Thermistor Thermometer

Software Design Document

Alex Senko and Lauren Pope

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1. Introduction

a. Purpose

This software design document describes the architecture and system design of a thermometer made of thermistors using LabView to calculate their Steinhart-Hart constants and display a temperature to the user. An attempt was made to use their Temperature-Resistance curves to find the steinhart-hart constants using a polynomial fit.

b. Scope

Our software will be able to calibrate a thermistor in a variety of ways in order to give the user several temperature readings that each use a different method of calibration. Also included will be Temperature - Resistance curves in order to see the hysteresis of the thermistor and store it for later reference.

c. Definitions and Acronyms

LV: LabView 2015 32-bit
T-R: Temperature - Resistance
PTC: positive temperature coefficient
NTC: negative temperature coefficient

2. System Overview

To create an accurate thermistor thermometer, we will need to measure the T-R curve of our thermistor. Over a small range of temperatures, the T-R curve is fairly linear as the change in resistance is proportional to the change in temperature. Thermistors can either have a positive or negative relationship between temperature and resistance and these are referred to as PTC or NTC respectively. The thermistor we used was an NTC thermistor. In order to make accurate measurements over the full operating temperature and not just a small range, we will need to use the Steinhart-Hart equation which is a 3rd order approximation of the temperature:

$$1/T = A + B * ln(R_T) + C * (ln(R_T))^3$$

Where R_T is the resistance measured at temperature T.

Thermistors are typically made of semiconducting material. In this kind of material there is an electron energy gap called the band gap between the valence and conduction band. As temperature increases electrons move from the valence band into the conduction band which reduces the resistance of the material.

In order to measure accurate environmental temperatures, the power dissipated by the resistor should be accounted for since the thermistor will generate heat as electricity flows through it. Modern thermistors have very low dissipation constants so this is not as important today, but in order to account for this change in temperature, one can use Newton's law of cooling as well as the assumption that all power dissipated by the resistor is manifested through heating. This allows for the ambient temperature to be found using this equation:

$$T_{env}=T(R)-I^2*R/k$$

where T(R) is measured using the Steinhart Equation, I and R is the current and resistance through the thermistor, and k is the dissipation constant.

Our first method is the most used method in calibrating thermistors. The thermistor is placed in a voltage divider occupying the first resistor position. The software reads a voltage which it then converts into a resistance using:

$$R_{thermistor} = (V_{in}/V_{out}-1)R$$

where R is given by the user as the 2nd resistor in the voltage divider.We will make resistance measurements at 3 known temperatures to determine the A,B and C coefficients of the Steinhart-Hart Equation. This will create a linear system of equations which can be solved using our software. The A, B, and C coefficients are then saved to a file for use later for making actual measurements.

The second method of measurement our software uses is a 3rd order polynomial fit to determine the Steinhart-Hart coefficients. After taking many measurements of resistance vs. temperature, the natural log of resistance vs. the inverse of the temperature can be fit using the polyfit function. The polyfit function in LabView uses the least squares method to find A, B, C, and D. Unlike the previous method, this method is able to use the log(R)^2 term in determining the final temperature which theoretically will make this temperature reading more accurate than the one measured using the first method. Lacking another method to measure the temperature during design and testing for this software, the first method was used to find the Steinhart-Hart coefficients which allowed us to read a temperature using this software and the same thermistor. The temperature and resistance readings over a range of temperatures was then used for the polynomial fit. This method likely adds much more variability to the data but doesn't require purchasing another temperature sensor.

The third and final method we are using to make temperature methods is to use the given values from the manufacturer for A,B, and C and measure the resistance of multiple thermistors. Taking the average of the resistance will give a final temperature reading. The theory behind this method is each thermistor has a different T-R curve from the factory due to tolerances in manufacturing. However, by taking multiple simultaneous measurements, it is expected that the tolerances will average out to close the given values from the manufacturer. This is likely the least accurate of the three methods but also requires the least amount of calibration time from the user.

The temperature values from each of these methods is displayed to the user in tabbed displays. The user can themselves decide which value is the most accurate based on the environment that they are using the thermometer in. The sub-VI used to fit the T-R curve from the thermistor also contains a graph to view the overall T-R curve of the thermistor.

3. System Architecture

a. Architectural Design

A thermistor thermometer requires measuring the voltage drop across the thermistor and converting that into a temperature. This is done using a voltage divider circuit connected to a USB DAQ, with all needed calculations performed using LabView in two primary parts:

Part 1: Calibrate thermistor

Before the thermometer is used it must be calibrated by determining the Steinhart-Hart constants for the thermistor or thermistors comprising the thermometer. Each thermistor will have different calibration constants, however thermistors of the same type will have very similar constants.

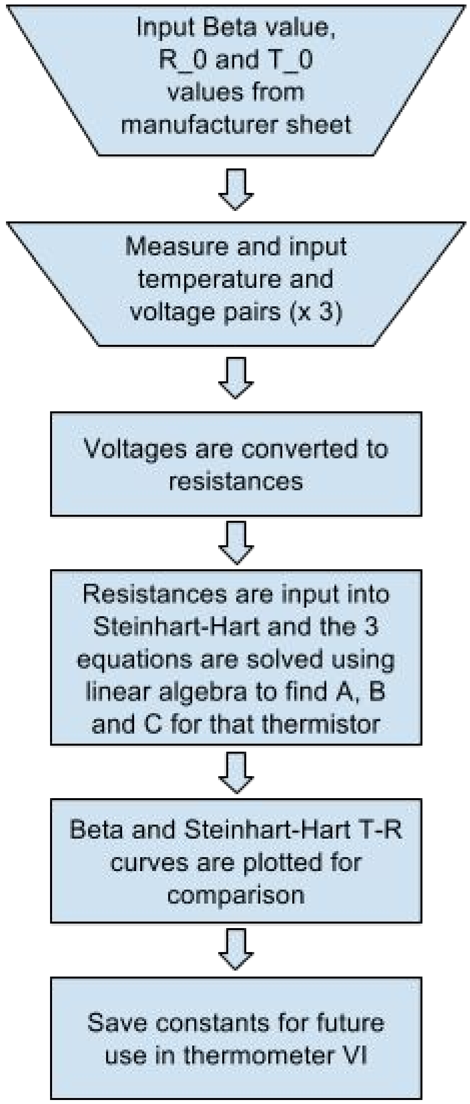
The Steinhart-Hart and Beta VI allows the user to input three pairs of measured voltages with the corresponding temperature at which those voltages were independently measured using an IR thermometer. The VI also requires the voltage flowing into the circuit and the value of the non-thermistor resistor in the voltage divider. From those inputs, the VI will automatically convert those voltages into resistances according to the voltage divider formula:

$$R_{thermistor} = (V_{in}/V_{measured} - 1) * R_{non-thermistor}$$

Using the resistance of the thermistor, the VI will automatically create a matrix of 3 Steinhart-Hart equations, one for each voltage/resistance - temperature measured pairs. Solving this matrix of 3 linear equation will provide the calibration constants for the thermistor:

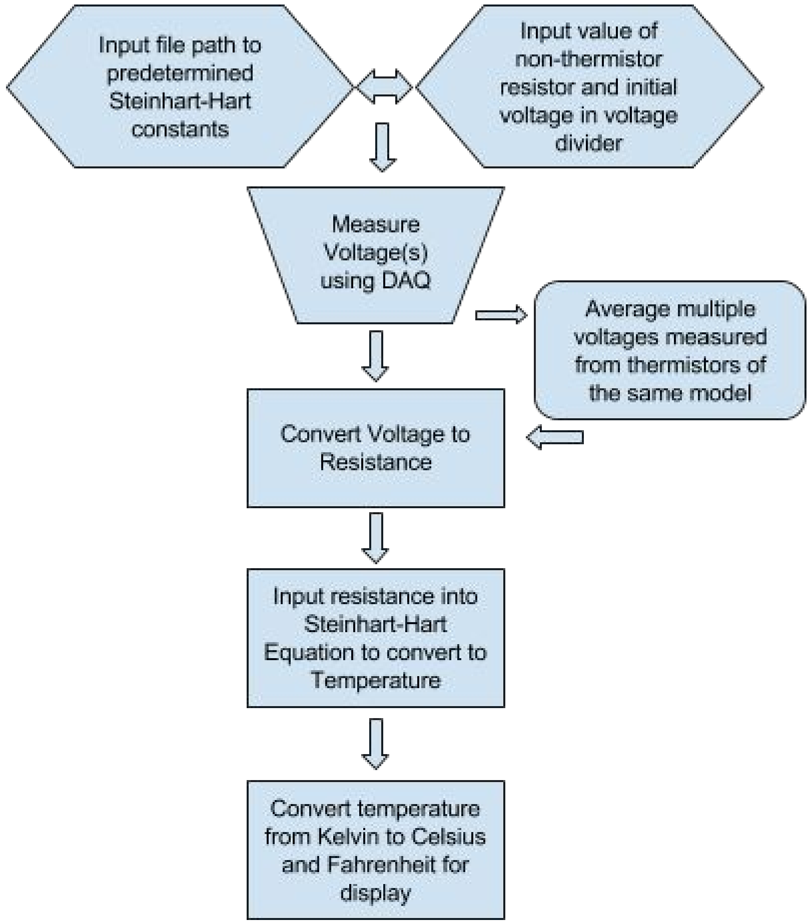
$$\begin{bmatrix} 1 & ln(R_1) & ln(R_1)^3 \\ 1 & ln(R_2) & ln(R_2)^3 \\ 1 & ln(R_3) & ln(R_3)^3 \end{bmatrix} * \begin{bmatrix} A \\ B \\ C \end{bmatrix} = \begin{bmatrix} 1/T_1 \\ 1/T_2 \\ 1/T_3 \end{bmatrix}$$

Once the constants have been calculated they will be used to display the T-R curve for the user to compare to the T-R curve generated from the manufacturer given Beta constant to ensure that a good calibration has been made. If the Steinhart-Hart constants derived from the measurements are good they can be saved to a file for future use in the Thermometer VI.



Part 2: Thermometer

The thermometer VI requires the previously determined constants for the thermistor and either the resistance of the thermistor or the voltage measured and initial components of the voltage divider (input voltage and value of the second resistor.) From this the temperature is calculated using the Steinhart-Hart equation and displayed in Kelvin, Celsius and Fahrenheit.



b. Design Rationale

The design is intended to require that the user only needs to calibrate the thermistor thermometer once, and from then on the constants may be loaded into the thermometer VI for as many uses as desired. Although it is somewhat labor intensive to find the Steinhart-Hart constants for each thermistor by measuring three temperature-voltage pairs, methods of self calibration proved to be beyond the scope of this project.

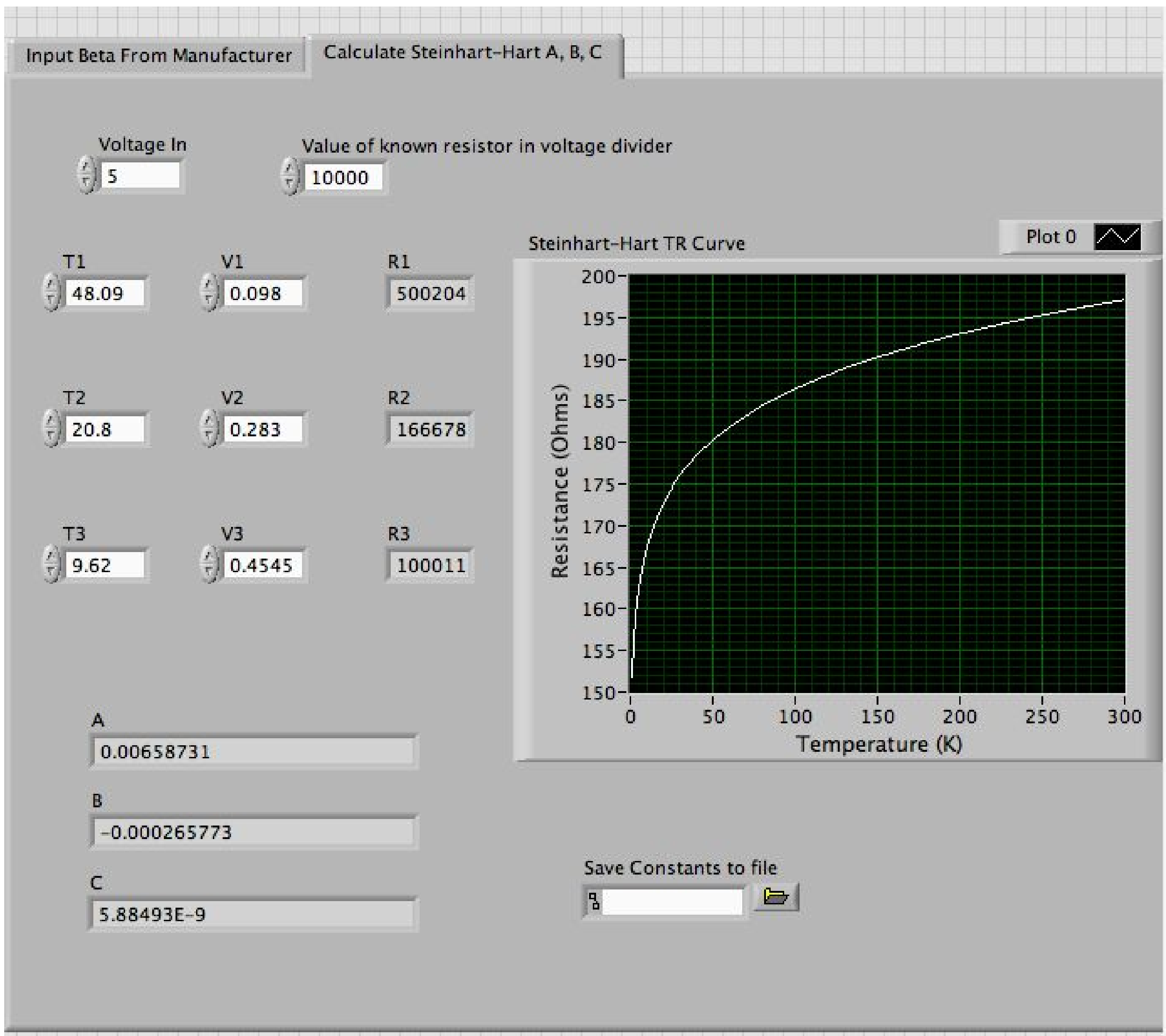
The final thermometer VI allows the user to use either a single thermistor or multiple thermistors averaged together to calculate temperature. This gives leeway for choosing simplicity or the potential for more accuracy.

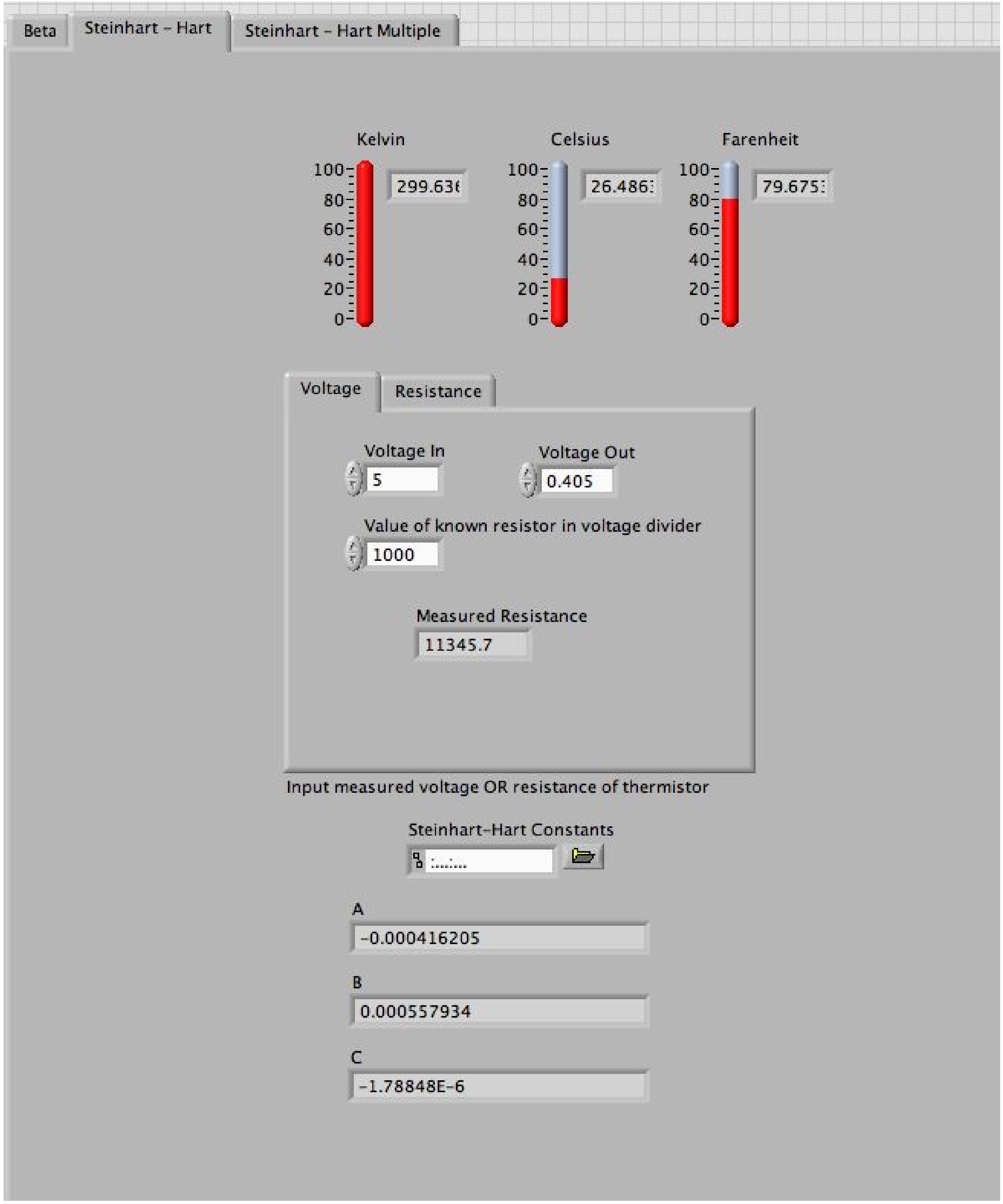
4. Human Interface Design

a. Overview of User Interface

The first time a thermistor is used in a thermometer it must be calibrated using the Steinhart-Hart and Beta VI. This VI requires the user to input three separate temperature and voltage measurements and also determine the file path in which to save the constants. The thermometer VI must be pointed at the predetermined constants, and gives the option of reading voltage from a DAQ and interpreting the resistance from the voltage divider information or manually inputting a resistance to get a temperature. Both VIs are designed to require the bare minimum from the user and all calculations take place behind the scenes.

b. Screen Images




Beta
Steinhart - Hart
Steinhart - Hart Multiple
Kelvin
299.636
Celsius
26.486
Farenheit
79.675
Voltage
Resistance
Voltage In
5
Voltage Out
0.405
Value of known resistor in voltage divider
1000
Measured Resistance
11345.7
Input measured voltage OR resistance of thermistor
Steinhart-Hart Constants
A
-0.000416205
B
0.000557934
C
-1.78848E-6