a torque sensor on each rotating shaft or a separate pressure sensor on the contact point. Additionally, any unexpected changes in temperature should be detected by our system, giving it the opportunity to advise the user to check modules for malfunctions.

Reference

[1] "Zoning", *Lennox*, 2019. [Online]. Available: https://www.lennox.com/products/comfort-controls/zoning. [Accessed: 08- Feb- 2019].

[2] "Multi Zone Home Heating and Cooling - Modernize", *Modernize*, 2019. [Online]. Available: https://modernize.com/home-ideas/12694/pros-cons-multi-zone-heating-cooling. [Accessed: 08- Feb- 2019].

[3] "ESP8266 - NURDspace", *Nurdspace.nl*, 2019. [Online]. Available: https://nurdspace.nl/ESP8266. [Accessed: 08- Feb- 2019].

[4] "ESP8266 Voltage Regulator For LiPo and Li-ion Batteries", *Random Nerd Tutorials*, 2019. [Online]. Available: https://randomnerdtutorials.com/esp8266-voltage-regulator-lipo-and-li-ion-batteries/. [Accessed: 08- Feb- 2019].

[5] "ACM Code of Ethics and Professional Conduct," Association of Computing Machinery. [Online]. Available: https://www.acm.org/code-of-ethics. [Accessed: 08- Feb- 2019].