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Performance Analysis of Automatic SPRT Module Calibration

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Abstract— **This paper aims to present a performance analysis of automatic calibration system of the standard platinum resistance thermometer module. The automatic method is based on the use of low thermal matrix scanners. Calibration results obtained from the automatic technique are compared with the results gotten by the conventional manual technique. The t-test, statistic hypothesis method, is used to assess whether the results of two techniques are statistically different from each other. The paired t-test analysis results show that there is no difference at the 95% confidence level. This confirms that the automatic technique using low thermal matrix scanner can be effectively employed. Moreover, it provides several advantages such as reduced errors caused by manual operation, reduced operating time, reduced paper usage, saving in labor cost, and obtaining benefits of electronic documents.**

Keywords— **SPRT Module, Low Thermal Matrix Scanners (LTMS), Automatic Calibration, Hypotheses Test**

I. Introduction

In conventional method based on manual operations, the process of the SPRT (Standard Platinum Resistance Thermometer) module calibration takes long time and requires all employees' participation in the entire calibration process. It also requires an expert for calculating the results and measurement uncertainty. In order to minimize these limitations, an automatic technique for use in the calibration of SPRT is introduced. This proposed technique is based on the use of LTMS (Low Thermal Matrix Scanners) to interface between the SPRT module and standard resistors. However, the literature describes a technique for design and implementation of the calibration system and shows the calibration results with uncertainty only.[1]

The aim of this paper, therefore, is to analysis the performance of the automatic calibration technique proposed in for verifying its workability. In order to ensure that using LTMS to implement the automatic calibration can provide calibration results which are similar to the results achieved from the manual calibration procedure done by the expert. The statistic hypothesis method called t-test is employed to assess whether the results of automatic and manual calibration methods are statistically different from each other.

II. AUTOMATIC CALIBRATION METHOD

The SPRT module is an instrument which is usually connected to the thermometer readout for reading data from the SPRT in the digital format. In general, the calibration of the SPRT module is conducted by connecting standard resistors with the SPRT module for reading data by the thermometer readout. Then the precision of the SPRT module is analyzed and further reported in the format of calibration results included with measurement uncertainty.[2-4]

Based on manual operations, the calibration process starts from setting instrument parameters. The operator must check the instrument for readiness. After that, a standard resistor is connected with SPRT module for manually reading and recording the resistance values. The recorded data are used to calculate the errors, means, and uncertainty according to the standard of calibration. Unfortunately, the above calibration procedure is done for one standard resistor only. This means that the operator must take long time to perform the calibration process for all standard resistors used. Normally, it takes about 5 hours to complete the calibration process for 5 standard resistors. However, the time for reporting the results is not added. This implies that the report of calibration results could be obtained on the next day. For minimizing these limitation caused by manual operations, the LTMS is used to interface between the SPRT module and standard resistors for providing automatic calibration process as shown in Fig. 1 [1].

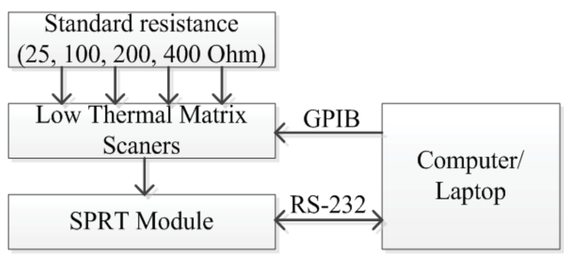

Fig. 1 Automatic SPRT module calibration.

From Fig. 1, a computer is employed to control operations of the entire system. The SPRT module and LTMS are connected to the computer via RS-232 and IEEE-488(GPIB), respectively. The LTMS provides multi-channel connectors to interface with standard resistors. The software for automatic reading and recording the values of standard resistors of the SPRT module as well as automatic reporting the results is developed by the authors [1].

Table I. Shown specification of 4210A automated LTMS. Standard resistors wiring to an automated LTMS as shown in Fig.2(a), and connection automated LTMS to SPRT module as shown in Fig. 2(b).

TABLE I
SPECIFICATION OF 4201 AUTOMATED LTMS.

Operation	Four Terminal Matrix
Thermal EMF's	< 50 nanovolts
Error Contribution	< 20 nanovolts
Contact Configuration	Relay - Two Coil Latching
Contact Resistance	<0.05 Ohms
Expected Relay Life	10^8 Operations
Insulation Resistance	$>10^{12}$ Ohms

(a) (b)

Fig. 2 The connection of LTMS to the SPRT module.

The automatic calibration system of the SPRT module can reduce the operation time of calibration from 5 hours, excluding time of recalibration, to 8 minutes which is the time for setting the program, connecting RS-232 cable with the thermometer readout, and linking GPIB (IEEE-488) cable to the automated LTMS. It also saves labor used in the calibration process, as well as reduces the complicated procedures that can cause errors in calibration. Time to wait for the process does not occur. A calibration program can be placed in advance to optimize the use of the standard. Lastly, this proposed method is easy to use and suitable for anyone inexperienced in calibration.

III. PROPOSED PERFORMANCE ANALYSIS

A. Hypothesis test

In some cases it is possible to pair the measurements. One member of each matched pair comes from one value or characteristic of a variable or design, and the other member of each pair comes from the other characteristic, but everything else is nearly the same (as closely as possible) for the two members of the pair. For example, we might have one member of each pair from an experimental type of equipment and the other member from a standard type. Aside from the variable used to form the pairs, factors which might have appreciable effects must be kept as constant as possible. We try to match the two items forming a pair. Randomization should still be used to minimize interference from other factors. Then the difference between the members of a pair becomes the important variable, which will be examined by a test of significance using the t-distribution. Is the mean difference significantly different from zero?[5].

This technique blocks out the effect of interfering variables. It is called a paired t-test or a t-test using a matched pair. Because both methods is how to calibrate SPRT module alike, but different in that the method presented has the equipment LTMS into the system to control input with SPRT module. Our approach uses t-test to compare the average of the two that were significantly different at 95% confidence level or not.

B. Hypotheses Tests for a Difference in Means, Variances Unknown

We now consider tests of hypotheses on the difference in means $\mu_1 = \mu_2$ of two normal distributions where the variances σ_1^2 and σ_2^2 are unknown. A t-statistic will be used to test these hypotheses. Two different situations must be treated. In the first case, we assume that the variances of the two normal distributions are unknown but equal; that is, $\sigma_1^2 = \sigma_2^2 = \sigma^2$. In the second, we assume that and are unknown σ_1^2 and σ_2^2 not necessarily equal.

Suppose we have two independent normal populations with unknown means μ_1 and μ_2, and unknown but equal variances $\sigma_1^2 = \sigma_2^2 = \sigma^2$. We wish to test.

$$H_0 : \mu_1 - \mu_2 = \Delta_0$$
$$H_1 : \mu_1 - \mu_2 \neq \Delta_0 \quad (1)$$

Let $x_{11}, x_{12}, \ldots x_{1n1}$ be a random sample of n_1 observations from the first population and $x_{21}, x_{22}, \ldots x_{2n2}$ be a random sample of n_2 observations from the second population. Let $\overline{x_1}$, $\overline{x_2}$, S_1^2 and S_2^2 be the sample means and sample variances, respectively.

It seems reasonable to combine the two sample variances S_1^2 and S_2^2 to form an estimator of σ^2. The pooled estimator of σ^2 is defined as follows.

$$S_p^2 = \left(\frac{(n_1-1)s_1^2 + \left((n_2-1)s_2^2\right)}{n_1+n_1-2} \right) \quad (2)$$

Has a t distribution with $n_1 + n_2 - 2$ degrees of freedom (ν). The test statistic is

$$t_0 = \frac{(\bar{x}_1-\bar{x}_2)-(\mu_1-\mu_2)}{S_p\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} \quad (3)$$

The rejection criterion H_0

$$t_0 > t_{\alpha/2,\nu} \quad (4)$$

or

$$t_0 < -t_{\alpha/2,\nu} \quad (5)$$

The use of this information to test the hypotheses in Eq.(1) is now straightforward simply replace $\mu_1 - \mu_2$ by Δ_0, and the resulting test statistic has a t distribution with $n_1 + n_2 - 2$

degrees of freedom under $H_0 : \mu_1 - \mu_2 = \Delta_0$. Therefore, the reference distribution for the test statistic is the t distribution with $n_1 + n_2 - 2$ degrees of freedom.

The location of the critical region for both two and one-sided alternatives parallels those in the one-sample case. Because a pooled estimate of variance is used, the procedure is often called the pooled t-test. [6]

IV. EXPERIMENTAL RESULTS

In experiments, all equipment for calibration, as shown in Fig. 3. Start a manual calibration step A., and record the results in Table II.

Upon completion of this step, the process of automatic calibration step B and record the results in Table II., as well.

A. *Calibration procedure*

1) Manual calibrate procedure:

1.1) Standard resistor connected directly to the SPRT module Fig. 3(a).

1.2) Connect the standard resistor 25 Ω controlled temperatures at 23 °C with SPRT Module.

1.3) Read and record the number of SPRT Module 60 time. The result shown in Table II.

1.4) Change standard resistor 100, 200 and 400 Ω to steps 1.2 respectively.

2) Automatic calibrates procedure:

2.1) Connect the standard resistor with Low Thermal Matrix Scanner to SPRT Module show in Fig. 3(b).

2.2) Start the LTMS to scan input at 25 Ω.

2.3) Read and record the value of the SPRT Module 60 time. The result shown in Table II.

2,4) The LTMS scan input to the standard resistor 100, 200, and 400 Ω to steps (2) respectively.

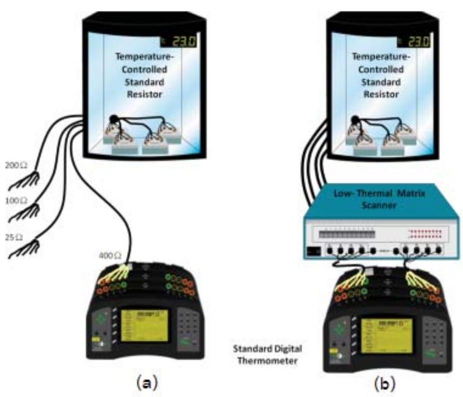

Fig. 3 Comparison between manual and automatic calibrations of the same SPRT module.

B. *Numerical Illustration.*

For an illustrative example, we consider standard resistor 25 Ω as shown in Table II., and the sample means and sample variances for all resistor as shown in Table III.

Table II.
RESULUT OF THE MANUAL AND AUTOMATIC CALIBRATIONS

Example : Resistor 25 Ω		
No.	Manual	Automatic
1	25.00025	25.00019
2	24.99993	25.00028
3	25.00036	24.99978
:	:	:
60	25.00005	25.00009

Table III.
RESULT OF THE SAMPLE MEANE AND SAMPLE VARIANCES

R	Manual		Automatic	
(Ω)	$\bar{x}_1$	S_1^2	$\bar{x}_2$	S_2^2
25	25.000119	1.84726E-08	25.0000751	1.48695E-08
100	99.999328	1.14607E-07	99.999298	1.40845E-07
200	200.000273	4.54192E-07	200.000326	4.14531E-07
400	399.999290	2.91176E-06	399.999541	2.94857E-06

C. *Result of t-test*

From Table III, we can calculate the value of t_0 according to equation 2 and 3, the result as follows.

$$S_p^2 = \left(\frac{(60\text{-}1)1.84726\text{E-}08 + \left((60\text{-}1)1.48695\text{E-}08\right)}{60 + 60\text{-}2}\right)$$

$$S_p^2 = 1.6671\text{E-}08$$

$$t_0 = \frac{(25.000119 - 25.0000751) - 0}{1.2911\text{E-}4\sqrt{\frac{1}{60} + \frac{1}{60}}}$$

$$t_0 = 1.880657$$

From t-distribution table is used to find the t-value such that $t_{\alpha/2,v}$ ($t_{0.025,118}$) approximately 1.98

Table IV.
RESULTS OF T-TEST

standard resistor (Ω)	t – stat (t_0)	t – critical ($t_{\alpha/2,v}$)
25	1.8806	1.9803
100	0.4598	1.9803
200	-0.4432	1.9803
400	-0.8053	1.9803

Conclusions: Since $-1.98 < t_0 = 1.88 < 1.98$, the null hypothesis cannot be rejected. That is, at the 0.05 level of significance, we do not have strong evidence to conclude that manual calibration results in a mean yield that differs from the mean yield when automatic calibration is used.

In this study, all of the experiments we use Excel program to calculate the value of t_0(t Stat), which reduces the computation time and accuracy in the experiment. The results were summarized in Table VI to VIII are as follows.

Table V.
RESULTS OF T-TEST FOR STANDARD RESISTOR OF 25 Ω

	Variable 1	*Variable 2*
Mean	25.0001195	25.00007517
Variance	1.84726E-08	1.48695E-08
Observations	60	60
Pooled Variance	1.6671E-08	
Hypothesized Mean Difference	0	
Df	118	
t Stat	1.880657019	
P(T<=t) one-tail	0.03124184	
t Critical one-tail	1.657869523	
P(T<=t) two-tail	0.062483679	
t Critical two-tail	1.980272226	

Table VI.
RESULTS OF T-TEST FOR STANDARD RESISTOR OF 100 Ω

	Variable 1	*Variable 2*
Mean	99.99932833	99.99929833
Variance	1.14607E-07	1.40845E-07
Observations	60	60
Pooled Variance	1.27726E-07	
Hypothesized Mean Difference	0	
df	118	
t Stat	0.459771711	
P(T<=t) one-tail	0.323263043	
t Critical one-tail	1.657869523	
P(T<=t) two-tail	0.646526085	
t Critical two-tail	1.980272226	

Table VII.
RESULTS OF T-TEST FOR STANDARD RESISTOR OF 200 Ω

	Variable 1	*Variable 2*
Mean	200.0002733	200.0003267
Variance	4.54192E-07	4.14531E-07
Observations	60	60
Pooled Variance	4.34362E-07	
Hypothesized Mean Difference	0	
df	118	
t Stat	-0.443234597	
P(T<=t) one-tail	0.32920381	
t Critical one-tail	1.657869523	
P(T<=t) two-tail	0.65840762	
t Critical two-tail	1.980272226	

Table VIII.
RESULTS OF T-TEST FOR STANDARD RESISTOR OF 400 Ω

	Variable 1	*Variable 2*
Mean	399.99929	399.9995417
Variance	2.91176E-06	2.94857E-06
Observations	60	60
Pooled Variance	2.93017E-06	
Hypothesized Mean Difference	0	
df	118	
t Stat	-0.805267288	
P(T<=t) one-tail	0.211142556	
t Critical one-tail	1.657869523	
P(T<=t) two-tail	0.422285113	
t Critical two-tail	1.980272226	

V. CONCLUSIONS

Performance analysis by comparison with the manual calibration of the same SPRT module as shown in Fig. 3. Tables 4 give the analysis results obtained from t-test when calibrating the SPRT module with standard resistors of 25 Ω, 100 Ω, 200 Ω, and 400 Ω, respectively. From all Tables 5-8, the values of t Stat are less than the values of t Critical two-tail, for example 1.8806 < 1.9803, it is shown that there is no difference at the significant level of 95% between two calibration results. This confirms the efficiency of the automatic calibration technique.

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