Elektrotehniški vestnik 68(4): 225–230, 2001
Electrotechnical Review, Ljubljana, Slovenija

Methods of Reading Liquid-in-Glass Thermometers

Valentin Batagelj, Jovan Bojkovski, Janko Drnovšek, Igor Pušnik
University of Ljubljana, Faculty of Electrical Engineering, Laboratory of Metrology and Quality, Tržaška 25, 1000 Ljubljana, Slovenija
E-mail: valentin.batagelj@fe.uni-lj.si, jovan.bojkovski@fe.uni-lj.si

Abstract. The objective of this paper is to analyse the different methods of reading Liquid-in-Glass Thermometers (LiGTs). The aim is to minimise uncertainty contributions in calibrations of LiGTs and make them easier to use. The inherent problem of the LiGTs is the objectivity of reading and hence the resulting uncertainty contribution. Most commonly, LiGTs are read with the naked eye or by using a magnifying glass. These are classified as subjective methods. Major improvements could be achieved by using specially designed stereoscopes. A stereoscope and standard platinum resistance thermometer together represent the reference standard in calibration of precise LiGTs. The entire procedure is considered as the reference method. As a new method, a CCD camera with specially developed image processing software is introduced. It combines the objectivity of the stereoscope readings and automation of LiGT measurements and calibrations.

Key words: reading of analogue instruments, LiGT, calibration, temperature, uncertainty of reading

Metode odčitavanja tekočinskih termometrov

Povzetek. Cilj tega članka je analizirati različne metode odčitavanja tekočinskih termometrov za minimiziranje prispevka negotovosti pri kalibraciji tekočinskih termometrov in poenostaviti njihovo uporabo. Inherentni problem tekočinskih termometrov je subjektivnost odčitavanja in iz nje izvirajoča negotovost odčitavanja. Ponavadi se tekočinski termometri odčitavajo s prostim očesom ali s pomočjo povečevalnega stekla. To sta subjektivni metodi. Bistveno izboljšanje pomeni uporaba posebej modificiranega stereoskopa, ki predstavlja referenčni standard, celotni postopek pa je referenčna metoda. Kot nova metoda je predstavljeno odčitavanje s CCD kamero in posebej razvito programsko opremo za obdelavo slike. Ta metoda združuje objektivnost odčitkov s stereoskopom in možnost avtomatizacije odčitavanja tekočinskih termometrov.

Ključne besede: odčitavanje analognih instrumentov, tekočinski termometri, kalibracija, temperatura, negotovost odčitavanja

1 Introduction

Liquid-in-glass thermometers (LiGTs) are analogue measuring instruments, where the height of the liquid column inside a glass stem is proportional to the exposed temperature. LiGTs are one of the earliest forms of thermometers, [1]. They have been developed for the use in the range from -190 °C up to 600 °C, including the measurement of temperature differences with a resolution down to a milikelvin. LiGTs are still very popular because of the chemical inertness of glass, good long-term stability at the same uncertainty level and reasonable price. The main disadvantage of LiGTs, as with most analogue measuring instruments, is the lack of any communication interface with a computer and thus the lack of possibilities to automate the measurement.

LiGTs can be calibrated with uncertainties from a few milikelvins up to a few degrees centigrade, mostly depending on the scale division and thus reading of a LiGT, [2, 3]. The reading is usually done with the naked eye or with the help of a magnifying glass. Other methods include specially designed stereoscopes and use of cameras together with image processing algorithms. In this paper we assume that all other uncertainty sources are well known and we highlight only a problem related to the uncertainty that is caused by the reading of a LiGT. A special emphasis is also given to the objectivity of reading with the different methods.

2 Reading With the Naked Eye

The basic method of reading LiGTs is reading with the naked eye. If one tries to read a temperature of a LiGT (Fig. 1) with the naked eye as precisely as possible, without any additional help, the readings are dispersed. An observer might read to one third of the scale division, while another just one quarter or even to one fifth of the scale division. The sight ability is an objective reason of influence on readings by different observers.

If one wants to remain realistic in making a pre-

Received 6 March 2001
Accepted 1 October 2001

Figure 1. Reading of a LiGT with the naked eye

cise reading without trying to overestimate the reading, a LiGT can be read with the naked eye up to one third of the scale division.

3 Reading With a Magnifying Glass

A possible improvement in reading LiGTs is the use of a magnifying glass. With a help of a magnifying glass one can estimate a reading within one quarter up to one tenth of a scale division, depending on a magnifying factor and distance between scale markings. But those readings are mostly biased and very dependent on the one who reads the temperature. For example, if a liquid column is somewhere between 22,12 °C and 22,14 °C, as shown in Fig. 2, an observer can read 22,13 °C while another observer can read 22,135 °C. Even skilled observers are not consistent. They tend to favour certain numbers in making estimates.

Figure 2. Reading of a LiGT with a magnifying glass

Again, if one wants to remain realistic in making a precise reading, without trying to overestimate the reading, LiGTs can be read up to one fifth of the scale division, [4, 5].

4 Reading With a Stereoscope With Special Lenses

An improvement can be obtained by using a specially designed stereoscope. A medical stereoscope used horizontally, not vertically, with a focal distance of 400 mm and the ten times magnification turned out to be suitable for the purpose of precisely reading LiGTs. In addition, a regular ocular was replaced with a special ocular with the lens, which has an engraving on it with ten major equidistant markings and ten additional minor markings between major markings. One is able to use these additional markings to uniquely and objectively read a thermometer, without any prejudice.

As illumination, cold-light sources should be used, which produce intensive, yet heat-free illumination. The infrared component of a light bulb has to be removed by a filter and the remaining visible light is directed via flexible light guides to a LiGT. With the use of such illumination, possible influences of the heat of a light bulb on the temperature of a LiGT are minimised.

By adjusting the magnification of the stereoscope, one is able to fit five additional scale markings inside one scale division of the LiGT used as an example, as in Fig. 4. It is possible to take the reading at one half of these additional scale markings, so one can take a reading at one tenth of a

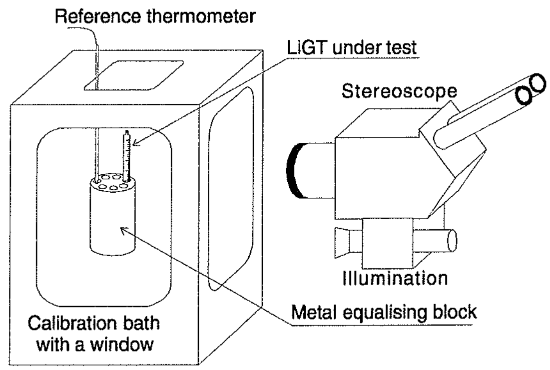

Figure 3. Measuring system for reading LiGTs with a stereoscope

LiGT scale division. This particular LiGT's scale division being 0,02 °C, the reading is possible with the resolution of 0,002 °C. It is important to realise that this reading is not an estimate, it is an objective, metrologically correct reading, independent of observer's skill, ability or other influences.

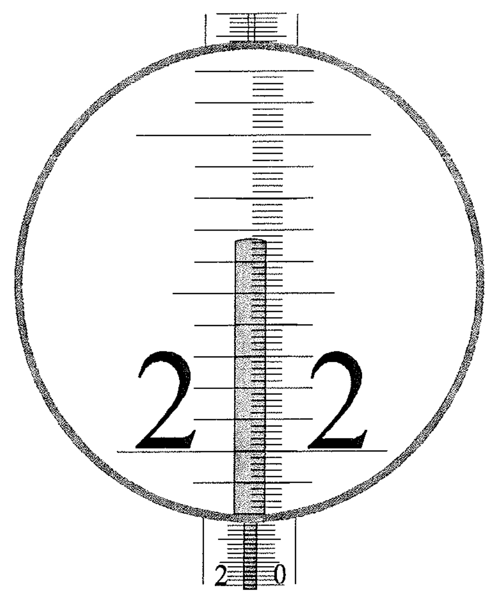

Figure 4. Reading of a LiGT with a stereoscope

5 Reading With a Camera and Image Processing Software

Reading of a LiGT with a CCD camera is commonly used in calibration laboratories, but only as an optical aid and sometimes as a method for permanent storing of acquired readings. Novelty in reading a LiGT using a camera is specially developed image processing software, which combines the objectivity of readings and automation of data processing, [6]. Such a measuring system is presented in Fig. 5.

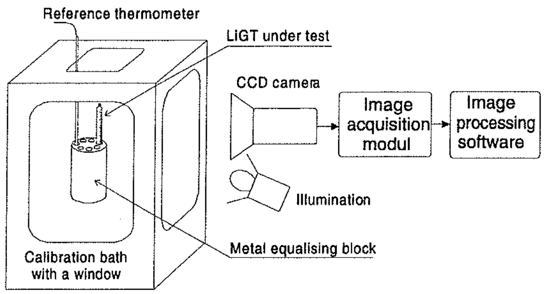

Figure 5. Measuring system for reading LiGTs with a CCD camera and image processing software

A LiGT is placed in a typical calibration setup consisting of a calibration bath with a window, metal equalising block and reference thermometer. The measuring system for reading a LiGT consists of a black & white analogue CCD camera, illumination, image acquisition module and image processing software. Camera lenses must provide good magnification at a required distance from a LiGT under observation. An image with good contrast and without reflections or shadows is achieved by appropriate placement of a cold-light source. When the LiGT is placed into the equalising block inside a calibration bath, the camera position has to be adjusted so that the top of the liquid column is visible in the image. The image acquisition module converts an analogue camera signal into digitised eight-bit greyscale images. These images are then transferred to a computer, where the image processing and analyses take place, resulting in the temperature reading of the observed LiGT.

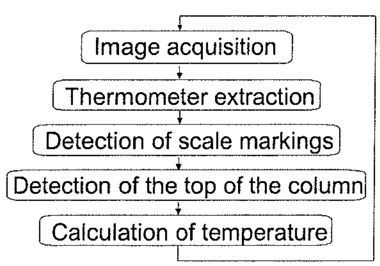

Figure 6. Algorithm for automatic reading of temperature of the LiGTs

The algorithm that determines the temperature reading from the acquired image of a LiGT is presented in Fig. 6. The only input data for this algorithm is the acquired image of a thermometer, as in Fig. 7.

The program first locates the exact position of the thermometer in the image. If the thermometer is not in a strict upright position, as in Fig. 7, the necessary image rotation

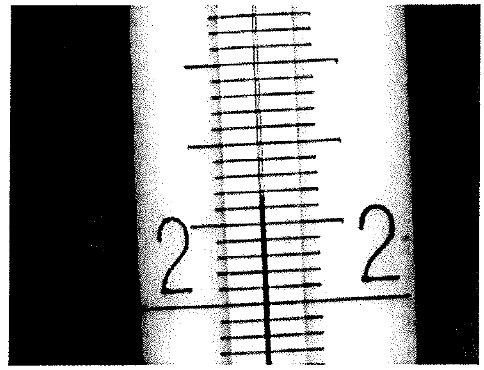

Figure 7. Original image as acquired from the camera

is performed. This makes the placement of the thermometer in a bath much more flexible. An input image can now be reduced to the image of the thermometer itself, as in Fig. 8.

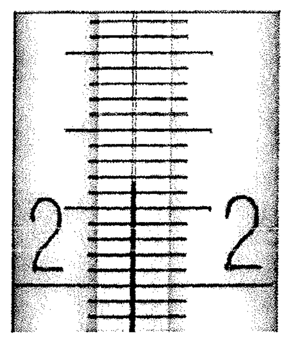

Figure 8. Reduced image containing the image of the thermometer in the upright position

One of the most important parts of the program is the recognition of the thermometer scale. The exact position of the individual scale markings must be determined. If the recognition of some markings is too ambiguous due to reflections, overlaying numbers or pieces of dirt, the program ignores the information extracted from the image and interpolates the missing value based on the properly recognised markings. The principle of the scale recognition is shown in Fig. 9. The vertical profile of the image is calculated by averaging pixel values in each row of the image. The resulting curve shows well visible valleys that match the position of each scale marking. To recognise the thermometer scale, the algorithm must find the exact position and depth of each valley. The main scale markings are recognised based on the depth of a valley that corresponds to the width of a scale marking. To get the complete scale information, it is necessary to manually input the LiGT scale division and the base of the LiGT scale. The base of the LiGT scale is the temperature of the first major scale division in the image (e.g. the scale division is 0,02 °C and the scale base is 22 °C for LiGT in Fig. 9).

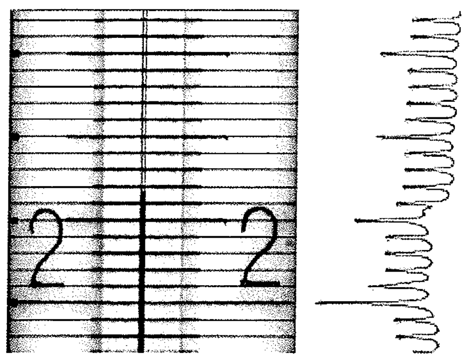

Figure 9. Recognition of the thermometer scale. The thermometer image is presented with recognised scale markings and the thermometer vertical profile

The temperature reading of a LiGT is determined by the length of the liquid column. To measure the length of the column, the thermometer image is first reduced to the part where the column is positioned. Digital filtering is then applied to remove undesired objects such as scale markings, numbers, random dark spots, etc. This filtering must not change the length of the column as this would directly result in a change of reading and hence fake measurements. The result of this image processing is shown in Fig. 10. A vertical profile of this image is then calculated and the position of the step determines the length of the column. Figure 10 clearly shows that in spite of some minor irregularities in the image (thin white strip at the left top of the column, etc.), the step in the vertical profile is clear enough to produce a reading with the uncertainty of one or two pixels.

Once the position and the temperature value of individual scale markings and the position of the top of the liquid column are determined, the temperature reading can be calculated by using a simple equation that interpolates the position of the top of the column between the two closest scale markings. The digitally magnified part of the thermometer, containing the top of the column, is shown in Fig. 11. Two recognised scale markings and the position of the top of the column are marked with lines. Additional lines are added uniformly between the scale markings to ease any manual check of this automated reading.

The image between the two scale markings has a typical resolution of approximately 25 pixels. The positions of the scale markings and the position of the top of the column can be read with the uncertainty of one or two pixels. Although this is a limiting factor, this is not the dominating source of error. If the top of the column is positioned just above a scale marking, software can not distinguish between the column and the marking. This error can be as large as one half the width of the scale marking. It represents the uncertainty limit of this method and can only be eliminated with application of special illumination techniques.

Figure 10. Thermometer column after image processing with the column vertical profile

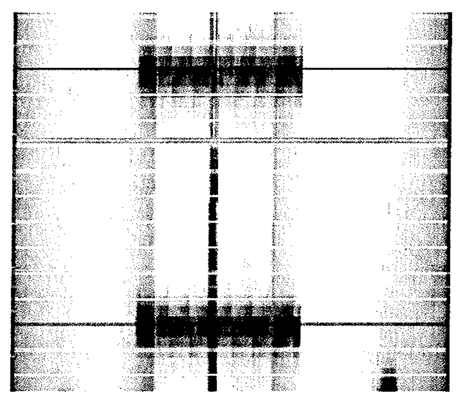

Figure 11. Magnified part of the image containing the top of the liquid column with two recognised scale markings and ten additional subdivisions

As can be seen in Fig. 11, the temperature of the thermometer can be read up to a tenth of the scale division. It is important to stress that this is an objective reading and not an estimation dependent on the skill and effort of an observer.

Another important advantage is that the reading of the thermometer can be stored in its natural way by saving the image of the thermometer as in Figure 7.

6 Experimental Results

For the sake of the experiment, the reading with the naked eye and with a help of a magnifying glass is classified as a subjective method. The reading with a stereoscope and camera is classified as an objective method. Experiments were conducted with a high precision mercury LiGT with 0,02 °C scale division in the temperature range from 15 °C to 30 °C. LiGT was placed in the calibration bath, filled with water. The calibration bath had a window used for observation of the LiGT. A metal equalising block was used to improve temperature stability and homogeneity, [7]. The LiGT had to be placed into a hole of the equalising block and the top of the column had to be visible through the window. Rotation of the LiGT is usually necessary, because most LiGTs can only be read at a certain angle. An observer must take readings perpendicularly to LiGTs to avoid the parallax. Two different experiments were performed to verify the presented methods of reading.

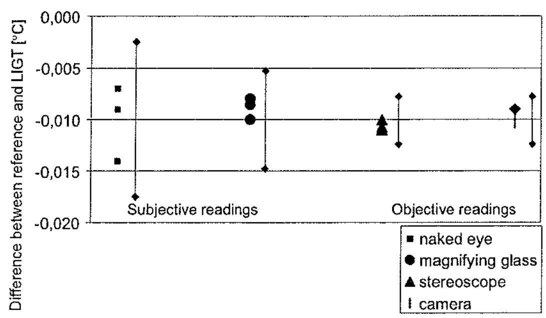

Figure 12. Results of the LiGT reading with the different methods

First we performed readings of the LiGT in the calibration bath at a constant temperature. Three readings were taken following each method by two experienced and one inexperienced observer. A reference thermometer (platinum resistance thermometer) was used to compensate for the influence of unavoidable temperature variations of the bath. Readings are presented in Fig. 12 as the difference between the temperature of the reference thermometer and the observed LiGT. Vertical lines represent the uncertainty of reading for each method. Uncertainty of reading is calculated using Eq. (1):

$$u_4 = d_s \frac{1}{n} \frac{2}{\sqrt{3}}, \quad (1)$$

where d_s is the LiGT's scale division, n is the number of subdivisions and $2/\sqrt{3}$ is added due to the rectangular distribution, [8]. As expected, the inexperienced observer made large errors with subjective methods, but also the readings of the experienced users were dispersed within the stated uncertainty. The readings with the objective methods however did not exhibit any difference between the experienced and the inexperienced observers. The readings were less dispersed and this dispersion might also be caused by other sources.

In the second experiment we performed four complete calibrations of the same LiGT, each time using a different method of reading. The procedure for calibration of LiGTs was relatively simple in comparison to the other types of thermometers. The LiGT and the reference thermometer were placed in the calibration bath and their readings were compared. Differences of readings at several temperature points were fitted to a polynomial function and the uncertainty of calibration was calculated. The uncertainty sources included repeatability of measurements u_1, inhomogeneity of the calibration bath u_2, the uncertainty of reference thermometer u_3 and uncertainty of reading u_4. Total uncertainty u was calculated as the geometric sum of all uncertainty contributions:

$$u = \sqrt{u_1^2 + u_2^2 + u_3^2 + u_4^2}. \quad (2)$$

One of the largest uncertainty contributions is represented by the uncertainty of reading. The uncertainty of reading depends on the LiGT scale graduation and on the possibility to objectively divide each scale division into a number of subdivisions. This may be accomplished by the use of advanced methods of reading of LiGTs, such as the use of a stereoscope or a camera with image processing software.

Table 1 shows all uncertainty contributions for the LiGT presented in the previous chapters. The uncertainty of reading and consequently the total uncertainty is greatly dependent on the method of reading, but that improvement of uncertainty is not as important as improvement in trustworthiness of this reading. In precise measurements, one has to avoid estimates and make reliable measurements.

7 Conclusion

In the presented paper current methods of reading of LiGTs are analysed. Besides analysing two frequently used subjective methods, two additional methods of objective reading of LiGTs are proposed. With minor modifications these methods can be applied to many other instruments with analogue reading.

The reading with a modified stereoscope represents the reference method of reading of analogue instruments. The reading can be typically performed at one tenth of the scale division and it can be classified as an objective reading, because the reading is obtained with the aid of an auxiliary scale inside the stereoscope. The stereoscope also allows estimation of the meniscus of the liquid column inside a stem and examination of a thermometer for irregularities, foreign materials and air bubbles inside the stem. Reading with the stereoscope is quite time consuming and the price of the apparatus is high.

The second method of objective reading is the use of a camera with image processing algorithms. The readings are taken at one tenth of a scale division, which is the same as with the stereoscope reading. Reading is auto-

	Subjective methods		Objective methods	
	naked eye	magnifying glass	stereoscope	camera
Repeatability u_1	0.010 °C	0.0042 °C	0.0033 °C	0.0033 °C
Inhomogeneity u_2	0.002 °C	0.002 °C	0.002 °C	0.002 °C
Reference standard u_3	0.0025 °C	0.0025 °C	0.0025 °C	0.0025 °C
Uncertainty of reading u_4	0.0077 °C	0.0047 °C	0.0023 °C	0.0023 °C
Total uncertainty u	**0.013 °C**	**0.007 °C**	**0.005 °C**	**0.005 °C**

Table 1. Uncertainty calculation for different techniques in calibration of LiGTs

mated; the observer must only adjust the system at the beginning of the reading sequence. This method also allows permanent storage of readings in the form of thermometer images as shown in Fig. 7. The whole system is considerably less expensive compared to the stereoscope system and most of the system value is in the custom made image processing software. On the other hand, the camera does not allow detailed inspection of the thermometer meniscus and the stem due to the limited spatial resolution and the dynamic range of the image.

8 References

[1] J. V. Nicholas, D. R. White, *Traceable Temperatures*, John Wiley & Sons, 1994.

[2] J. A. Wise, R. J. Soulen, *Thermometer Calibration*, U. S. Department of Commerce, 1986.

[3] J. Drnovšek, J. Bojkovski, I. Pušnik, *Quality manual*, FE, University of Ljubljana, 1996.

[4] J. Bojkovski, I. Pušnik, J. Schramm, V. Batagelj, J. Drnovšek, Precise Reading of Liquid-in-Glass and Analog Indicating Thermometers, *Proceedings of the TEMPMEKO 1999*, vol. 1, pp. 263-267, 1999.

[5] V. Batagelj, J. Bojkovski, I. Pušnik, J. Drnovšek, Automation of reading of liquid-in-glass thermometers, *IMTC/2000: proceedings of the 17th IEEE Instrumentation and Measurement Technology Conference*, vol. 1, pp. 299-303, 2000.

[6] *IMAQ Vision for G*, National Instruments, 1996.

[7] J. Drnovšek, J. Bojkovski, I. Pušnik, Analysis and Modelling of Equalising Blocks, *Instrumentation Science & Technology*, vol. 26, no. 5, pp. 491-501, 1998.

[8] European Accreditation, Publication reference EAL-R2, *Expression of the uncertainty of measurement in calibration*, Edition 1, April 1997.

Valentin Batagelj was born in Postojna, Slovenia, in 1975. He received his B.Sc. degree in Electrical Engineering in 1998 from the Faculty of Electrical Engineering of the University of Ljubljana. In November 1998 he became a Research Staff Member at the Laboratory of Metrology and Quality at the same faculty, where he is presently a postgraduate student and is working towards his M.Sc. His current research interests are automation of measuring systems in calibration laboratories, objective reading of analogue instruments and temperature calibrations.

Jovan Bojkovski was born in Belgrade, Yugoslavia, in 1970. He received his B.Sc. degree in Electrical Engineering in 1994 from the Faculty of Electrical Engineering of the University of Ljubljana. In October 1992 he became a Research Staff Member at the Laboratory of Metrology and Quality at the same faculty, where he is presently a postgraduate student and is working towards his Ph.D. His current research interests are temperature calibration, International Temperature Scale 1990, thermometers, relative humidity and on-site calibrations.

Janko Drnovšek was born in Ljubljana, Slovenia, in 1952. He received his M.Sc. degree from the Imperial College of Science and Technology, London, the UK, in 1979, and his Dr. Sc. from the Faculty of Electrical Engineering of the University of Ljubljana in 1986. He joined the Faculty of Electrical Engineering in 1980. Between 1982 and 1986 he was the project leader for laboratory measuring systems at Iskra Kibernetika, Kranj. At the Faculty of Electrical Engineering he is a Professor and the Head of the Laboratory of Metrology and Quality, which is an accredited calibration laboratory for temperature and relative humidity. Dr. Drnovšek is President of the Slovenian Society for Process Control and Measurement, President of Metrology Council at the Standards and Metrology Institute of the Republic of Slovenia, Deputy Chairmen of TC-11 in the International Measurement Confederation IMEKO, and the Slovenian delegate to the EUROMET.

Igor Pušnik was born in Ljubljana, Slovenia, in 1970. He received his B.Sc. and M.Sc. degrees in Electrical Engineering from the Faculty of Electrical Engineering of the University of Ljubljana in 1995 and 1997, respectively. In 1995 he became a Research Staff Member at the Laboratory of Metrology and Quality of the Faculty of Electrical Engineering in Ljubljana, where he is presently a Senior Lecturer and is working towards his Ph.D. His current research interests are temperature calibration, International Temperature Scale 1990, radiation thermometry, relative humidity, on-site calibrations and quality systems.