Chapter 4

Design and Development of a Temperature Compensated Relative Humidity & Room Temperature Measurement System.

4.1 Introduction

Measurement of humidity is essential in many situations. Humidity is the amount of water vapour present in air. It is measured in terms of Relative Humidity (RH), Absolute Humidity, and Specific Humidity. The RH is defined as the ratio of partial pressure of water vapour in a certain amount of air to the saturated vapour pressure of water at a prescribed temperature.

Measurement of RH plays an ever increasing role in industrial, laboratory, and process control applications. It can improve the quality of product and can reduce the production cost in different domain of industrial applications. In warehouse RH control protects corrosive or humidity sensitive materials, such as coils of steel, food, dried milk, tea leaves etc. If RH in the paper dryer is monitored, the dryer can be turned off as soon as the humidity is below a certain level. This could save a large amount of energy. In tea factory RH measurement is an important issue in different stages of tea processing.

Several human comfort and health related issues demand the measurement of RH. Examples are found in humidity controlled hospital operating rooms, incubators, air conditioning, meteorological applications, auto emissions, air pollution, ozone depletion studies etc. [2,8,9,11].
Proper storage, operating, and fabricating conditions of Integrated Circuits (IC) are strongly dependent on RH [8].

RH measurement system is important in investigation of microenvironment in a building environment. Such a work has been reported by Baker, P.H. et al [9]. In this work a commercially available RH sensor is used to study the microclimatic measurements in typical flooring constructions with different floor coverings such as carpets, sponge underlay and medium density fibreboard. A satisfactory result has been obtained when compared with dynamic heat and moisture transfer model [9].

Measurement of RH is more difficult than the measurement of most other properties such as flow, temperature, level, and pressure. It is because of its wide dynamic range and widely varying measurement environments. The range of RH measurement starts from one parts per billion or less at 0°C which represents a partial vapour pressure of about $0.8 \times 10^{-6}$ mm of Hg to saturated steam at 100°C which corresponds to a partial pressure of 760mm of Hg. This gives a dynamic range of the order of $10^9$ [2].

RH measurement may have to be made in widely varying environments, for example, from ambient temperature -80°C to 1000°C, in the presence of a wide range of gases which could be corrosive or non-corrosive, and in the presence of a variety of contaminants of particulate and/or chemical nature [2].

As RH measurement is so important in industrial applications, the older and simpler humidity or dew point detectors such as dry/wet bulb Psychrometer, hair hygrometers, and dew cups are no longer considered as suitable for most of such applications due to their response time, cost, and readout difficulties.

More sophisticated instrument’s requirement evolves in this field of measurement due to the rigid requirements and government regulations of the Environment Protection
Agency (EPA), Food and Drug Administration (FDA), Federal Aviation Administration (FAA) and nuclear agencies [2]. For this kind of instrumentation electrical RH sensors are widely used due to its faster response and electrical output. Widely used electrical humidity sensors are bulk polymer sensors, either capacitive and or resistive type [3,8,15,19]. Bulk polymer humidity sensors consist of a miniature electrode base plate coated with a humidity sensitive hygroscopic macro polymer. An electrical grid structure is vapour deposited upon the element. Electrical measurement is made across the two electrodes which is a function of relative humidity. Overall, the capacitive sensor is more suitable than resistive one as the capacitive one has wide operating temperature range and faster response than the resistive one [3]. In case of a capacitive polymer sensor the polymer is either polyamide or cellulose acetate. The typical construction of a bulk polymer capacitive RH sensor is shown in Fig.4.1.

![Fig. 4.1 Typical construction of a bulk polymer capacitive RH sensor [3].](image-url)
It consists of a substrate base, two electrodes, and a thin layer of the polymer in between the two electrodes. The substrate base, typically a glass plate, used to support the other layers of the sensor. First electrode is made of conductive and corrosion resistant material. There is a thin polymer film in between the two electrodes, the thickness of which varies from 1μm to 10μm. The amount of water absorbed by this film is a function of ambient RH. The second electrode is electrically conductive and strong corrosion resistant. This determines the performance and characteristic of the sensor. For faster response it should have good permeability for water. Due to such constraints in designing of the upper electrode, a separate metallization for making reliable contacts is often required. The advantages of polymer RH sensors are:

i. fast response (of the order of few seconds)

ii. low hysteresis (of the order 1% to 2%)

iii. less sensitive to contaminants

iv. require less frequent recalibration and replacement

v. low temperature coefficient (typical value 0.16pF/°C)

vi. wide range of operation (2% to 100%)

vii. low cost

viii. calibration of sensors can often be performed in the field.

As they are secondary measurement devices so without proper calibration, measurement with such devices are meaningless. These sensors require stable ac excitation with zero dc bias to prevent polarization [15]. Conditioning hardware with the functionalities like rectification, filtering, and linearization are required for them. This extra hardware introduces error due to the component tolerances and noises basically due
to RF and EM interferences. The temperature drift of these conditioning circuit is a major concern over accuracy and precision [12,13]. Voltage output humidity sensors reduce these problems to a large extent. Voltage output humidity sensors are basically capacitive or resistive humidity sensor with on chip signal conditioning [14]. It is designed for application in industries and it comes with calibration data given by the manufacturer. It is less corrosive, faster in response and has lower hysteresis [14].

Temperature compensation is one of the crucial steps for online RH measurement. It can be done either by adding temperature sensor and analog computation or by using digital temperature sensor and embedded processor.

An essential part of humidity measurement is the calibration against a standard. The most fundamental standard that is employed by national standard laboratories is Gravimetric Hygrometers [7]. Though this method gives the most accurate measurement it is very cumbersome, expensive, and time consuming. Some national laboratories, such as National Institute for Standard and Technology (NIST), in the United States, National Physical Laboratory (NPL) in the United Kingdom, National Research Laboratory of Metrology (NRLM) in Japan, and Physicalisch-Technische Bundesanstalt (PTB), in Germany have the availability of gravimetric hygrometers to calibrate other standards which are easier and faster to use for day-to-day calibrations such as two pressure humidity generator, a precision chilled mirror hygrometer or a psychrometer [5,6,8,21].

There are three categories of standards for calibrating humidity instruments namely primary standard, transfer standard, and secondary standard.

The primary standard instruments rely on fundamental principles and base units of measurements. A gravimetric hygrometer is such a device. As this device is very expensive and require many hours of operation it is not an attractive system for day-to-day
use. At lower accuracy level, two pressure generators, two temperature generators, and some other systems are customarily used as primary standards.

The transfer standards operate on fundamental principles. The commonly used instruments for the transfer standards are Chilled Mirror Hygrometer, Electrolytic Hygrometer, Psychrometer [4,5,20,21]. Chilled Mirror Hygrometer is the most widely used instrument for transfer standard. In this hygrometer, a mirrored surface in contact with the gas stream to be monitored is cooled until condensation is formed. The dew or frost point of the gas at which condensation is formed is directly related to the saturation water vapour of the sample. From this data and the gas temperature and pressure humidity can be calculated. The electrolytic hygrometer is based on Faraday’s law of electrolysis to determine the amount of moisture in a gas stream. In a dry/wet bulb psychrometer, pure water is evaporated from a wick surrounding a temperature probe placed in the gas stream. The evaporation process causes a lowering of the temperature of the wet bulb, which under ideal conditions, is directly related to the RH of the gas at the prevailing temperature. The prevailing temperature is measured by the dry bulb thermometer.

The secondary devices are non-fundamental and must be calibrated against a transfer standard or other fundamental system. Impedance hygrometer, polymer film RH sensors falls to this category.

For calibration of top-end dew point and humidity sensors, the design and its result of a single pressure dew point generator is presented by Hudoklin, D. etal [10].

The classification of the humidity measurement instruments are shown in Table-4.1.
Table 4.1 Humidity Measurement Instruments Classifications [6]

<table>
<thead>
<tr>
<th>Type</th>
<th>Suitable for use as a standard</th>
<th>Class</th>
<th>Typical Range</th>
<th>Typical measurement accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravimetric</td>
<td>Yes</td>
<td>Primary</td>
<td>+50°C/-50°C dew point</td>
<td>0.1°C dew point</td>
</tr>
<tr>
<td>Chilled Mirror</td>
<td>Yes</td>
<td>Fundamental (Transfer)</td>
<td>+90°C/-90°C dew point</td>
<td>0.1°C dew point</td>
</tr>
<tr>
<td>Electrolytic Hygrometer</td>
<td>Yes</td>
<td>Fundamental</td>
<td>1 to 2000 ppm (Volume fraction)</td>
<td>5% of reading ppm ((Volume fraction)</td>
</tr>
<tr>
<td>Psychrometer</td>
<td>Yes</td>
<td>Fundamental</td>
<td>10% to 100% RH at 0°C to 100°C ambient</td>
<td>2% RH</td>
</tr>
<tr>
<td>Impedance Hygrometer</td>
<td>No</td>
<td>Secondary</td>
<td>-100°C to +30°C dew point</td>
<td>2°C to 4°C dew point</td>
</tr>
<tr>
<td>Polymer RH Sensor</td>
<td>No</td>
<td>Secondary</td>
<td>5 to 95% RH 0°C to 100°C ambient</td>
<td>2% to 5% RH</td>
</tr>
</tbody>
</table>

4.2 System Architecture:

The block diagram of the RH measurement system designed and developed is shown in Fig.4.2. (Photograph A3, Appendix A)
4.2.1 Sensors

For humidity sensing low power (200uA) RH to voltage converter is used [14]. It is basically a LASER trimmed, thermoset polymer capacitive type sensing element with on chip integrated signal conditioning [10]. The sensing element is resistant to most application hazards such as wetting, dust, dirt, oils and common environmental chemicals due to its multilayer construction. It requires 4.5 to 9Vdc (V_{SUPPLY}) supply [10,14]. The output is ratio metric with the supply voltage. The output voltage (V_{OUT}) and RH is related by the following equation typically at 25\textdegree C [14]:

\[
RH = \left( \frac{V_{OUT}}{V_{SUPPLY}} - 0.16 \right) \times 161.29\% \quad \text{(4.1)}
\]

The true RH requires temperature correction given by the following equation [14]:

\[
\text{RH}_{\text{true}} = K_{T} \times \text{RH}
\]

where \(K_{T}\) is the temperature correction factor.
\[ TrueRH = \frac{RH}{(1.0546 - 0.00216t)} \% \quad (4.2) \] where "t" is the ambient temperature in degree Celsius.

For ambient temperature a Temperature to Digital Converter (TDC) TMP121 (Texas Instruments) is taken [17]. This Serial Synchronous Interface (SSI) compatible temperature sensor requires no external component for conditioning. Digital data corresponding to the temperature can be read directly.

The RH sensor and TDC are assembled close to each other to minimize the temperature gradient between them and exposed to ambient environment.

4.2.2 Digital Interface

The circuit schematic of the system is shown in Fig.4.3. To read the analog voltage output of the RH sensor a 12-bit A/D converter (ADS1286) (U1) (Texas Instruments, USA) with serial interface is selected [16]. This serial A/D converter operates with no missing code, low power consumption (typically 250 micro ampere) and occupies less board space (8 pin PDIP). The reference voltage is applied from a highly stable reference (Floating Gate Analog Technology) FGA™ (X60003B) (U4) (FGA™ is a trademark of Intersil). It features very low temperature co-efficient (10ppm/°C), excellent long term stability (10ppm/1000hour), low noise and excellent line and load regulations. It works from input voltage 4.5 V to 9V [18]. The functioning of the A/D converter is controlled by an 8051 core microcontroller (89S52) (U2), (Atmel). The A/D converter is interfaced with the microcontroller using Serial Synchronous Interface (SSI). The TDC is directly interfaced with the microcontroller in SPI mode to read the ambient temperature. The firmware for calculating RH using equation-4.1 and temperature correction using equation-4.2 is embedded in the flash ROM of the microcontroller. True RH is displayed
in the 16×2 line character liquid crystal display (LCD) and also sent to a PC via RS232C (U3) for data display and data logging. Port 2 of the microcontroller generates required control for the LCD. Port 0 is used for data to the LCD.

![Circuit Schematic of RH measurement system](image)

**Fig.4.3: Circuit Schematic of RH measurement system**

### 4.2.3 Firmware

The firmware developed for this purpose serves the following task:

(i) Initialize A/D converter, LCD, UART

(ii) Read A/D converter and TDC

(iii) Calculate RH using equation-1

(iv) Calculate True RH using equation-2

(v) Send the result to LCD and to PC via RS232
4.2.4 Calibration of the System:

Though the RH sensor comes with factory calibration, the whole system is calibrated using a dry/wet bulb Psychrometer. The dry wet bulb Psychrometer is a transfer standard which is based on fundamental principle [6, 9, 12]. For these 10 readings of RH, taken with the system, is compared with a Dry/Wet bulb Psychrometer (Mfd. By Zeal, England). These readings are taken on different days in the Department of Instrumentation and USIC, Gauhati University, Assam, India in a well ventilated room. The data taken for this calibration is shown in Table 4.2. During the days RH varies from 54% to 86% and in this range the error of the system in terms of RH is found to be ± 2.5%. The error compared with the RH from dry and wet bulb is shown in Fig.4.4.

Table 4.2 Data for calibration of the system

<table>
<thead>
<tr>
<th>RH Reading in %</th>
<th>Dry/Wet bulb Psychrometer</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>54.0</td>
<td>54.2</td>
<td></td>
</tr>
<tr>
<td>59.0</td>
<td>58.0</td>
<td></td>
</tr>
<tr>
<td>60.0</td>
<td>62.0</td>
<td></td>
</tr>
<tr>
<td>67.0</td>
<td>67.0</td>
<td></td>
</tr>
<tr>
<td>72.0</td>
<td>70.0</td>
<td></td>
</tr>
<tr>
<td>74.0</td>
<td>73.8</td>
<td></td>
</tr>
<tr>
<td>78.0</td>
<td>80.5</td>
<td></td>
</tr>
<tr>
<td>83.0</td>
<td>84.0</td>
<td></td>
</tr>
<tr>
<td>86.0</td>
<td>88.4</td>
<td></td>
</tr>
<tr>
<td>87.0</td>
<td>84.5</td>
<td></td>
</tr>
</tbody>
</table>
A plot of data taken by the system for 12 hour at one hour interval is shown in the Fig.4.5. A corresponding curve representing RH measured by Dry/Wet bulb method is also shown on the same plot. The maximum error is found to be ±2.5%.
4.2.5 Field Trial

The system has been installed for testing at Sonapur Tea Factory, Sonapur, Kamrup, Assam (India). In tea processing tea leaves are fermented after withering and cutting. The RH and room temperature of the fermentation room are key parameters that determine proper fermentation, which ultimately affects the quality of tea. The system developed is installed in the fermentation room and used to monitor and store the RH and room temperature data. The screenshot of the graphic user interface (GUI) for data logging and monitoring is shown in Fig.4.6. It shows the variation of RH for three hours in a particular day. A plot of collected data for six days (From 7/26/2009 to 7/31/2009 during working hours of the factory) is shown in Fig.4.7. The fermentation room is situated at a
distance of 30 meters from the control room. So RS232C communication works properly in this environment.

![Screen shot of the GUI](image_url)

Fig. 4.6: Screen shot of the GUI
Fig. 4.7: Variation of RH and RT for six days during working hours of factory

The system is being run continuously during factory operation. During a period of 90 days the system is found to be stable. From the GUI and from offline data reveals that the system is free from EMI and RF noises that arise in that particular industrial environment. So compared to the present method of RH measurement in this particular tea factory i.e. Dry/Wet bulb Psychrometer this system is more efficient.

4.3 Summary

The features of this system are:

i. Built in signal conditioning, A/D conversion, data correction

ii. Temperature compensated RH measurement

iii. PC interface, provides data monitoring and logging

iv. Accuracy ±3%
v. Cost is almost 25% of that of a typical commercial system (Model No. RH820W, Mfd. by Omega Engineering Inc. [22]).

References


Electrical Resistance Temperature Based on MSC1210", IEEE ICIA conference (2004), 220-223


[14] Datasheet of HIH4000 at

<http://sensing.honeywell.com/index.cfm/ci_id/1/document/l/re_id/0>


<http://www.sensormag.com>

[16] Datasheet of ADS1286 from Texas Instruments < http://www.ti.com>


[18] Datasheet of X60003BIG3-41T1 from Intersil < http://www.intersil.com>


[20] P.R. Wiederhold etal, True Accuracy of Humidity Measurement,

<http://sensormag.com>
