Evaluation and calibration of inexpensive humidity sensors for mass-deployed weather stations

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Introduction

In recent years, tiny, integrated, low-cost humidity-pressure-temperature sensors have become available on the market, with nominal specifications rivaling those of professional (and expensive) weather stations. Together with the widespread availability of equally inexpensive, fully-featured microprocessor boards this opens the concrete possibility of deploying an IoT sensor network for monitoring meteorological phenomena at unparalleled spatial and temporal resolution.
Here we evaluate the suitability of two such sensors (BOSCH's BME280 and TS Connectivity's MS8607) for humidity measurements. We build a thermostated apparatus that exploits the humidity fixed points of binary saturated aqueous solutions in order to construct calibration curves for the humidity sensors [1, 2]. A theoretical model is constructed to help interpret the results. Our preliminary results show the default factory calibration may be inadequate, but the characteristics of the sensors are in line with the claims of their vendors, provided that the sensor is carefully recalibrated.

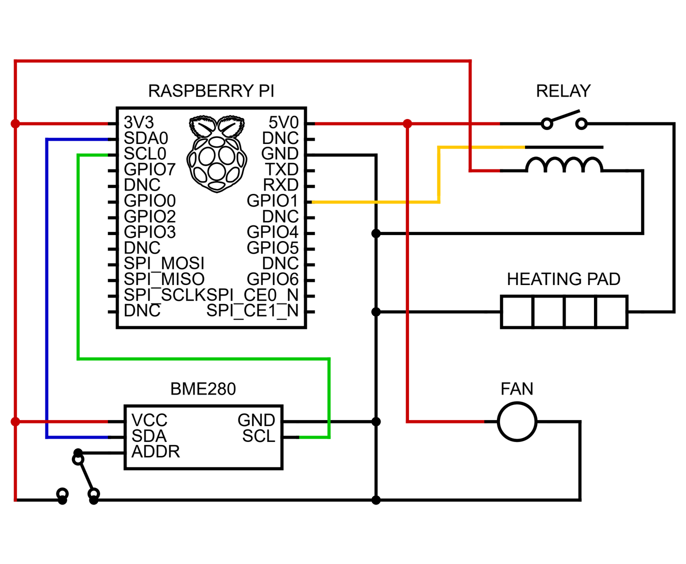


Figure 1:Circuit Diagram

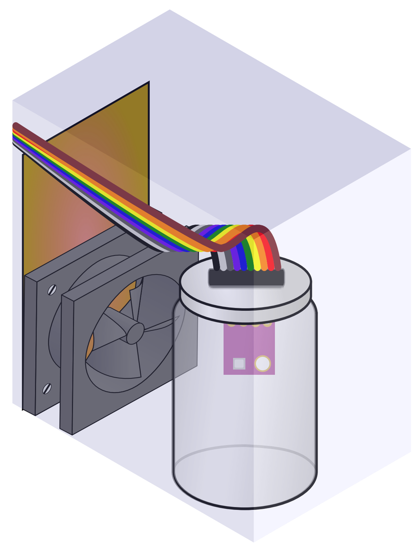


Figure 2:Box Setup

Problem Statement

Initial attempts at calibrating the aforementioned sensors for relative humidity showed the importance of isothermal conditions. The humidity readings are highly volatile as temperature changes, as shown in Figure 3. Therefore, creating an environment for the solutions to be at a constant temperature was paramount. The first few problems encountered were due to large temperature fluctuations, but small temperature fluctuations and temperature gradients between the sensor and the binary saturated aqueous solution were also areas of contention.

Data

The BME280 sensor claims to have an absolute accuracy tolerance of ±3% RH and reports with a resolution of 0.008% RH, the absolute accuracy temperature is ±0.5°C with a resolution of 0.01°C [3].

Methodology

A slushy [4] of water and our selected salt was kept in a glass jar, with a sensor placed at the top to measure the relative humidity. This jar was wrapped in aluminum foil in order to create as close to an isothermal environment as possible. Furthermore, a PID controlled heating pad and fan were set up next to the jar to prevent a temperature gradient and ensure isothermal conditions. The components were wired up as in Figure 1, taking the sensor handling instructions into consideration [5]. These were all placed inside an acrylic box, which was placed inside an insulated box. See Figure 2.
The following salts were used for the binary saturated aqueous solutions:

- Sodium Chloride (NaCl)
- Magnesium chloride ($MgCl_2$)

Table

Summary of Least Squares Fits to RH= $\Sigma_{i=0}^{3} A_i t^i$ for selected saturated salt solutions [1]

Salt	A_0	A_1	A_2	A_3
NaCl	75.5164	.0398321	$-.265459 \times 10^{-2}$	$.284800 \times 10^{-4}$
$MgCl_2$	33.6686	-.00797397	$-.108988 \times 10^{-2}$	

Mathematical Section

One definition of relative humidity is the ratio of actual water vapor pressure, e, to the equilibrium, or saturation, vapor pressure, e_s [6, 7]. We can approximate the relative humidity as follows:

$$RH = 100\frac{e(x^*, T)}{e_S(T)} = 100\frac{RT\chi}{c\exp\left(\frac{AT}{B+T}\right)} = F(T)\chi$$

Where $F(T)$ is the temperature component in the relative humidity formula and χ is the absolute humidity. It uses the Magnus approximation and the law of perfect gases. [8]

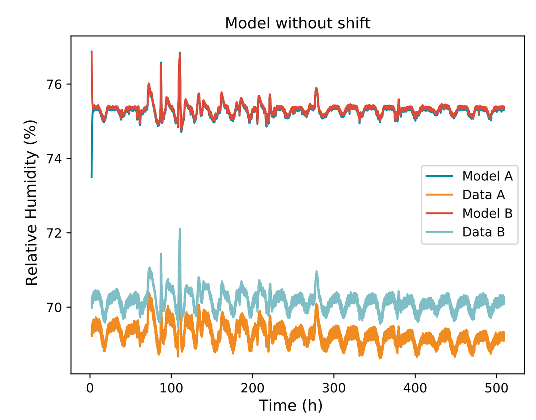
A = 17.625 Nondimensional
B = 243.04 Centigrades
C = 610.94 Pascal
R = 461.523 J / (Kg*K)

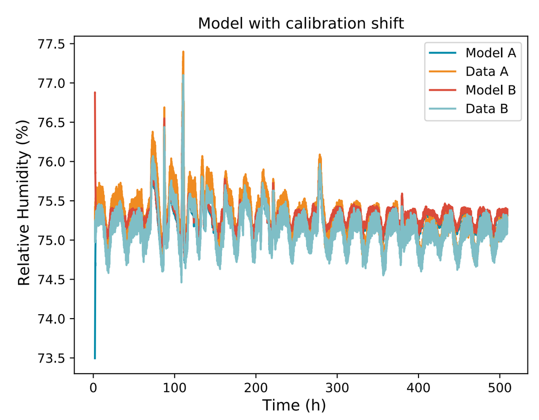
There exists a saturation $RH_S(T)$ at equilibrium:

$$F(T)\chi = RH_S(T) \implies \chi_{eq}(T) = \frac{RH_S(T)}{F(T)}$$

We construct a relaxation model, visualized below:

$$\frac{d\chi}{dt} = -\frac{\chi - \chi_{eq}(T)}{\tau}$$





Current Achievements

We constructed a thermostated apparatus that utilizes binary saturated aqueous solutions to create a microenvironment which has a known, constant relative humidity. This allows us to verify and correct the factory calibration of inexpensive relative humidity sensors.

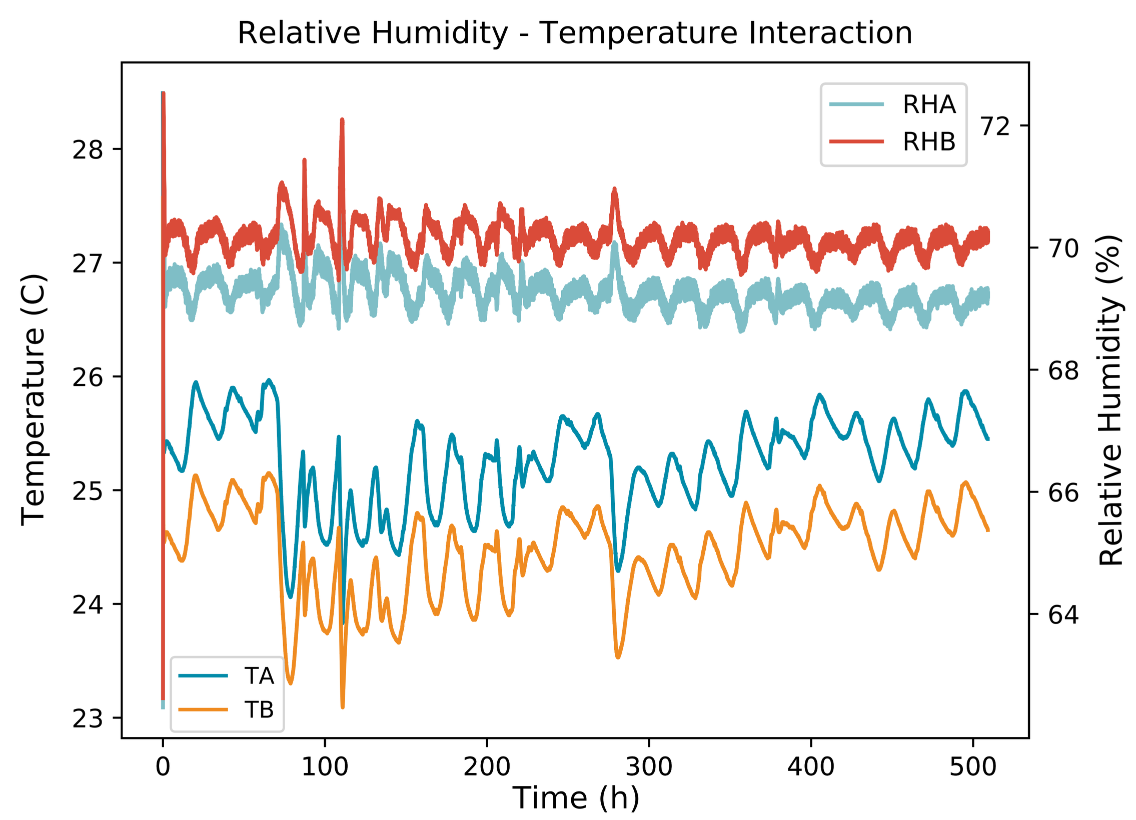


Figure 3:Relative Humidity-Temperature Interaction

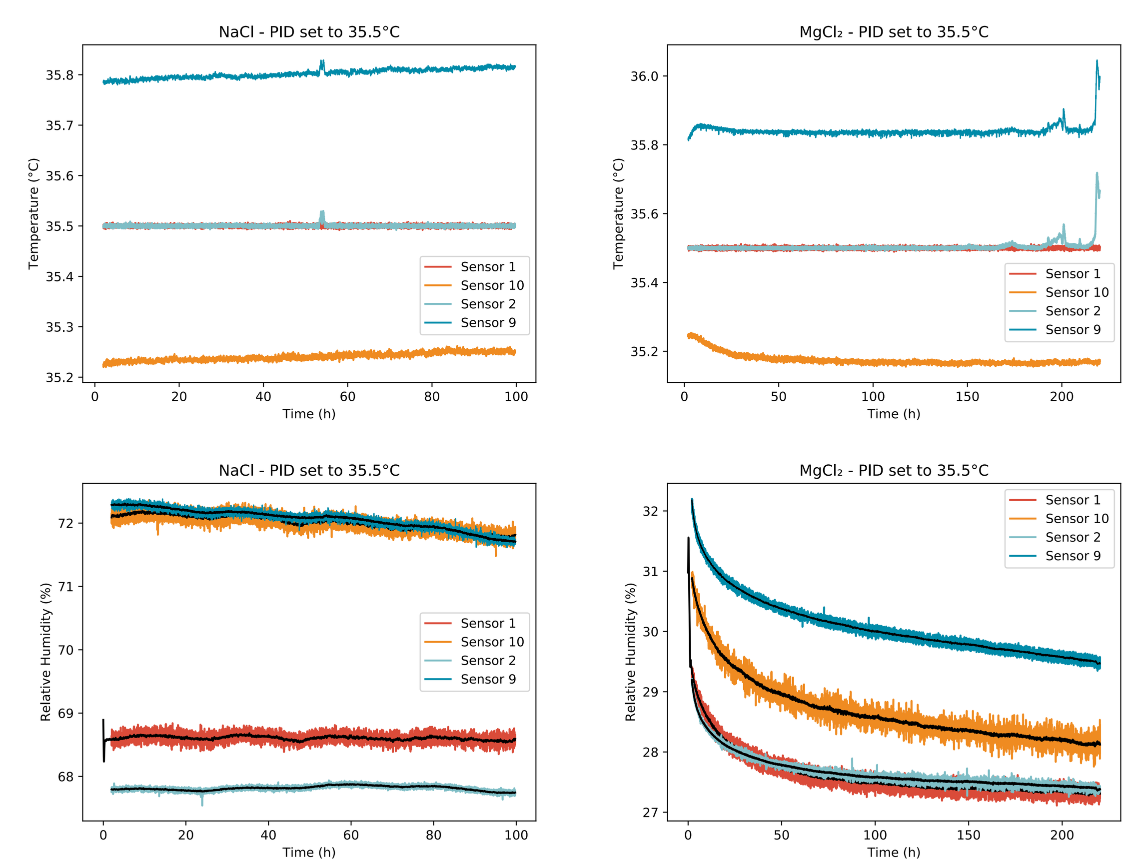


Figure 4:Results

Future Work

Further work will look into the downward drift seen in the data, currently we hypothesize this might be due to the sensor being affected by the large concentration of salt ions in the jar. A more accurate calibration of the sensors can be achieved with additional calibration setpoints; we set out to gather data for other temperatures as well as other salts, namely Lithium chloride (LiCl) and Potassium Chloride (KCl). These span a wide range of relative humidity (from 11.2% to 88.6%) [1] and are relatively safe to use. We shall also construct a temperature-dependent calibration function.

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