OPTIMIZED AUTOMATIC CALIBRATION TOOL FOR FLIGHT TEST ANALOGUE PARAMETERS

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ABSTRACT

The calibration processes consume a big quantity of resources: equipment and people, time and cost. As the number of calibration points increase the resources increase in the same extent.

This automatic tool, aimed to reduce these resources, has been designed for commanding, managing and analyzing in real time a large number of acquired data points coming from the specimen under calibration and the standards used in the calibration process, applying at the same time the metrological algorithms which validate the calibration point. Its greatest achievement is the implementation of the rules for accepting or discarding the data point and the level of automation of the process.

In the last flight test campaign its usage has been crucial for providing on time the data with the high accuracy required. It was achieved the commissioning of almost 200 temperature parameters in a short period of time taking advantage of equipment which nominal accuracy was not high enough for their direct application.

Keywords: Calibration, Optimization, Flight Test

1. INTRODUCTION

In the last years the number of parameters extracted from digital sources in flight tests has increased significantly becoming a high percentage of the total parameter in the aircraft. In general, the effort necessary for implementing one of these digital parameters is considerably less than that for the equivalent analogue one, even more when this analogue parameter requires a dedicated particular calibration. In some cases the digital parameters have replaced the ones that used to be installed when digital world was not so widely implemented but not always, especially when the platform does not incorporates a big quantity of digital sources or when the test requires special characteristics of the parameter such as high sampling rate or fine accuracy.

Several scenarios can be present in the implementation and commissioning of these types of parameters: calibration of the sensor and the acquisition card, the calibration of the acquisition card only or the direct calibration of the whole measurement chain. These scenarios summarize the 99 per cent of the cases. Always the acquisition card has to be calibrated and not only as an acceptance procedure but as a calibration process. So, in this context, this paper will focus on the tool developed in Airbus Defence and Space FTI department for doing automatically analogue acquisition card calibrations.

As required by the calibration processes, it must be performed following the stated metrological standards. In our case, in addition to the procedures stablished by the company [2], [3] it is followed the criteria marked in the GUM [1], used by accredited International Laboratories of Metrology (e.g. BIPM, CEM, PTB, NIST….).

2. JUSTIFICATION OF THE METHOD

Let us start introducing the instrumentation systems used for flight tests, in particular when analogue parameters are acquired. The system core is the data acquisition system (DAS), composed of cards that condition and acquire the signal coming from the sensors. The DAS outputs the data through Ethernet, packeted complying with IENA protocol. The data are available in the network for recording, monitoring, analysing and transmitting if necessary.

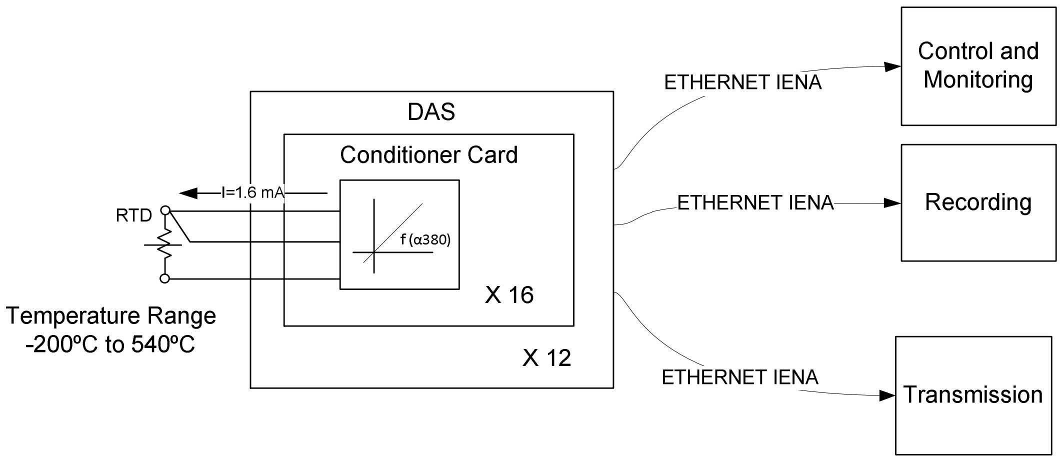

Figure 1: It depicts the instrumentation system; in particular the measurement chain for temperature.

When measuring, it is essential to know the reliability of the measure, not only the measurement value must be provided but also its uncertainty. The uncertainty of a measurement is obtained from the proper composition of the measurement chain element uncertainties. The way to compose them is detailed in the GUM [1]. There, it is stated how to obtain the measurement uncertainty depending on the information that is available.

The uncertainty can be obtained using directly the information given by the manufacturer of the elements, which is normally called the nominal values, or calibrating them. Both procedures are exactly valid in the same degree but they do not normally give the same uncertainty value.

When the uncertainty obtained using the nominal values of the element it is not enough for the trial, calibration of the element is required.

Purpose of the calibration:

- ✓ Improve the metrological characteristics of the instrument.
- ✓ Identify and quantify the credibility of the measure.
- ✓ Ensure that the measurement obtained is traceable to the primary pattern.
- ✓ Get a precise relationship between the magnitude of measurement and instrument unit. That is, obtaining the BSL: Best Strait Line.
- ✓ Identify the range within which the measure will be found with a probability of 95%, if instead of measuring with the test instrument you have measured with the primary standard. This range is called "*measurement uncertainty*" and is represented as U.
- ✓ Get the calibration certificate that gives evidence of the quality measurement and provides information that allows limiting the validity of the data obtained in the trial.

In general the calibration is an activity that requires special equipment and expertise. The objective seems to be difficult when there are many elements to calibrate and it should be done with limited resources and time. However, using the method and tool that is explained from now on, we will see that it is possible to comply with the metrological quality criteria stated and within the required time. Moreover, as a result of it, it is possible to use acquisition cards whose re-adjustment period recommended by the manufacturer has expired, thereby optimizing available resources.

3. CALIBRATION TOOL

The calibration system necessary to address the task is made of the acquisition system which channels are going to be calibrated, a multiplexer that switches channel by channel and the control application that commands the actions, analyses the data and makes the decisions regarding the validity of the calibration point.

This particular case consists of the calibration of 192 temperature acquisition channels. It will be done using a standard temperature simulator which will be connected sequentially to all the channels that are going to be calibrated.

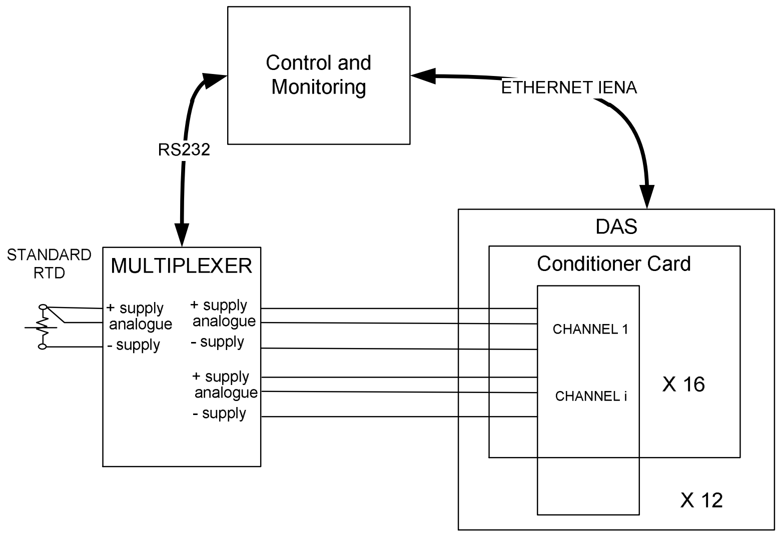

Figure 2: It shows the configuration of equipment to perform the calibration.

The calibration system is designed to be able to address a high number of RTD conditioning channels to the calibration standard device. For doing so it is necessary to integrate into the acquisition chain a multiplexer that allows selecting channels automatically.

The acquisition of the calibration points will be performed in three steps:

- ✓ The conditioner channel is addressed by means of the multiplexer through a RS232 serial line.
- ✓ The setpoint of the simulated temperature is set by the RTD standard through a RS232 serial line.
- ✓ The value read in the channel corresponding to the simulated temperature is put through ETHERNET.

Theoretically, we have to acquire sequentially all the necessary setpoints defined for the calibration of one channel. When that channel is finished the control would direct the process to the following channel and so on up to calibrate all of them.

This ideal process is not so simple or direct. It is necessary to wait for the stabilization of both, the setpoint and the measure. The identification of the stabilized moment, of when the acquired information is valid, is one of the key points of this method. These validation criteria will result in the reduction of the time of selection of setpoints and the channels switching, optimizing the calibration. To stablish the validation criteria, the study has focus on the evolution of the measure in both ways, the transition between setpoints and the stabilization of it.

<u>Validation of setpoint.</u>

The usual calibration process consists of acquiring a number of samples per setpoint, when the standard value in the setpoint is valid, and obtaining from those samples the significant parameters of the setpoint; in particular the mean and standard deviation of the setpoint. Depending on the quantity of samples acquired for a particular setpoint the values of the significant parameters will be more or less reliable. In one hand, acquiring many points will give greater reliability in the measurement, but on the other hand, it will increase the calibration time.

As stated before, two of the aims of the calibration are obtaining the calibration coefficients (BSL coefficients) and the uncertainty of the measurement. For getting both it is necessary to have a number of samples enough for giving reliability to the calculations. The number of samples will depend, in one hand on the equipment accuracy and on the other on the number of setpoints required.

When changing from a setpoint to the following the acquired samples will be as in figure 3. There are two clear zones that will have influence in the measurement result:

- ✓ Zone A: This area represents the transition with overshoot and damping. Samples in this area are not valid for the calibration point. There is no certainty of anything here. Neither the value of the standard nor the values acquired from the channel could be stable.
- ✓ Zone B: This area represents the stabilized signal, where only the instrument accuracy has influence. All is stabilized and the variability corresponds only to the uncertainty.

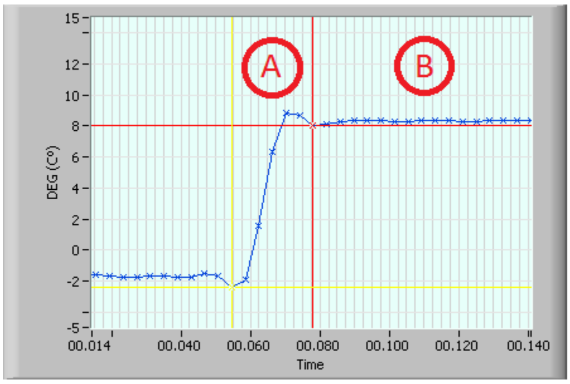

Figure 3: Samples before and after the transition from 0ºC to 10ºC is represented.

Accordingly, to validate the setpoint will be necessary to identify the samples acquired in the transition in order to discard them. Once it is identified the stable area, it must be acquired a number of samples to calculate the mean and standard deviation needed for the calculations. The area "B" represents the instrument accuracy, defined as the ability of the instrument to repeat the measurement result when it is applied to it the same amount of magnitude. In Figure 4 is shown with more detail the dispersion of measures for 10°C, the zone B in figure 3.

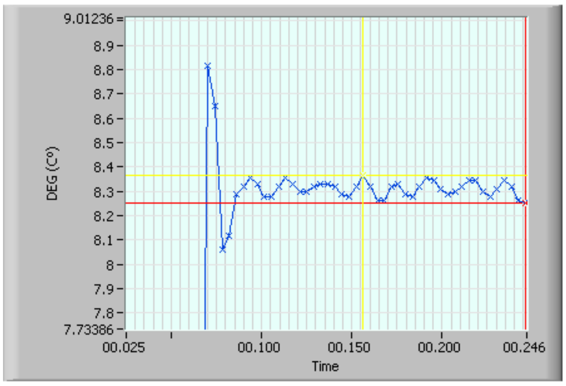

Figure 4: Zone B. The dispersion of measures for 10°C.

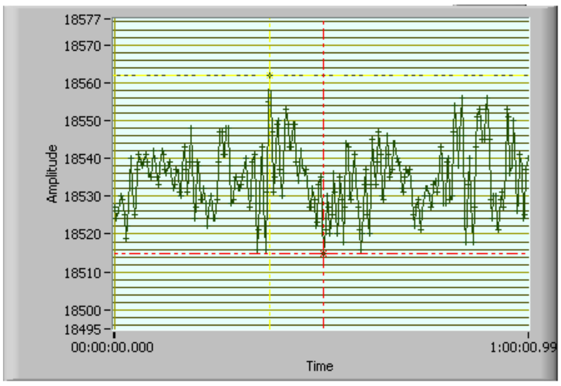

Figure 5: Zone B Dispersion for 10°C in instrument units given in number of converter of 16 bits.

Making a continuous acquisition and representing the probability function of the samples acquired it is obtained Figure 6.

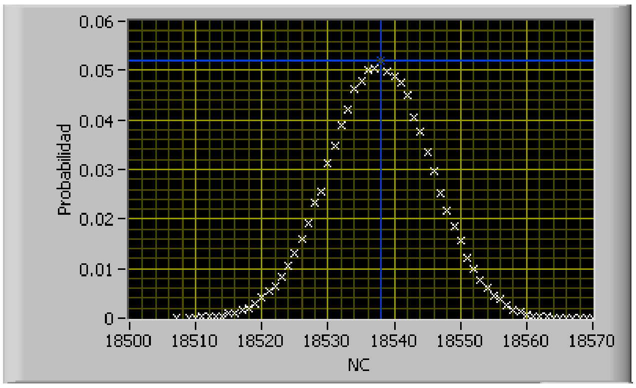

Figure 6: Probability function of the samples acquired.

Figure 6 shows that the probability function follows a normal distribution, this means that it could be used the usual statistical tool. The problem arises with the number of samples necessaries, since a small number, may not be representative, while a high number will make the calibration slower. The number of samples used in Figure 6 is 106.000, knowing that they are acquired to 256 s/s, the validation time could reach 7 minutes. This result forced to seek a method to validate the setpoint more efficiently.

For doing so, to calculate the mean and standard deviation of the set point, we will use 100 samples, filling a shift register of 100 elements, so that all samples will pass from the first position to the last, after which it will be discarded. The register is divided into five blocks with 20 samples each. Each time a sample is entered and the displacement is performed, the mean and standard deviation for each group of 20 samples is calculated. The values are passed to a validation module where the data are evaluated, aiming to fulfil the validation criteria which identifies and discards transients and states where the measure has not been yet stabilized. In the Figure 7 it is shown the block diagram.

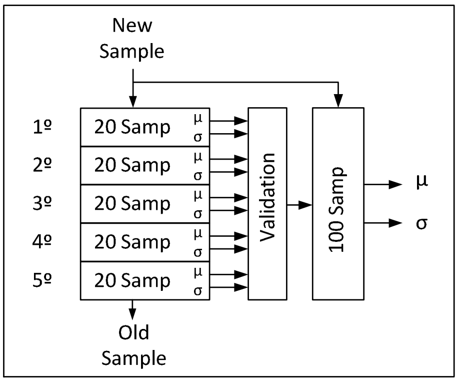

Figure 7: Shift register and validation criterion.

The validation criterion consists of finding a representative set of samples of a stable measure. For it, in the set of selected samples must be guaranteed:

- ✓ The average value should not follow an increasing or decreasing function.
- ✓ In each setpoint, the noise should be uniform.

This criterion allows obtaining a significant set of samples and gives information about possible failures in the acquisition channel, such as thermal drifts or interferences that affects to the quality of the measure. This information would lead to discard the module.

4. CALIBRATION CALCULATIONS

In this application all the channels are calibrated from -200ºC to 540ºC. It will be acquired 22 setpoints. Two of them correspond to the maximum and minimum range points, the rest of 20 are distributed uniformly between 90% and 10% of the range. The validation of setpoint is performed according to exposed in this article while the information is as followed:

- ✓ Best Straight Line (BSL) coefficients: m and b. Obtained according to the following expression:

$$y = mx + b \tag{1}$$

Where:

$$m = \frac{n\sum_{i=1}^{n}(x_i y_i) - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \tag{2}$$

$$b = \frac{\sum_{i=1}^{n} x_i^2 \sum_{i=1}^{n} y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n}(x_i y_i)}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \tag{3}$$

Where x_i and y_i are the measured values in the same sample and n is the number of samples.

- ✓ Combined uncertainty of measurement (Uc). Calculated following the guidelines in the GUM. The expression is composed by the following contributions:

$$U_c = \sqrt{U_1^2 + U_2^2 + U_3^2 + U_4^2} \tag{4}$$

Where: U1 is the uncertainty calibration of the standard device from its certificate of calibration ucc, corresponding to a normal distribution function or Gauss.

$$U_1 = \frac{u_{cc}}{2} \tag{5}$$

Where: U2 is the uncertainty from the samples. It is given by the experimental standard deviation of the mean, normal distribution function. To estimate the standard deviation of the data from a sample, i.e., a set of observations of a particular magnitude taken under the same conditions, the experimental standard deviation σ (x) is used.

$$\sigma(x) = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{(n-1)}} \tag{6}$$

The best estimate of experimental standard deviation, it is the experimental standard deviation of the mean:

$$U_2 = \sigma(\bar{x}) = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n(n-1)}} \tag{7}$$

Where: U3 is the uncertainty calculated from the maximum error in absolute value obtained from the residues of the Best Straight Line (BSL), treated as a rectangular distribution function:

$$U_3 = \frac{|MaxErrorBSL|}{\sqrt{3}} \tag{8}$$

Where: U4 is the uncertainty due to the quantification error of converter of data acquisition system card, treated as a rectangular distribution function:

$$U_4 = \frac{(QuantizitationError / 2)}{\sqrt{3}} \tag{9}$$

- ✓ Expanded Uncertainty U. Is the result of multiply the combined uncertainty by a coverage factor K.

$$U = \pm K \times U_c(y) \tag{10}$$

For a coverage factor K = 2 the probability of containing the true value is 95%.

$$Y - U \leq TrueValue \leq Y + U \tag{11}$$

Where Y is the measured value.

5. CONCLUSION

For those trials where the digital sources do not provide the parameters with the characteristics that the tests require, for those where the number of analogue parameters is very high and the resources for coping with their commissioning are limited, it is compulsory to find solutions that give the possibility of having available the results in a short of period of time, keeping the balancing between "Quality - Time - Cost".

Taking into account that increasing the resources, would increase the cost exponentially, it is necessary to reduce the calibration time used, the data acquisition and analysis as well as in documentation generation.

The automation of the calibration is mandatory, but not enough; we have to include validation criteria that allow having a significant number of samples, with a low acquisition time. In this particular case, this criterion is applied to 192 conditioning and measurement channels of RTD's PT100 temperature sensors. The comparative time is:

- ✓ Manual calibration: 150 hours
- ✓ Automatic calibration: 80 hours
- ✓ Automatic calibration with validation algorithms: 45 minutes.

6. ACKNOWLDGEMENTS

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7. REFERENCES

[1] Guide to the expression of Uncertainty in Measurement, JCGM, 2008

[2] Quality Procedure DP-000-021, Airbus Defence & Space. Internal Document, 2009.

[3] Standard CASA-1294, Airbus Defence & Space. Internal Document, 2014.

8. GLOSSARY

BSL: Best Straight Line.
BIPM: Bureau International des Poids et Mesures.
CEM: Centro Español de Metrología.
DAS: Data Acquisition System.
GUM: Guide to the expression of Uncertainty in Measurement.
IENA: Installation d'Essais pour les Nouveaux Avions
JCGM:Joint Committee for Guides in Metrology
PTB: Physikalisch-Technische Bundesanstalt.
NIST: National Institute of Standards and Technology.
RTD: Resistance Temperature Detector.