Monitoring Instrument for X-Ray Box

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***Abstract*— A humidity and temperature readout instrument has been designed and implemented in order to monitor the X-Ray Box used for testing the silicon detectors prototypes of the ITk. The sensors are connected to an Arduino Mega board equipped with 16 analog inputs and a serial port to a computer. A user-friendly software has been also designed in order to give an easy access to all measurements.**

I. INTRODUCTION

The task of a monitoring instrument is to record and to report the behavior of specific measurable variables. For the monitoring of the X-Ray Box, temperature and humidity are the variables to be measured. This kind of instruments are usually implemented with devices such as sensors and microcontrollers. The main characteristics of the devices used in this particular project are:

<u>HIH 4000 humidity sensor</u>

Fig. 1. HIH 4000

Features [1]

- Near linear voltage output vs % RH
- Enhanced accuracy
- Fast response time
- Stable performance

<u>NTC temperature sensor</u>

Fig. 2. 100kΩ NTC thermistor

Features [2]

- Heat resistivity
- Highly stable
- Very short response time
- Measurements between -55°C and 300°C

<u>Arduino board with Atmega1280 microcontroller</u>

Fig. 3. Arduino MEGA

Features [3]

- 54 digital I/O pins
- 16 analog inputs
- ADC resolution of 10 bits (i.e. 1024 different values)
- Measurements from ground to 5V

II. CONTENTS

<u>Sensors setup</u>

The simplified Steinhart - Hart equation relates temperature and resistance in the 100kΩ NTC thermistor [4].

$$\frac{1}{T} = \frac{1}{\beta} ln\left(\frac{R}{R_o}\right) + \frac{1}{T_o}\ [K] \qquad (2)$$

Solving for T and converting to Celsius,

$$T = \frac{1}{\frac{1}{\beta} ln\left(\frac{R}{R_o}\right) + \frac{1}{T_o}} - 273.15\ [C] \qquad (3)$$

In order to provide a measurable voltage signal in the Arduino input, it is necessary to implement the circuit shown in figure 4.

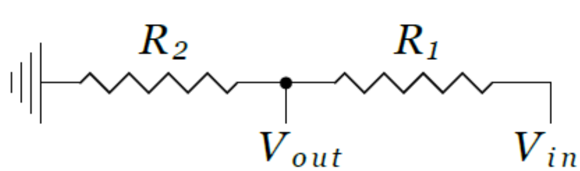

Fig. 4. Resistive voltage divider

- R_1 = Thermistor's resistance
- R_2 = fixed resistance
- V_{in} = 5V input voltage
- V_{out} = Voltage provided to the Arduino

V_{out} is defined by

$$V_{out} = V_{in} \frac{R_2}{R_2 + R_1} \qquad (4)$$

Solving for R_1

$$R_1 = \left(\frac{V_{in}}{V_{out}} - 1\right) R_2 \qquad (5)$$

Substituting (5) in (3) gives

$$\boldsymbol{T = \frac{1}{\frac{1}{\beta} ln\left[\frac{R_2}{R_o}\left(\frac{V_{in}}{V_{out}} - 1\right)\right] + \frac{1}{T_o}} - 273.15} \qquad \textbf{(6)}$$

Which is the equation that relates the voltage in the Arduino input with the thermistor temperature. For the specific sensor used in this setup, the parameters of (6) are:

$T_o = 298.15$ K
$R_o = 100$ kΩ
$\beta = 4120$
$V_{in} = 5V$
$R_2 = 217$ kΩ

Note: R_2 was determined empirically with some tests described later.

The equation relating humidity and output voltage in the HIH-4000 is

$$\boldsymbol{RH = \frac{V_{out} - zero\ offset}{slope}} \qquad \textbf{(7)}$$

The connection implemented for the humidity sensor is shown in figure 5, where the load represents the Arduino itself.

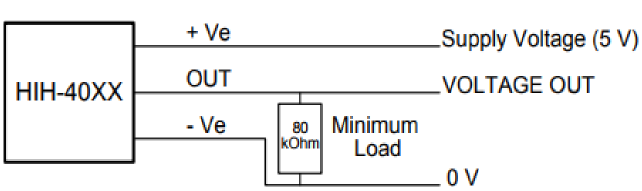

Fig. 5. Setup for humidity sensor HIH-4000

For the specific humidity sensor used in the monitoring instrument, the parameters of (7) given by the manufacturer are:

$zero\ offset = 0.794\ V$
$slope = 0.030\ \ V/\%RH$

Software

The Arduino is connected via USB to the computer, where data is processed with the help of an easy-to-use software. Some of the features of the software are:

- It saves all measurements in text files.
- All the graphs and histograms are saved in a ROOT file.
- It is designed to run permanently. Measurements of each day are stored separately in different files.
- Real time measurements can be visualized by the user.

A graphic interface was implemented in order to have an easy access to the measurements. As observed in figure 6, the interface is divided in two parts:

1. Upper window: Allows the user to take measurements in real time.
2. Lower window: Gives access to previous measurements already stored.

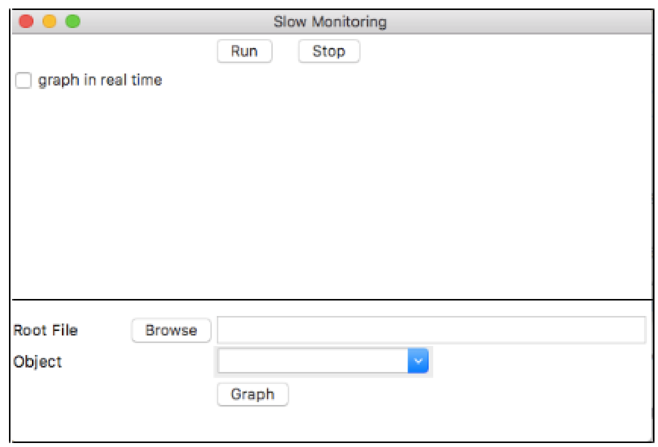

Fig. 6. Graphic interface for the monitoring instrument

Tests

Note: all tests were done in a climate chamber.

The resistance in the thermistor can take values up to 16 MΩ. In this situation, the voltage of R_2 in figure 4 can be very low. In consequence, the voltage signal provided to the Arduino can become very sensitive to noise. In order to avoid this noise, the resistor R_2 must have a reasonable high value.

R_2 was selected after several tests with resistances between 100 kΩ and 1 MΩ. Figure 7 shows one of these tests. Temperature measurements of a 217 kΩ resistance (left) and a 463 kΩ resistance (right) are compared. It can be observed that the 217 kΩ resistance has less fluctuation than the 463 kΩ one.

Tests of accuracy and response were also done. The 217 kΩ resistance was selected after all tests were carried out.

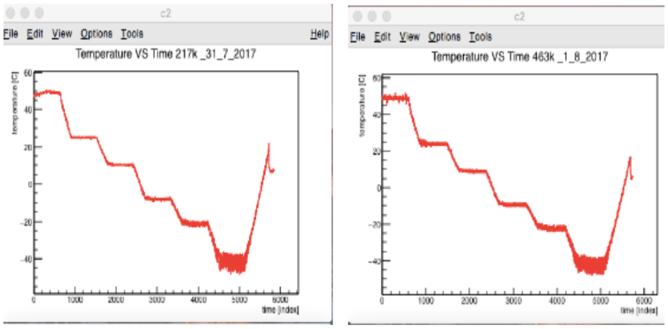

Fig. 7. Stability test for two different resistances

Tests of accuracy and response were also done. The 217 kΩ resistance was selected after all tests were carried out.

The operational range of the temperature sensor was also tested. Figure 8 shows the typical behavior at different temperatures. For regular temperatures, the measurements oscillate in a range of ± 1 ° C around the real value. For temperatures below -25 °C the fluctuation stars to increase. Below -40 °C the fluctuation is very high.

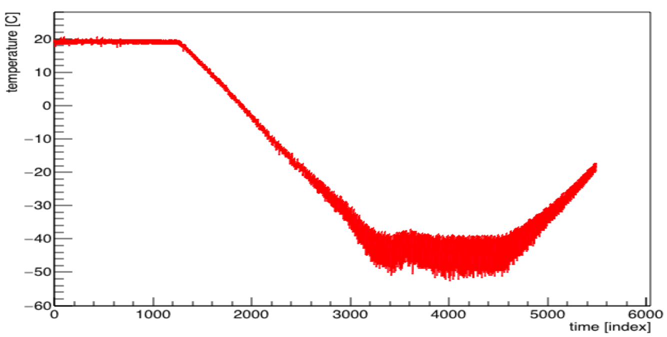

Fig. 8. Typical measurements of the NTC thermistor at different temperatures

Tests for the humidity sensor were also carried out. Figure 9 displays the measurements obtained when dry air is introduced in the climate chamber.

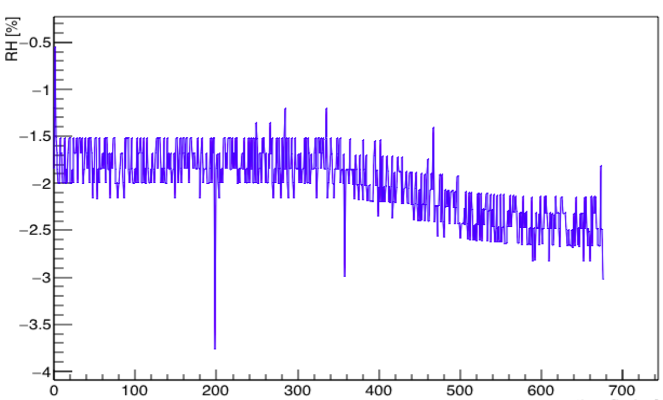

Fig. 9. Typical measurements of the humidity sensor inside the climate chamber.

As observed in figure 9, the relative humidity values oscillate in a range of 0.5, which indicates a very good stability. However, the measurements are taken negative values. Although the real values are near zero (because of the dry air inside the chamber) the measurements should not be negative.

From the observations done, it is evident that the sensors do not give good measurements when they work near their operational limits (-55 °C for the thermistor, and 0% for the humidity sensor)

Comparison tests between temperature and relative humidity were also carried out. Figure 10 displays the measurements of relative humidity (right) and temperature (left) simultaneously. It can be observed that relative humidity is inversely related to temperature.

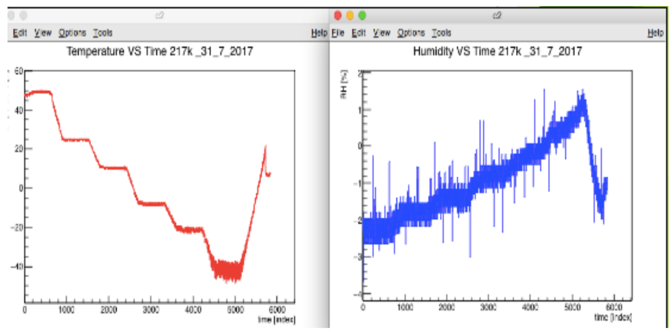

Fig. 10. Simultaneous measurements of temperature and relative humidity

Additional observations

- In the first tests, the temperature sensor measurements were very fluctuating. The leads were removed and replaced for shorter twisted cables. The measurements improved substantially.
- During the tests carried out in the temperature sensor, it was observed that the thermistor was very sensitive to changes in temperature. Its response was even faster than the climate chamber's sensor response. Its values also changed depending on the sensors position inside the chamber.

Improvements

- The humidity sensor needs to be calibrated using another trustable sensor as reference. The climate chamber has a temperature sensor installed but not a humidity sensor.
- Implementation of Wi-Fi communication between Arduino board and computer.

III. CONCLUSIONS

- Measurements in the humidity sensor are not trustable in environments with relative humidity close to 0 %
- Temperature sensor is not reliable under -25 °C.

- The leads of the temperature sensor must be kept as short as possible. Twisted cable is also recommended.
- The temperature sensor must be located as close as possible to the DUT.

REFERENCES

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[3] Arduino official website: https://www.arduino.cc/en/Main/arduinoBoardMega
[4] J. S. Steinhart and S. R. Hart, “Calibration curves for thermistors,” Deep Sea Research and Oceanographic Abstracts, vol. 15, no. 4, pp. 497 – 503, 1968.