ASSESSMENT OF THE CONDITION OF NON-CONTACT THERMOMETERS

TATIANA KELEMENOVA, MICHAL KELEMEN, IVAN VIRGALA, LUBICA MIKOVA, ERIK PRADA, MARTIN VARGA, PETER MARCINKO, MAREK SUKOP, DOMINIK NOVOTNY

Technical University of Kosice, Faculty of Mechanical Engineering, Kosice, Slovakia

DOI: 10.17973/MMSJ.2023_10_2023074

michal.kelemen@tuke.sk

The article deals with the methodology of verification of non-contact thermometers. A black body calibrator intended for infrared non-contact thermometers, which is considered an etalon gauge, is used to assess selected metrological properties. Also contact thermometer was used to check black body temperature. Industrial infrared thermometers, hand infrared thermometers and infrared thermal cameras were evaluated. Absolute measurement errors, standard deviations and measurement uncertainties of these devices were monitored.

KEYWORDS

temperature, gauges, uncertainty, black body calibrator

1 INTRODUCTION

Measurement as a process cannot be performed under ideal conditions and with ideal measuring equipment. Therefore, with every measurement, there are errors that, if we can identify them, it is possible to at least partially eliminate them. If the errors are systematic, which do not change their value under the same conditions, then we can correct the measurement result. If it is a gross error that noticeably deviates from the range of measured values, then we can exclude such a damaged measurement from the range of measured values. The biggest problem is with random errors, which are problematic to identify and eliminate. The distribution of these random values can take on a different character. To characterize the degree to which we can believe the value of the measured quantity, we use the term measurement uncertainty, which tells us that we cannot know the true value, so we replace it with an estimate of the mean value and the measurement uncertainty, which is in the form of an interval around this mean value. With a certain probability, it is assumed that the true value is within this interval defined by the uncertainty of the measurement. In terms of valid regulations and legislation, we are therefore obliged to indicate the measurement uncertainty in the measured value in order to be able to characterize the degree of trustworthiness of the determined value of the measured quantity. In order to identify measurement errors and uncertainties, we perform a process of meter verification and calibration, where we determine the condition of the measuring device and assess its suitability for measurement processes [ACT 157/2018, DECREE 161/2019, DIRECTIVE 2009/34/EC, DIRECTIVE 2014/32/EU, EA-4/02 1999, JCGM 100 2008, JCGM 104 2009, Kelemen 2021, Kelemenova 2021a, Mikova 2022].

One of the frequently measured quantities is the temperature of objects or the environment. For temperature measurement, procedures and standards have already been developed for determining temperature using contact methods, where we use various physical principles and it is possible to achieve very good measurement uncertainty values. The situation becomes complicated if, for some reason, it is not possible to measure the temperature by contact methods. The only solution is non-contact temperature measurement methods. Several types of measuring devices with different metrological properties are available on the market. When choosing the right solution, we therefore decide which measure is suitable to use in terms of the achievable maximum permissible error and measurement uncertainty. Manufacturers should state these values, but it often happens that these values in our measurement conditions may differ, and also the measuring device may have been damaged in the process of use, and it is then necessary to identify its condition using its metrological properties.

The aim of this article is to identify selected metrological properties of selected gauges for non-contact temperature measurement of objects and thus to identify unknown metrological characteristics or to verify their current status and compliance with the metrological characteristics declared by the manufacturer of the measuring device. Non-contact temperature measurement uses the determination of the rate of infrared radiation emitted by the body whose surface temperature we want to determine. The manufacturer sometimes does not state what effect the distance of the measuring device from the object of measurement has on the errors and uncertainties of the measurement. Or it is necessary to verify these characteristics. The proposed methodology therefore takes into account that the distance from the object of measurement can play a significant role when measuring the surface temperature.

2 VERIFIED MEASURING DEVICES AND THEIR VERIFICATION METHODOLOGY

Three gauges (Fig. 1) for non-contact temperature measurement are evaluated: industrial infrared thermometer (industrial IR thermometer), hand infrared thermometer (hand IR thermometer) and infrared thermal camera (IR thermal camera). A black body calibrator (Fig. 1) is used as the reference standard. To check the functionality of this calibrator, it was suggested to use a contact measuring device for measuring temperature with higher accuracy (contact thermometer) (Fig. 1).

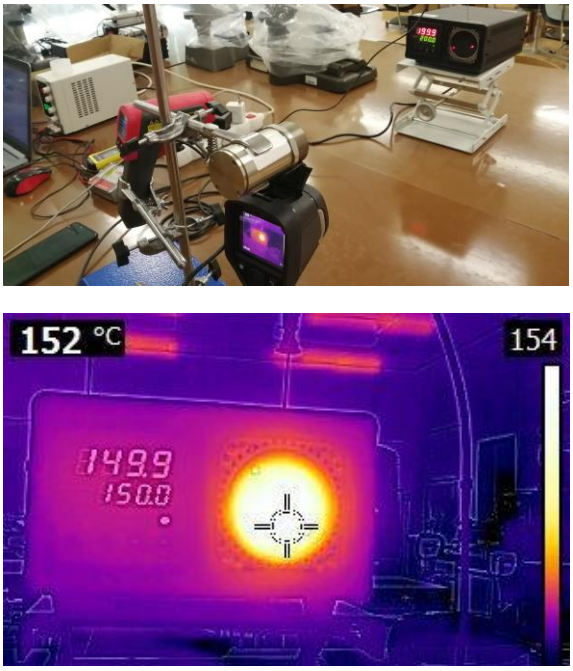

Figure 1. Verified gauges and reference standard

The evaluated devices were already in the process of use and thus may show a change in metrological properties. For the protection of the consumer and the reputation of the manufacturer of measuring devices, we will not list the types and manufacturers of measuring devices considered by the manufacturer.

The assessment methodology will include an assessment of absolute measurement errors, which will be assessed from the maximum permissible error (*MPE*) stated by the manufacturer of the measuring device. This assessment will give information about the capability of the measuring device for the temperature measurement process. The next step is the assessment of the standard deviation and standard uncertainty of the measurement determined by method A, which provide information about the dispersion of the measured data around the estimate of the mean value of the measured quantity. Next, the standard uncertainty determined by method B will be evaluated, which will be determined from the information available from the manufacturer of the measuring device. From these two standard measurement uncertainties, a combined uncertainty will be processed, which provides information on the measurement uncertainty for the measured measuring device or measurement chain. All the mentioned characteristics are monitored at different distances of the measuring device from the surface of the object whose surface temperature needs to be identified. The verification process will also show the influence of the measurement distance on these metrological characteristics.

The rest of the article presents the results of the assessment of absolute errors, standard deviations and measurement uncertainties for individual measuring devices.

The proposed methodology is designed for a quick assessment of the capability of the gauges, which we can perform internally as needed. According to the applicable standards, the assessed gauges must be periodically assessed in terms of suitability for measurement processes in a certified laboratory. However, in the case of a negative result of the proposed assessment methodology, there is reason to doubt the capability of the measuring device and thus there is a reason for premature assessment of this measuring device in a certified laboratory.

For each distance (200 mm, 300 mm, 400 mm, 500 mm and 600 mm) of the measuring device from the black body calibrator, the reference temperature values of the black body calibrator were gradually set (50°C, 75°C, 100°C, 125°C, 150°C, 200°C and 250°C). At each set distance of the gauges from the calibrator and for each temperature value, 10 samples were taken from which average values and individual metrological characteristics were determined.

3 ASSESSMENT OF SELECTED METROLOGICAL CHARACTERISTICS

Selected metrological characteristics were evaluated from the measured values (Figs. 2-6). Measurement errors were determined as absolute measurement errors using the difference between the temperature value from the black body calibrator and the indication values from the individual measuring devices under consideration:

$$T_E = \overline{T}_M - T_{BBC} \,. \tag{1}$$

Where:

$\overline{T}_M$ is the temperature indication value determined from the measuring device under consideration;

T_{BBC} is the temperature indication value determined from the black body calibrator.

Standard deviations were also determined from the series of measured values:

$$S_D = \sqrt{\frac{\sum_{i=1}^{n} \left(\overline{T}_M - T_{Mi}\right)^2}{n-1}} \,. \tag{2}$$

where:

T_{Mi} is an indication of the value measured using the measuring device under consideration,

n is the number of indications of measured values under the same measurement conditions.

The standard uncertainty of the measurement determined using method A is then determined from the standard deviation of the measurements:

$$u_A = \frac{S_D}{\sqrt{n}} \,. \tag{3}$$

The standard measurement uncertainty determined using method B is determined from the maximum permissible error (*MPE*) value given by the manufacturer:

$$u_B = \frac{MPE}{k} \,. \tag{4}$$

where k is the coverage factor and for the used gauges that have a digital output, the considered value is $k = \sqrt{3}$.

For individual gauges, manufacturers state the values of the maximum permissible error as a percentage of the measured value, which for practical use needs to be converted to a value in degrees of Celsius.

The values of the maximum permissible error converted to a value in degrees of Celsius are also displayed in the graphs of measurement errors for a quick assessment of the capability of the evaluated gauges. For a more detailed assessment of the meter, it is necessary to assess each measured value individually, whether it does not exceed the interval defined by the maximum permissible error.

For the industrial infrared thermometer (industrial IR thermometer) the maximum error value is ±1%, for the hand infrared thermometer (hand IR thermometer) the maximum error value is ±1.8% and the infrared thermal camera (IR thermal camera) is the maximum error value of ±2%. For the contact thermometer, the manufacturer states a maximum error value of ±0.1°C, and for the black body calibrator, the maximum error value is ±1°C. The contact thermometer is only used to verify the functionality of the black body calibrator, and the black body calibrator will be considered a reference standard.

The combined measurement uncertainty is then determined from the standard measurement uncertainties:

$$u_C = \sqrt{\left(u_A^2 + u_B^2 + u_{BBC}^2\right)} \,. \tag{5}$$

Where u_{BBC} is the uncertainty of the reference standard and will be considered in the total combined measurement uncertainty.

If it is necessary to determine the extended uncertainty of the measurement using the individual assessed gauges, this uncertainty will need to be determined as the product of the combined uncertainty of the measurement and the relevant coverage factor. Which would be good to experimentally identify or use the value √3, which is currently used for digital measurements and considers the uniform distribution law of the measured values.

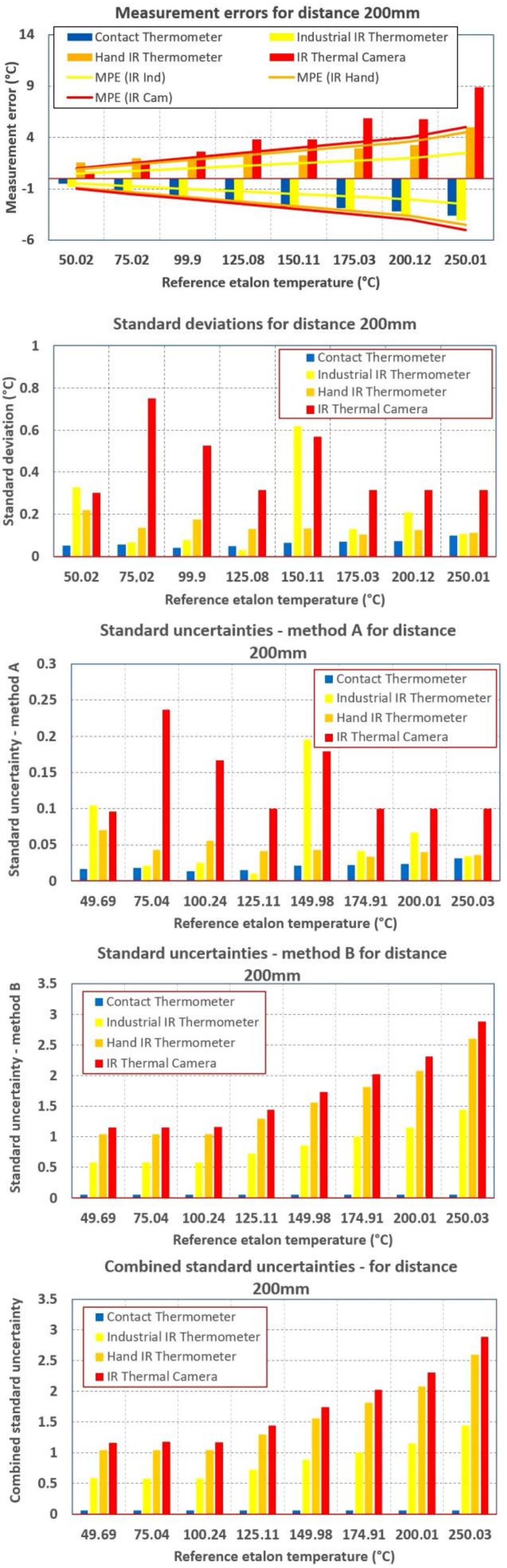

Figure 2. Selected metrological characteristics at a distance of 200 mm

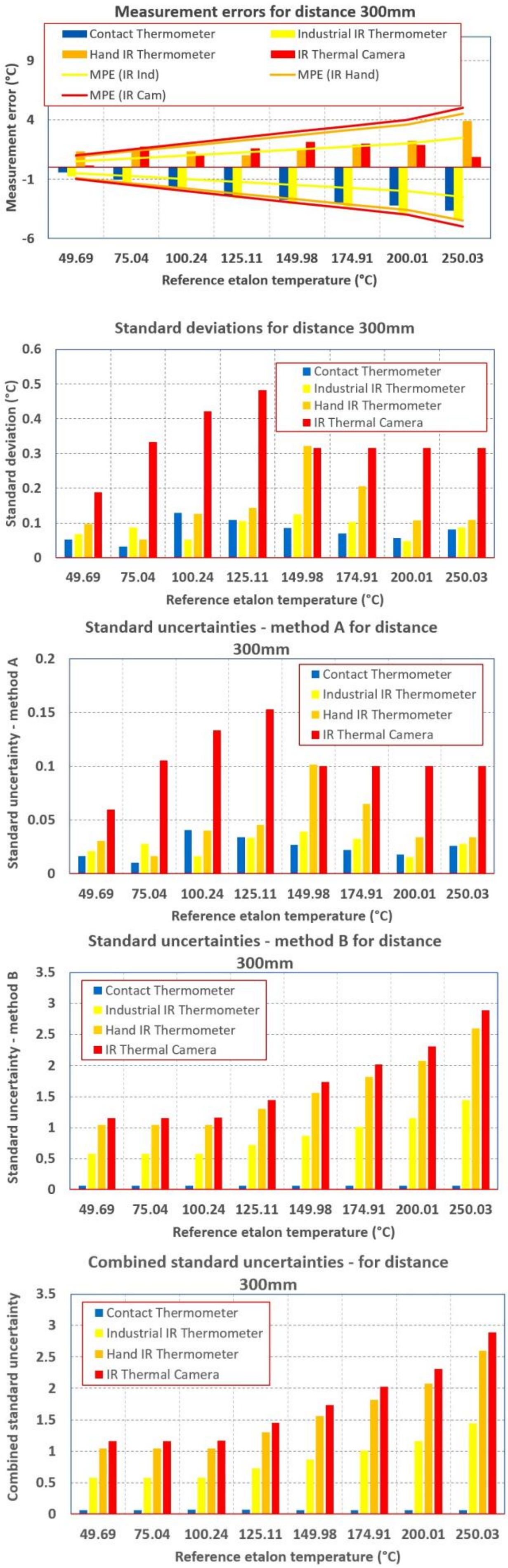

Figure 3. Selected metrological characteristics at a distance of 300 mm

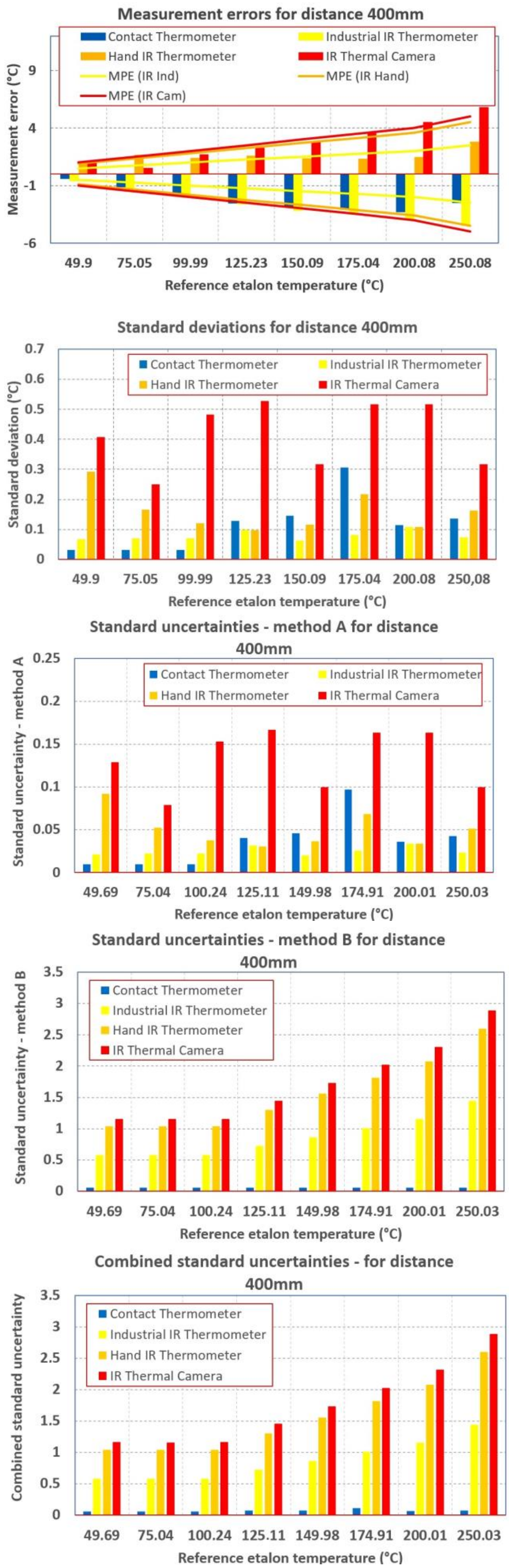

Figure 4. Selected metrological characteristics at a distance of 400 mm

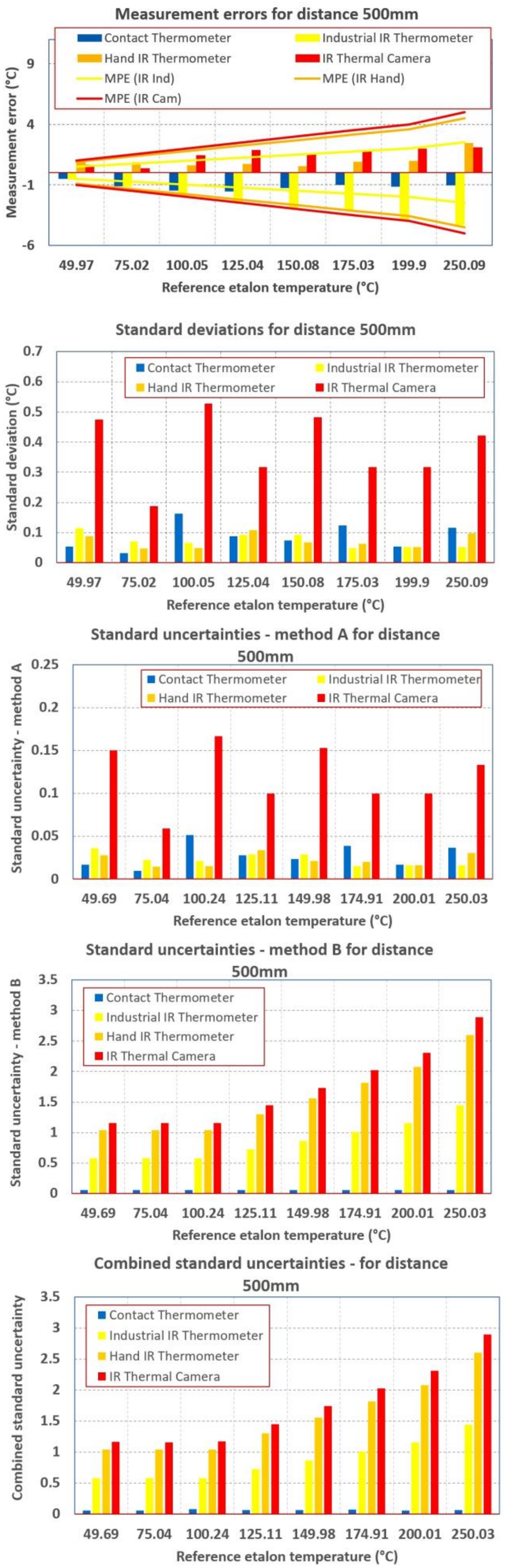

Figure 5. Selected metrological characteristics at a distance of 500 mm

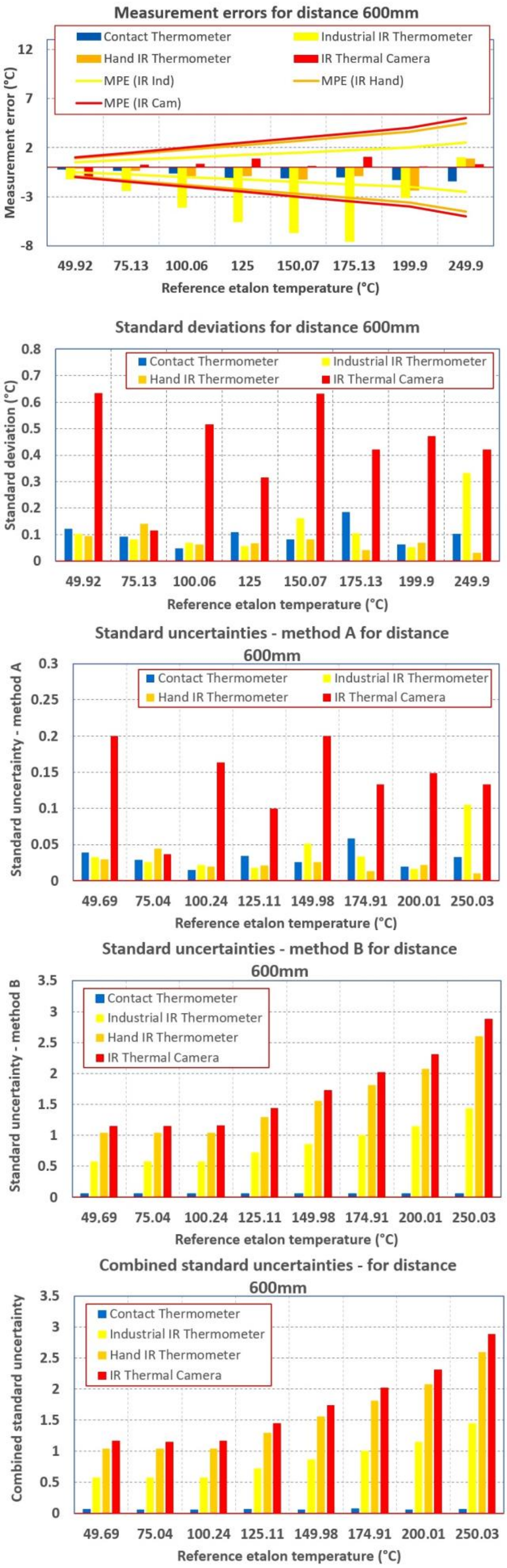

Figure 6. Selected metrological characteristics at a distance of 600 mm

4 EVALUATION OF SELECTED METROLOGICAL CHARACTERISTICS AT DIFFERENT DISTANCES

Measurement errors of individual measuring devices are confronted with maximum permissible errors. Assessments of the capability of the assessed measuring devices are listed in Tab. 1. It follows from these evaluations that the industrial thermometer does not suit almost any of the cases in which it was tested. Hand thermometers are suitable for measuring from a distance of 400 mm in all cases. The IR thermal camera is designed for measurement from a distance of 500 mm.

Table 1. Measurement errors and assessment of the capability of the measuring device

Temperature of black body calibrator	The indication error is less than the maximum permissible error MPE (Y/N) Distance (200, 300, 400, 500, 600 mm)		
	Industrial thermometer	Hand IR thermometer	IR thermal camera
50°C	☒,☒,☒,☒,☒,	☒,☒,☑,☑,☑,	☑,☑,☑,☑,☑,
75°C	☒,☒,☒,☒,☒,	☒,☑,☑,☑,☑,	☑,☑,☑,☑,☑,
100°C	☒,☒,☒,☒,☒,	☑,☑,☑,☑,☑,	☒,☑,☑,☑,☑,
125°C	☒,☒,☒,☒,☒,	☑,☑,☑,☑,☑,	☒,☑,☑,☑,☑,
150°C	☒,☒,☒,☒,☒,	☑,☑,☑,☑,☑,	☒,☑,☑,☑,☑,
175°C	☒,☒,☒,☒,☒,	☑,☑,☑,☑,☑,	☒,☑,☑,☑,☑,
200°C	☒,☒,☒,☒,☒,	☑,☑,☑,☑,☑,	☒,☑,☒,☑,☑,
250°C	☒,☒,☒,☒,☑,	☒,☑,☑,☑,☑,	☒,☑,☒,☑,☑,

For a better assessment of the overall situation, the overall situation of measurement errors is shown for the individual measuring devices under consideration (Fig. 7). The graph (Fig. 7) shows the error values according to the distance, as can be seen in the bottom detailed view at a temperature of 50°C. From this graph, it is possible to compare the assessed measuring devices with each other in terms of measurement errors. According to this graph, the best hand IR thermometer is the one that has the smallest errors among non-contact thermometers.

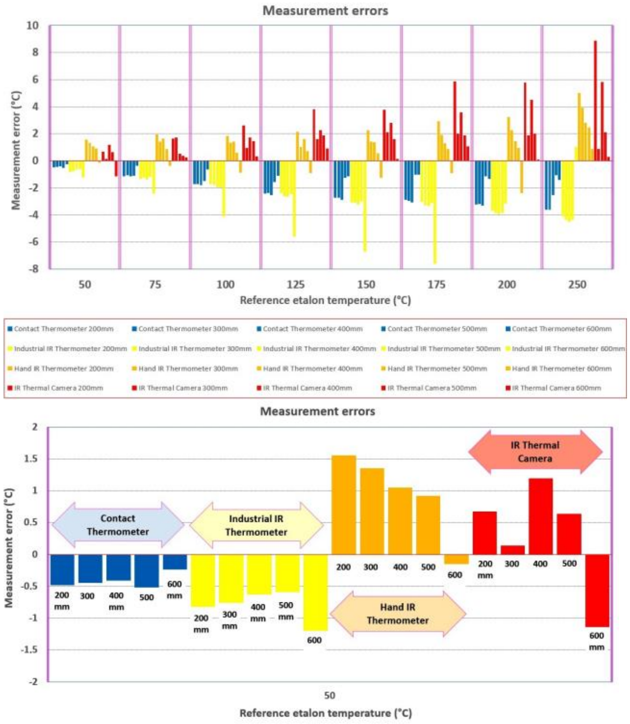

Figure 7. Overview of measurement errors for all cases of temperature measurement for all measured measuring devices. A detailed view of the cases at a temperature value of 50°C.

The graph (Fig. 8) shows the measurement standard deviations for all measurement cases (for all distances and temperatures) for each considered measuring device. Standard deviations characterize the dispersion of measured values. The best measuring device in terms of standard deviations is the hand IR thermometer, which has the smallest standard deviations. The IR thermal camera has the largest standard deviations. The detailed view (Fig. 8) shows the standard deviations for a temperature of 50°C for all measuring devices and all distances of the meters from the black body calibrator.

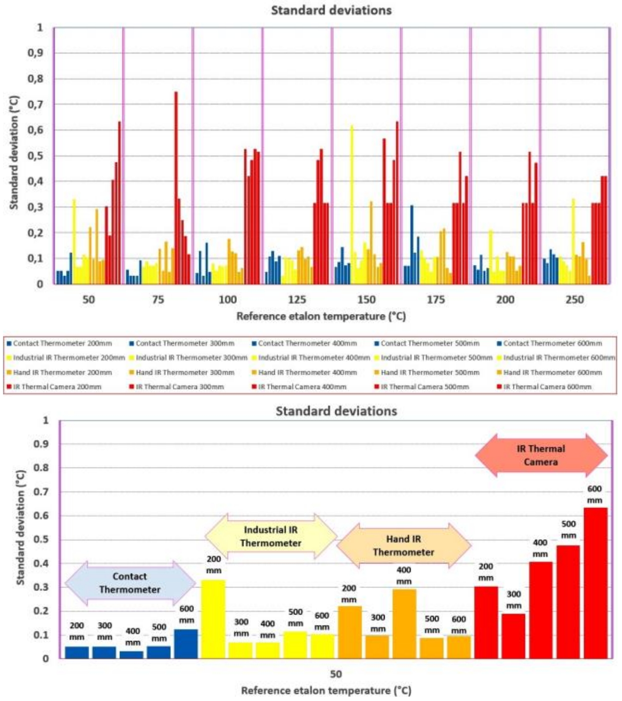

Figure 8. Overview of standard deviations for all cases of temperature measurement for all measured measuring devices. A detailed view of the cases at a temperature value of 50°C.

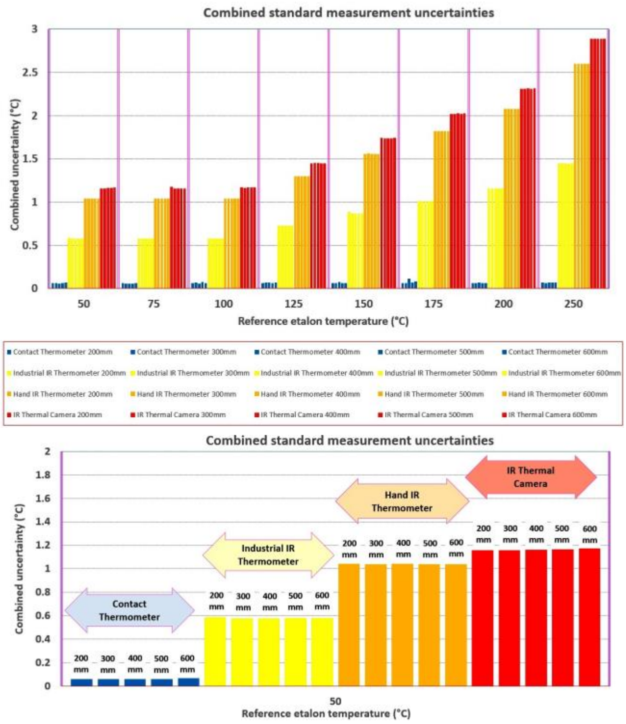

Figure 9. Overview of combined measurement uncertainties for all cases of temperature measurement for all measured measuring devices. A detailed view of the cases at a temperature value of 50°C.

The detailed view (Fig. 8) shows the standard deviations of the measurement for a temperature of 50°C for all measuring devices and all distances of the meters from the black body calibrator.

The graph (Fig. 9) shows the combined uncertainties for all considered measures and all measurement cases. In this case, the best is the industrial IR thermometer, which has the smallest combined measurement uncertainties of all non-contact measuring devices. The detailed view of the combined uncertainties (Fig. 9) shows the values of the combined uncertainties for a temperature of 50°C.

5 CONCLUSIONS

The result of this work is a qualitative assessment of selected metrological characteristics for evaluating the state of measuring devices. At the same time, the influence of the distance of the gauges from the measured object was investigated, which is not a standard considered factor. Such an assessment of the condition of the gauges is very important for determining the condition of the gauges and their ability to provide measured data that are close to the actual value of the measured quantity.

The mentioned methodology is designed for regular internal assessment of the condition of the gauges [Murcinkova 2013, Koniar 2014, Mascenik 2016, Saga 2019, Blatnicky 2020, Peterka 2020, Saga 2020, Kelemenova 2021b, Klarak 2021, Suder 2021, Zelnik 2021, Pivarciova 2021, Hortobagyi 2021, Hroncova 2022a, Hroncova 2022b, Lestach 2022, Bratan 2023, Ivanova 2023].

ACKNOWLEDGMENTS

The authors would like to thank the Slovak Grant Agency - project KEGA 027TUKE-4/2022, project KEGA 054TUKE-4/2022 and project KEGA 016TUKE-4/2021.

This publication was created thanks to support under the Operational programme Integrated Infrastructure for the project Center for the Development of Textile Intelligence and Antimicrobial Technologies co-financed by European Regional Development Fund. ITMS2014+ 313011AVF5 Center for the Development of Textile Intelligence and Antimicrobial Technologies.

REFERENCES

[ACT 157/2018] ACT 157/2018 of the Slovak Republic of 15 May 2018 on metrology and on the amendment of certain laws, 2018.

[Blatnicky 2020] Blatnicky M., et al. Design of a Mechanical Part of an Automated Platform for Oblique Manipulation. Applied Sciences, 2020, Vol. 10, No. 23, Art. No. 8467. DOI: 10.3390/app10238467.

[Bratan 2023] Bratan, S., Sagova, Z., Saga, M., Yakimovich, B., Kuric, I. New Calculation Methodology of the Operations Number of Cold Rolling Rolls Fine Grinding. Applied Sciences, 2023, Vol. 13, No. 6. eISSN 2076-3417. DOI: 10.3390/app13063484.

[DECREE 161/2019] DECREE 161/2019 of the Office for Standardization, Metrology and Testing of the Slovak Republic of 27 May 2014 on measuring instruments and metrological control, 2019.

[DIRECTIVE 2009/34/EC] Directive 2009/34/EC of The European Parliament and of the Council of 23 April 2009 relating to common provisions for both measuring instruments and methods of metrological control, 2009.

[DIRECTIVE 2014/32/EU] Directive 2014/32/EU of The European Parliament and of the Council of 26 Feb. 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of measuring instruments (recast), 2014.

[EA-4/02 1999] Expression of the Uncertainty of Measurement in Calibration. European co-operation Accreditation Publication Reference, 1999.

[Hortobagyi 2021] Hortobagyi, A. et al. Holographic Interferometry for Measuring the Effect of Thermal Modification on Wood Thermal Properties. Applied Sciences, 2021, Vol. 11, No. 6, pp. 1–11. DOI: 10.3390/app11062516.

[Hroncova 2022a] Hroncova, D. et al. Robot Trajectory Planning. MM Science Journal, 2022, No. November, pp. 6098-6108. ISSN 1803-1269. DOI: 10.17973/MMSJ.2022_11_2022093.

[Hroncova 2022b] Hroncova, D. et al. Forward and inverse robot model kinematics and trajectory planning. In: 20th Int. Conf. on Mechatronics - Mechatronika (ME), Pilsen, Czech Republic, 2022, pp. 1-9. DOI: 10.1109/ME54704.2022.9983355.

[Ivanova 2023] Ivanova, T.N. Krenicky, T., Korshunov, A.I., Koretckiy, V.P. Water Production Isolation Techniques for Oil-wells With High Reservoir Temperature. MM Science Journal, 2023, Vol. June, pp. 6484-6488.

[JCGM 100 2008] JCGM 100 – Evaluation of measurement data – Guide to the expression of uncertainty in measurement (ISO/IEC Guide 98-3). 1st edition, September 2008. Available online: http://www.iso.org/sites/JCGM/GUM-JCGM100.htm

[JCGM 104 2009] Evaluation of measurement data – An introduction to the "Guide to the expression of uncertainty in measurement" (ISO/IEC Guide 98-1). 1st edition, July 2009. Available online: http://www.bipm.org/en/publications/guides/gum_print.html

[Kelemen 2021] Kelemen, M. et al. Head on Hall Effect Sensor Arrangement for Displacement Measurement. MM Science Journal, 2021, No. October, pp. 4757-4763. ISSN 1803-1269. DOI: 10.17973/MMSJ.2021_10_2021026.

[Kelemenova 2021a] Kelemenova, T. et al. Verification of Force Transducer for Direct and Indirect Measurements. MM Science Journal, 2021, No. October, pp. 4736-4742. ISSN 1803-1269. DOI: 10.17973/MMSJ.2021_10_2021021.

[Kelemenova 2021b] Kelemenova, T. et al. Verification of the Torque Gauges. MM Science Journal, 2022, No. March, pp. 5533-5538. ISSN 1803-1269. DOI: 10.17973/MMSJ.2022_03_2022014.

[Klarak 2021] Klarak, J. et al. Analysis of Laser Sensors and Camera Vision in the Shoe Position Inspection System. Sensors, 2021, Vol. 21, No. 22, pp. 1-20. ISSN 1424-8220. DOI: 10.3390/s21227531.

[Koniar 2014] Koniar, D. et al. Virtual Instrumentation for Visual Inspection in Mechatronic Applications. Procedia Engineering, 2014, Vol. 96, pp. 227-234. ISSN 1877-7058. DOI: 10.1016/j.proeng.2014.12.148.

[Lestach 2022] Lestach, L. et al. Two-legged Robot Concepts. MM Science Journal, 2022, No. October, pp. 5812-5818. ISSN 1803-1269. DOI: 10.17973/MMSJ.2022_10_2022091.

[Mascenik 2016] Mascenik, J. and Pavlenko, S. Controlled testing of belt transmissions at different loads. MM Science Journal, 2021, No. December, pp. 5497-5501. DOI: 10.17973/MMSJ.2021_12_2021045.

[Mikova 2022] Mikova, L. et al. Upgrade of Biaxial Mechatronic Testing Machine for Cruciform Specimens and Verification by FEM Analysis. Machines, 2022, Vol. 10, No. 10, pp. 1-29. ISSN 2075-1702, DOI: https://doi.org/10.3390/machines10100916.

[Murcinkova 2013] Murcinkova, Z. and Krenicky, T. Implementation of virtual instrumentation for multiparametric technical system monitoring. In: SGEM 2013: 13th Int. Multidisciplinary Sci. Geoconf., Vol. 1; 16-22 June, 2013, Albena, Bulgaria. Sofia: STEF92 Technology, 2013, pp. 139-144. ISBN 978-954-91818-9-0.

[Peterka 2020] Peterka, J. et al. Diagnostics of Automated Technological Devices. MM Science Journal, 2020, October, pp. 4027-4034. DOI: 10.17973/MMSJ.2020_10_2020051.

[Pivarciova 2021] Pivarciova, E. et al. Interferometric Measurement of Heat Transfer above New Generation Foam Concrete. Measurement Science Review, 2019, Vol. 19, No. 4, pp. 153-160. DOI: 10.2478/msr-2019-0021.

[Saga 2019] Saga, M. et al. Contribution to Random Vibration Numerical Simulation and Optimisation of Nonlinear Mechanical Systems. Scientific Journal of Silesian University of Technology-series Transport, 2019, Vol. 103, pp. 143-154. DOI: 10.20858/sjsutst.2019.103.11.

[Saga 2020] Saga, M. et al. Case study: Performance analysis and development of robotized screwing application with integrated vision sensing system for automotive industry. Int. J. of Advanced Robotic Systems, 2020, Vol. 17, No. 3, 172988142092399, pp. 1-23. DOI: 10.1177/1729881420923997.

[Suder 2021] Suder, J. et al. Experimental Analysis of Temperature Resistance of 3D Printed PLA Components. MM Science Journal, 2021, No. March, pp. 4322–4327. DOI: 10.17973/MMSJ.2021_03_2021004.

[Zelnik 2021] Zelnik, R. et al. Research and Diagnostics for the Laboratory of Pressure Resistant Sensors. MM Science Journal, 2021, No. October, pp. 4853-4856. DOI: 10.17973/MMSJ.2021_10_2021041.

CONTACTS:

Michal Kelemen, prof. Ing. PhD. Professor
Technical University of Kosice, Faculty of Mechanical Engineering,
Institute of Automation, Mechatronics, Robotics and Production Techniques,
Letna 9, 04200 Kosice, Slovak Republic
michal.kelemen@tuke.sk