XIX IMEKO World Congress
Fundamental and Applied Metrology
September 6–11, 2009, Lisbon, Portugal

DEVELOPMENT OF AN AUTOMATIC CALIBRATION SYSTEM FOR CLINICAL ELECTRICAL THERMOMETERS

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Abstract – An automatic test system for clinical electrical thermometers was developed to enhance the efficiency of error tests. Besides the temperature measurement unit, mechanical drive and machine vision units were designed to implement automatic tests. An uncertainty analysis was also presented. According to the special measurement action of clinical thermometers, the Monte Carlo method was used to evaluate the uncertainty. The accuracy of recognition of indications was greater than 99% in experiments.

Keywords: calibration system; clinical electrical thermometer; CCD

1. INTRODUCTION

Clinical electrical thermometer is one of the substitutes of mercury thermometer and has been used widely in hospitals and homes. As a temperature measurement device, electrical thermometer should comply with the request of maximum permissible errors [1-3]. The same tests for error are taken in factory laboratories before electrical thermometers go to the market, in hospitals at regular intervals and in administrative departments for measurement. A specialized water bath for clinical thermometer calibration has been reported by Pusnik [4]. Another problem concerned in this paper is the amount of test work is huge especially in factories and hospitals. To improve efficiency, an automatic test system for clinical electrical thermometer was developed.

Water bath and reference thermometer are necessary in both manual acting and automatic systems. In addition, movements of thermometers rely on PLC controller and mechanical drive, and acquirements of thermometer's readings are accomplished through the use of CCD camera and programs of image processing and character recognition in automatic systems. All units of the system are coordinated by a master computer. So system can complete a test cycle automatically, i.e. control water bath to reference conditions, immerse the tested thermometer into water bath, raise the thermometer from water, read the indication of reference thermometer from digital multimeter and of tested thermometer from its LED screen, compare the indicators, and finally generate test report.

2. SYSTEM

The structure of the system is showed in Fig.1. It involves three functional units: water temperature measurement and control unit, mechanical control and transmission unit, and machine vision unit. These units communicate with the upper computer and make up a coordinated system.

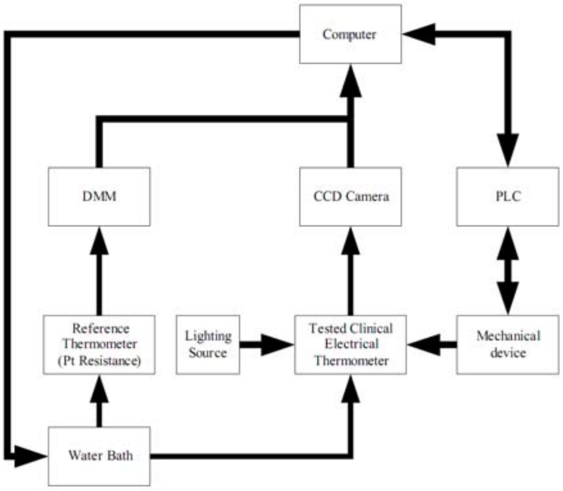

Fig. 1. Diagram of the automatic test system for clinical electrical thermometers

2.1. Temperature Measurement and Control Unit

This unit provides a stable temperature field for calibration, and measures the value of this temperature. It consists of water bath, temperature controller, traceable Pt resistance thermometer, digital multimeter (DMM) Agilent 34401A and computer.

Standards usually give several reference temperature points to test thermometer which are 35.00℃, 36.00℃, 37.00℃, 38.00℃, 40.00℃ and 41.50℃ according to GB/T 21416. So the first task of this unit is to make the temperature of water reach the reference value and have a specified stability. The closed loop is constructed as shown in Fig.2.

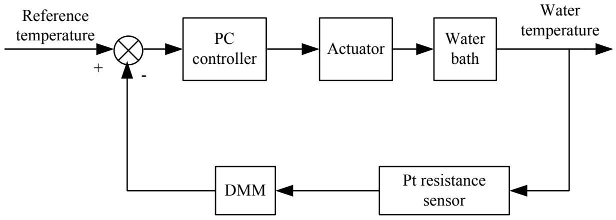

Fig.2. Temperature control diagram

In the loop, standard Pt resistance is treated as a sensor. The resistance is measured by DMM and sent to computer. The value of temperature calculated by interpolation method is compared with the reference value; and then the difference is used to control the actuator heat or refrigerate through PID method.

The second task of this unit is to determine the temperature of water bath when it is stable. The result is used to calculate the error of tested thermometer from the following expression:

$$e = t_{\mathrm{i}} - t_{\mathrm{wb}} \tag{1}$$

where

t_{i} is the temperature indicated at the thermometer to be tested and;

t_{wb} is the temperature of the water bath determined with the reference thermometer.

2.2. Mechanical Drive Unit

Mechanical drive device is designed for two reasons: 1) when measuring temperature, the electrical thermometers must be immersed into water bath; then they are raised up to aim the indication to CCD camera. 2) Considering the efficiency, several thermometers are clamped on the mounting bracket so they can be tested in one time. A mechanical device is needed to bring every thermometer to the camera in proper order.

The vertical movement of bracket and thermometers are driven by a steam cylinder. Programs in PLC control a solenoid valve to decide whether the cylinder pulls the bracket up or pushes it down and how long it moves.

A stepper motor is used to rotate the bracket when it is raised. Hall approach switches are mounted on the side of the CCD to determine the locations of thermometers. When a thermometer is rotated in front of the CCD, Hall approach switches send a signal to the PLC controller, then PLC stops the motor so CCD can take pictures of the indication. The pictures are sent to the upper computer which will give a message to the PLC after the receptions. Receiving computer's message, the PLC drives the motor to locate the next thermometer. The system repeats this process until every thermometer's picture is taken.

2.3. CCD Indication Reading Unit

Different from most instruments in lab, the measurement results of electrical thermometers don't have a form of electrical signals. The CCD reading unit takes the role of human's eyes. TEC M55 lens and MTV-1881EX-3 CCD image sensor are used as camera. Signals from CCD are sent to image acquisition card NI PCI-1411 and are translated to gray image which can be processed by computer.

The series of steps are taken by computer to process images and recognize indications, as shown in Fig.3.

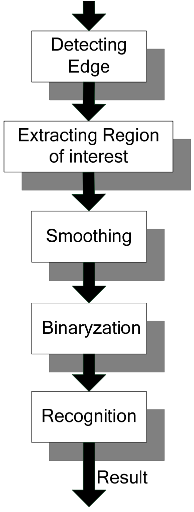

Fig.3. Steps of image processing and results from the steps

The first step is detecting edges in gray image, which is used to determine the region that contains the indication and to extract the region. The next steps are smoothing the image of extracted region and transforming it to a binary image. The steps mentioned above are useful to enhance the accuracy and reduce the amount of computation of the recognition. In the recognition step, the processed binary image is cut into several segments. Each segment contains only one character. The segments are compared with a template library to determine the numbers they represent.

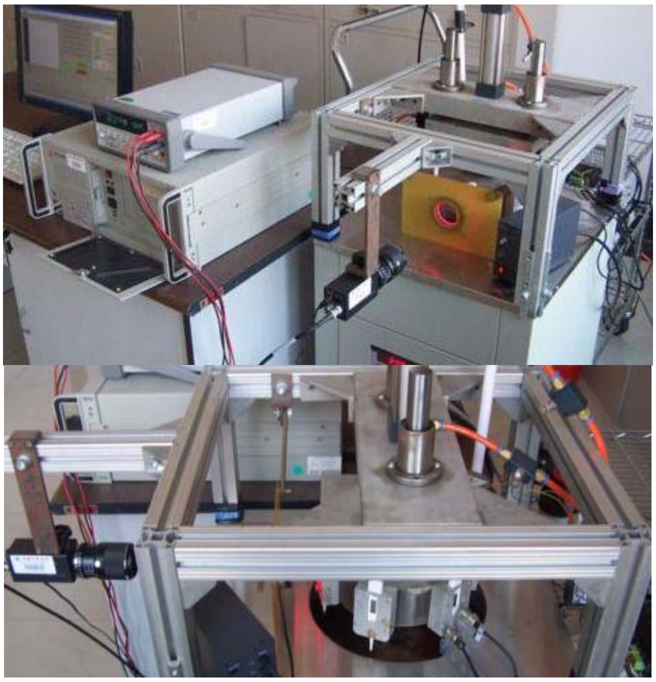

Fig.4. Pictures of the automatic calibration system

3. SOFTWARE

Units mentioned in Section 2 are coordinated by the software in upper computer, which is designed in LabVIEW environment. The operation steps are shown in Fig.5.

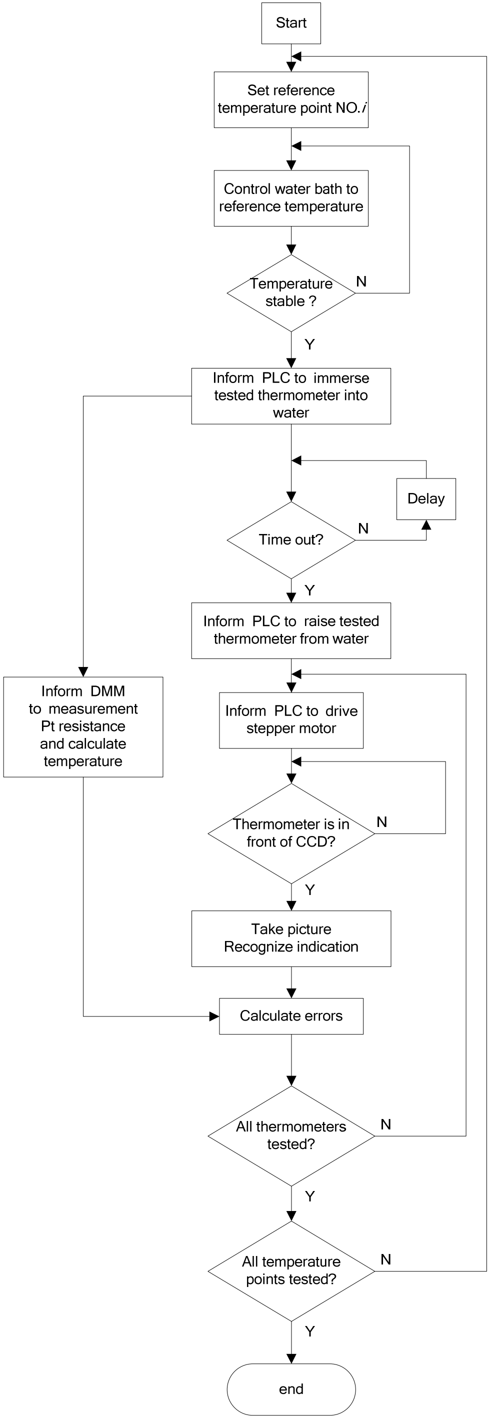

Fig.5. Flow chart of the software

4. UNCERTAINTY

If the system is for calibration, the uncertainty of the measurement result should be given in report. Calculation and analysis of the uncertainty is discussed in this section.

4.1. Calculation

At each reference temperature value, a correction calculated by equation (1) is given to the tested thermometer. The standard uncertainty of the correction can be given by standard deviation of the samples.

$$u = \sqrt{\frac{\sum_{i=1}^{N} e_i}{N-1}} \qquad (2)$$

where

N is the number of the independent observations.

4.2. Analysis

The model used to evaluate the uncertainty of the correction δ*t* is given by

$$\delta t = t_s + \delta t_1 + \delta t_2 - G(t_x) + \delta t_3 + \delta t_4 \qquad (3)$$

where t_s is the temperature measured by the standard Pt resistor, δt_1 the correction corresponding to the change of triple point value of the Pt resistor, δt_2 the correction corresponding to the error introduced by the DMM, δt_3 the difference in temperature between standard and tested thermometer caused by temperature fluctuation, δt_4 the difference caused by inhomogeneous distribution of the temperature, and $G(t_x)$ the reading of the tested clinical thermometer.

The reading $G(t_x)$ of the clinical thermometer is obtained by the following steps:

1) acquire samples of temperature t_x, here the sampling rate is 1kHz and the duration is 5min;
2) find maximum value of the samples;
3) round the maximum value to 1 decimal place;
4) output the indication $G(t_x)$.

Table 1. Probability distribution functions assigned to the quantities

	Distribution	Parameter(℃)				Degree of freedom
		a	b	μ	σ	
t_s	Gaussian			37	0.002	5
δt_1	Rectangular	-0.0007	0.0007			12
δt_2	Rectangular	-0.0029	0.0029			50
δt_3	Arc sine	-0.0075	0.0075			2
δt_4	Rectangular	-0.005	0.005			12
t_x	Gaussian			37	0.1	5

When the test point is 37℃, each quantity on the right of (3) can be assigned a distribution except for $G(t_x)$. It is difficult to assign a usual distribution function to $G(t_x)$. However, a Gaussian distribution can be assigned to the quantity t_x . In such a case, the Monte Carlo method (MCM) is employed to implement the propagation of the distributions.

10^4 trails were taken by the Monte Carlo procedure. The results of δ*t* are shown in Fig.6; and the probability density function (PDF) is shown in Fig.7. The expectation of δ*t* is -0.47℃ and the standard uncertainty *u*(δ*t*) is 0.049℃.For 95% coverage probability, the shortest coverage interval is calculated to be [-0.518, -0.394].

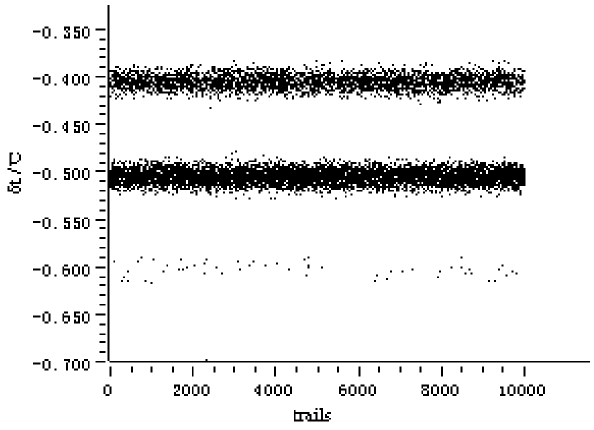

Fig.6. Results for δ*t* with MCM

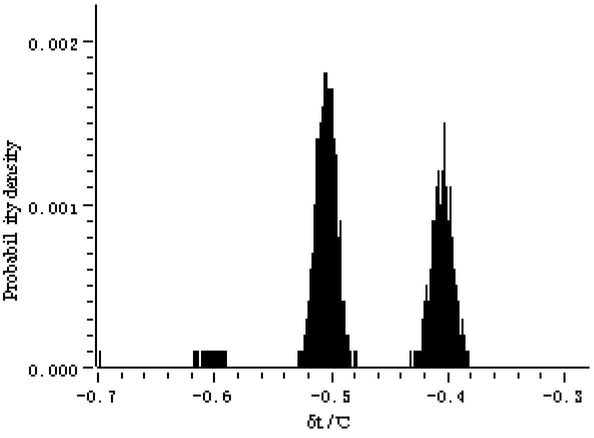

Fig.7. The PDF for δ*t* with MCM

. The PDF for δ*t* is multimodal, which is mainly caused by step 3 in obtaining $G(t_x)$. Decreasing the sampling rate in step 1 or improving the accuracy of clinical thermometer will be helpful to make the PDF close to unimodal. Smaller standard uncertainty and shortest coverage interval may be obtained with a unimodal PDF.

5. CONCLUSION

An automatic test system for clinical electrical thermometers is developed. Lab experiments show that it can enhance the test efficiency greatly, and the accuracy of recognition of indications is greater than 99%.

Future works include: 1) improve the accuracy of recognition and develop a self-adapting lighting source; 2) make the system miniaturized.

ACKNOWLEDGMENTS

This work was supported by the National Special Research Programs for Non-Profit Trades (Quality Supervision, Inspection and Quarantine) (No. 2007GYJ016).

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