AUTOMATING TEMPERATURE CALIBRATION BATHS WITH SIMPLE LOW COST IMAGE ACQUISITION

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Abstract

A low cost video camera, "Web Cam" is used in conjunction with a PC and Temperature Calibration Bath to automatically calibrate handheld digital thermometers which have no provision to be connected to an external computer.

Introduction

Calibration of thermometers including the use of video cameras is not new. Various National Metrology Institutes have used analog and digital video cameras to calibrate Liquid in Glass (LiG) thermometers with the benefit of recording the information and helping to read the liquid column within the thermometers graduations [1]. The purpose of this paper is to describe a system using a digital low cost consumer camera to calibrate thermometers with a digital display that can only be recorded manually.

Method

The handheld thermometer is calibrated by comparing it against a reference probe at a series of temperatures. A calibration bath is used to automatically generate the desired calibration points by computer control. When the system is stable the temperature from the reference or standard thermometer is recorded to a log file; rather than the operator noting the value from the readout of the test thermometer a digital camera captures the display. This allows for unattended operation and lower calibration costs.

The software is then able to set the calibration bath to the next temperature and repeat the process. At the end of the calibration run a series of images are available which show the date and time the image was created and the images are captioned with the temperature of the standard probe.

Equipment

The system consists of

- I, A heat source (Isocal-6 Temperature Calibrator)
- II, A reference thermometer
- III, A PC with appropriate software
- IV, A Digital Camera
- V, To calibrate up to 16 RTDs or thermocouples multiplexers may be used

The heat source is an ISOCAL-6 Calisto model. The Calisto can be used in different modes. Here it is used a "Dry Block Calibrator" the reference probe and thermometer under test are placed into suitable pockets of a metal insert which is located in the Calisto's isothermal calibration volume. For higher accuracy requirements it would be possible to use the Calisto as a "Stirred Liquid Bath" as the Calisto is a multifunctional heat source with options for Dry Block, Liquid Bath, Blackbody and even ITS-90 Fixed Point Calibration. All the ISOCAL-6 models include a serial PC interface for monitoring and control from the PC.

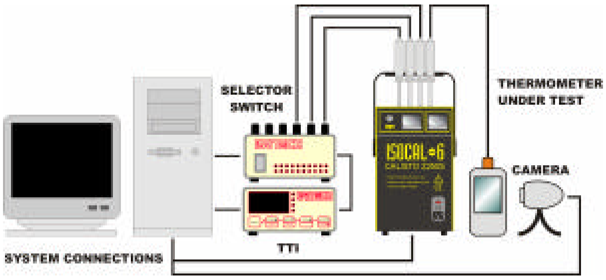
The standard probe is a platinum resistance thermometer which has been calibrated with an Isotech Model TTI-6 temperature indicator. The TTI-6 is a high precision portable thermometer it is particularly suitable as the reference standard for temperature calibration baths. Based on a high resolution Analogue to Digital converter, all measurement computations are performed digitally without drift. The 5 digit display provides a readout to 0.01ºC. The system uncertainty with the reference thermometer over the temperature range of the Calisto is 0.025°C. The indictor is connected to the PC via a serial interface.

Although most off the shelf cameras can be used the Intel PC Camera Pro was found suitable in that it has very good image quality and can focus down to 25mm. The device has a standard USB interface. Good results have also been obtained from other cameras including models from Logitech and Philips. All the cameras have the benefit of being low cost consumer items available from around 600 rand. The cameras simply plug into a standard USB port and require no additional hardware or complex configuration.

The software has the provision to calibrate resistance thermometers and a maximum of 16 can be connected to external selector switch or multiplexers, Isotech model 954.

Using an indicator that can read both thermocouples and RTDs increases the number sensor types that can be calibrated and there is a compatible thermocouple selector switch, model 958.

Other models of temperature baths can be used so that the system can cover temperature ranges from -75°C to 1300°C.



Software

The I-cal software sets the calibration bath to the first temperature and monitors the temperature controller, when the set temperature and the indicated temperature are within a user definable band for a chosen time period the software monitors the standard. The user can specify a number of samples and a variation, when the standard has met its criteria the data is logged from the instrument and an image is grabbed from the camera. This image is captioned with the actual temperature as measured by the reference thermometer and the image is saved to the PC with the file name consisting of the date and time of the capture.

Set Temperature

Monitor Bath for Stability

Monitor Standard for Stability

Acquire Image
Log Reference
Probe + Dry Block

The provision of the user being able to specify the stability criteria allows the use of different calibration baths and temperature ranges. For example the criteria for liquid bath would be smaller than the appropriate setting for a high temperature thermocouple calibration furnace.

The self documenting images can be verified against the computer log file which also contains

the value read from the TTI-6 along with the date and time.

The I-cal software allows for a number of images to be captured at each calibration point. These images can be examined to see if the display was stable during the unattended calibration.

I-cal also has provision to upload images to a local or remote server which allows the system to be monitored over a network or the internet. This has proven useful for monitoring equipment away from the laboratory and opens the possibility of future remote calibration.

Determining the Uncertainty

The measurement system, TTI-6 and Resistance thermometer have UKAS accredited calibration and the uncertainty can be taken from the calibration certificate.

The thermometer under test is compared to the TTI-6 and the Zeroth Law of Thermodynamics is relied upon in the assumption that the test thermometer and the standard thermometer are at the same temperature.

The Zeroth Law of Thermodynamics states , "If two systems are in thermal equilibrium, each having the same temperature as a third system, the two systems have the same temperature as each other".

For calibrating a thermometer in the Dry Block, the law could be written as, "If two thermometers are in thermal equilibrium, each having the same temperature as the Dry Block, the two thermometers have the same temperature as each other".

Each Calibration Bath will have special characteristics of temperature distribution in the block of the calibrator. If the Dry Block has a calibration certificate that specifies an uncertainty including the temperature distribution in the calibration area this value can be used.

The combined uncertainty of the system can then be established by combing the uncertainties of the standard and Dry Block using the RSS method.

$$Uct = \sqrt{u_{std}^2 + u_{db}^2 + u_{cnt}^2} \qquad (1)$$

Where

Uct = Combined System Uncertainty

u_{std} = Uncertainty of the Standard, TTI-6 and probe

u_{db}= Uncertainty of the Dry Block

u_{cnt} = Uncertainty of the connections

The uncertainty associated to the calibration remains controversial. Simplistically in the UK a UKAS accredited laboratory would include the uncertainty of the unit under test with the calibration uncertainty and specify this on the calibration certificate. Other laboratories may omit the uncertainty of the unit under test and state only their ability to create a know isothermal condition.

How to Estimate the Dry Block Uncertainty

If the Dry Block uncertainty is not known it must be calculated. The European co-operation for Accreditation (EA) has published Guidelines on the Calibration of Temperature Block Calibrators [2].

In general the largest uncertainty will be the vertical temperature distribution or <u>Axial temperature homogeneity along the boring in the measurement Zone.</u> This is usually the largest uncertainty source. Figure 1 illustrates this parameter.

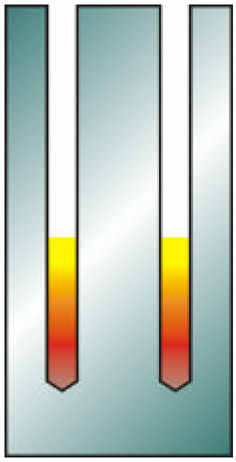


Figure 1

It will be most significant when the standard and the unit under test have different properties.

Figure 2 shows a thermocouple with short sensing length being compared to a resistance thermometer which has an internal sensing element of 15mm. The thermocouple is sensitive to changes in temperature from it's junction whilst the resistance thermometer will to a large extent integrate the temperature over its length.

The measurement zone should be specified by the manufacturer and should not be less than 40mm.

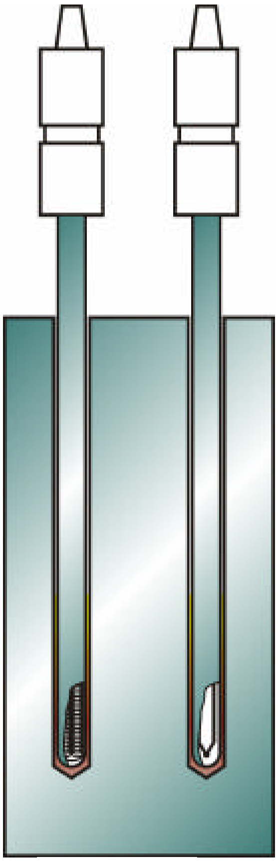


Figure 2

<u>Axial temperature homogeneity along the boring in the measurement Zone.</u> This is usually the largest uncertainty source.

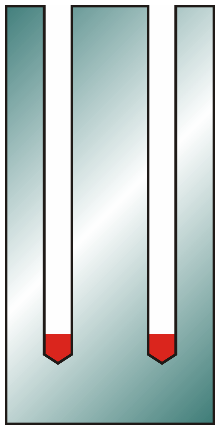
<u>Temperature differences between the borings</u>

For most type and brands of Dry Block this parameter is smaller than the axial homogeneity, see figure 3. This parameter can be measured relatively easily. A good method is to use two probes moving them between the pockets of interest and calculating the difference,

Dt, using: -

$$Dt = \tfrac{1}{2}\,[(TA1 - TA2) + (TB1 - TB2)] \qquad (2)$$

Figure 3



TA1 is Thermometer A in Pocket 1
TA2 is Thermometer A in Pocket 2
TB1 is Thermometer B in Pocket 1
TB2 is Thermometer B in Pocket 2

Influence upon the temperature in the measurement zone due to different Loading
This value is determined by taking measurements with different block loadings. Using an external reference thermometer (not the Dry Block's internal control sensor) reduces this effect.

Stability with time The variation with time of the Dry Block will introduce a further uncertainty. The effect will be most significant when the standard thermometer and the unit under test have different time constants. Stabilities of +/-0.02°C over 30 minutes are readily achieved with modern control techniques.

Temperature deviation due to heat conduction
There will be a flow of heat along the thermometer stem. As the difference between the environment temperature and the Dry Block temperature increases the error will proportionally increase. To minimize this effect, Stem Conduction or Immersion Error the thermometers need to be adequately immersed. For probes of 6mm and less the EA Guidelines state a minimum immersion depth of the thermometer to be calibrated is "at least equal to 15 times the outside diameter of the thermometer to be calibrated".

Other Uncertainty Sources

Uncertainty of the Standard Thermometer
Standard Thermometer including measurement with standard thermometer this can usually be taken from the calibration certificate.

Hysteresis The temperatures indicated may show a deviation due to hysteresis in cycles of increasing and decreasing temperatures. This can be ascertained by taking measurements as the temperature decreases after excursion to the maximum temperature.

Resolution The uncertainty due to the resolution of the device under test needs to be taken into account, the uncertainty contribution form the standard being included in the standards own uncertainty budget.

The uncertainty, Uct, is calculated by:

$$Uct = \delta t_{std} + \delta t_i + \delta t_R + \delta t_H + \delta t_B + \delta t + \delta t_V \qquad (3)$$

where:

Future Developments

δt_{std}	-	temperature of the reference thermometer derived from the resistance measurement including temperature correction and an allowance for drift since its last calibration
δt_i	-	temperature correction due to limited
δt_R	-	Temperature difference between borings
δt_H	-	temperature correction due to hysteresis in the increasing and decreasing branches of the measuring cycle;
δt_B	-	temperature correction due to axial inhomogeneity of temperature in the borings
δt_L	-	temperature correction due to differences in the loading of the block with thermometers to be calibrated
δt_V	-	temperature variations during the time of measurement.

It has been suggested that Optical Character Recognition and the support of multiple cameras would enhance the system. These could be implemented but it would move the project away from the starting point of a low cost general purpose system.

Conclusion

A simple low cost system has been built to capture data from indicators without a PC interface. Low cost consumer digital cameras can be used to perform automatic temperature calibration.

References

[1] C. Dawn Vaughn and Gregory F. Strouse THE NIST INDUSTRIAL THERMOMETER CALIBRATION LABORATORY National Institute of Standards and Technology, TEMPMEKO 01

[2] European co-operation for Accreditation (EA) EA-10/13 Guidelines on the Calibration of Temperature Block Calibrators, FEB 2000