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Design of a system to analyse the performance of certified measuring instruments

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***Abstract*—The aim of this article is to present modern methods for analysing the performance of certified measuring instruments. The design of a system for analysing the performance of certified measuring instruments is presented. In the first part, the traditional process of certification of measuring instruments and methods of market surveillance are described. The other part proposes an electronic solution to support the certification process by supervising the correct operation of measuring instruments.**

***Keywords*—certification; digital methods and certificates; digitisation; certificate system; measuring instruments; analysis of measuring instrument operating conditions**

I. Introduction

THE importance of metrology in the economy has gradually become apparent as the technological sophistication of manufacturing processes has increased. Changing manufacturing technology requires high standards for component metrology and quality, as an incomplete detail ultimately results in defects in the final product.

The increase in automation and robotisation of production lines in manufacturing processes since the 1970s has made metrology an essential element for the development of manufacturing processes [1]. Three areas of metrology can be distinguished: scientific, industrial and legal metrology (Figure 1). Metrology enters the fields of interest mainly in the fields of engineering and technical sciences, medical and health sciences, and science and life sciences, drawing on the achievements of these sciences. Metrology makes up the framework that standardises the rules for making and developing measurement results in various scientific, industrial and commercial fields.

The idea of free movement of goods and services presupposes harmonisation of regulations of the member states of the European Union. This process is implemented through the ratification on 10 October 2009 of directives introducing the implementation in legislative processes of relevant provisions in line with the implemented EU law according to the guidelines of Article 288, paragraph 3 TFEU[2].

In the European Union, after 1985, the so-called 'New Approach' was introduced to harmonise technical rules that enable and facilitate the harmonisation of the disparate national rules governing the field controlling the safety of industrially manufactured products [3]. Directives contain essential requirements related to safety, health, user protection and environmental protection. Other detailed technical requirements are contained in the relevant harmonised European standards (EN) [4].

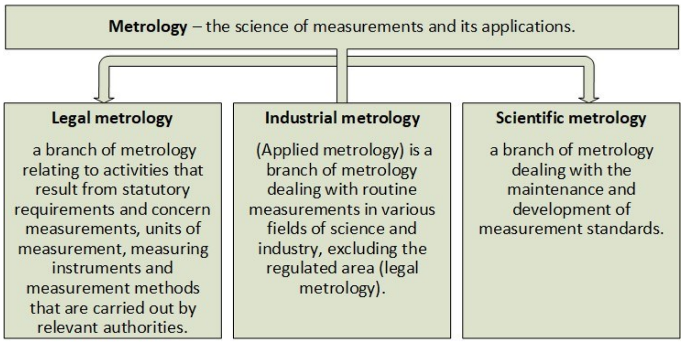

Fig. 1. Sections of metrology. Source: based on [1]

Measuring instruments placed on the market in EU member states in accordance with the directives must be characterised by compliance with the metrological requirements.

Proper metrological supervision is necessary to meet the EU requirements. The measurement equipment used for calibration, testing and metrological inspection has a very significant impact on the measurement results. At the national level, measuring equipment must be supervised by a national metrology institution, which in Poland is the Central Office of Measures [5]. This equipment can be maintained as a benchmark of various levels or in use. Metrological supervision of measurement equipment can be carried out within the structure of legal metrology or within the structures of voluntary metrological supervision, i.e. scientific and industrial metrology.

II. Certification Methods in Poland and Worldwide

Nowadays, at a time of rapid development of globalisation, digitalisation and automation, directly or indirectly, in every sphere of modern reality, there is a demand for newer and newer services aimed both at people and increasingly at things. Material objects are now acquiring newer properties. The functions so far implemented in instruments are not sufficient for the novel tasks of processing and analysing, often large amounts of data. A conducive environment is still required to enable intercommunication between instruments and central units. The solution here is *Internet of Things* (IoT).

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In many industries, solutions based on networked measurement sensors have been introduced, taking advantage of the ability of distributed sensors to communicate using the IoT. Given the ageing of the sensors, it would be necessary to calibrate them with reference instruments that preserve the chain of hierarchical relationships maintained by the NMI (National Metrology Institute) [6]. Due to the large number and location of sensors in difficult-to-reach areas, calibration becomes costly or very difficult to implement. The alternative is to perform a self-calibration of the instruments at the site and the conditions of use. This carries the risk of environmental influences. Furthermore, it is potentially possible to have an approximate drift of the readings, which will result in the risk of not detecting measurement errors that occur during autocalibration. The proof of the auto-calibration performed is the digital calibration certificate (DCC). There are various models for the implementation of self-calibration, built according to the practical use case.

A. Digital Calibration Certificate (DCC)

To improve reliability, the use of cryptographic device identifiers, digital calibration certificates (DCC), and the digital SI (D-SI) data model has been proposed to allow extension of the [7] measurement data of sensors using the Internet of Things, thus enabling validation of uncertainty, authenticity [5], and integrity of measurement sensor data.

To date, XML file syntaxes have been developed to allow the data contained in the certificate to be machine readable, as well as in the traditional human-readable way. The basic structure of a digital calibration certificate (DCC), shown in Figure 2, includes [7]:

1) Administrative data

Administrative (regulated) data containing the relevant information necessary to uniquely identify the instrument and the calibration itself. The fields of these data are defined by default.

2) Measurement result area

The measurement results area is also strictly regulated. The data it contains is assumed to be based on the SI System, and individual records are created according to a scheme and contain in turn: symbol, measurement value, expanded measurement uncertainty, expansion factor and unit and time (optional). Provision is also made for the realisation of units from outside the SI system (e.g. degree Oechsle, millimetre of mercury column, nautical miles). Nevertheless, it should always be remembered that the indications given in SI units apply.

3) Record of comments and graphs

Comments and graphs are stored in the non-standardised and non-regulated part of the document. Data can also be deposited here in already existing data-exchange formats (or in formats not yet in force as approved standards).

4) Data reading

The file thus constructed can be read by a human as intended. Using designed software, it can be issued as a digital or printed document, in a manner similar to a traditional calibration certificate, complete with digital signatures to authenticate and confirm the consistency and immutability of the data over time.

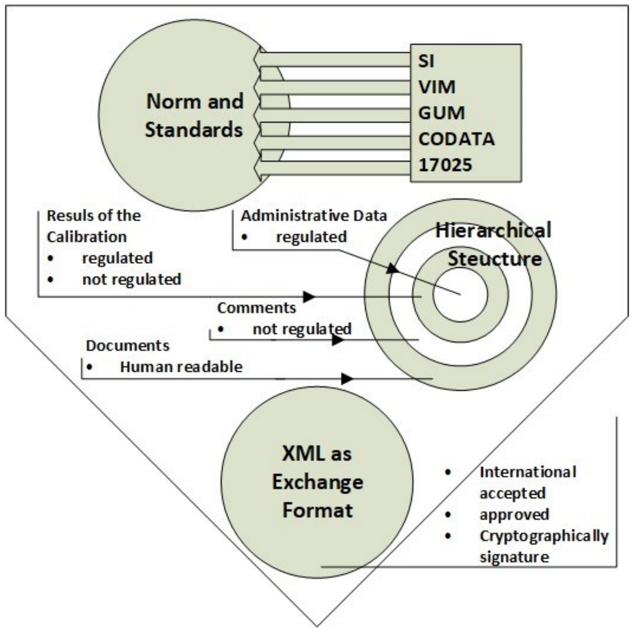

Fig. 2. Diagram of the digital calibration certificate (DCC) [8]. Source: brochure https://www.ptb.de/cms/fileadmin/internet/forschung_entwicklung/digitalisierung/digital_calibration_certificate.pdf

Today's instruments for laboratory use contain advanced software (built-in) that extends the functionality of the instrument. Such a solution makes it possible to generate summaries of the calibration process in reports summarising the process, in the form of a display of these data stored in the device memory, their printouts or files, e.g. in "xls" format [9] or "pdf" [7].

B. Metrology cloud

The platform that coordinates the operation of existing and emerging infrastructures[10] was assumed to be the proposal initiated by the PTB (*Physikalisch-Technische Bundesanstalt*) [11]. On the basis of this, reference architectures for measuring instruments, as well as digital services, are used using legal metrology data and new technologies. An example of adapting to the development of a digital infrastructure is the construction of a central repository containing virtual metrology software parts and data-based services linked to distributed sensor networks (Software as a Service - SaaS). Emerging services created on the use and implementation of new technologies should be based on developed reference architectures to be offered to European notified bodies taking into account national safety standards. The European Metrology Cloud [12] achieving its objectives is programmatically part of the support of the Digital Single Market.

C. Thermometric Platform of the SCA

A response to the trends of European actors involved in the development of metrology by creating a DCC with the character of a universally applicable system is the initiative proposed by the Department of Mechanics and Thermal Processes of the Kielce University of Technology. The ongoing project entitled.

"Thermometric analyses of selected contact and non-contact temperature measurements" has been approved and financially supported by the Minister of Education and Science as part of the activities for Polish Metrology, under the project entitled "Metrology - the opportunity and challenge of the future". The digital Thermometry Platform, which is being developed as part of the project, will be aimed at meeting the needs in the area of thermometry analysis. Of particular interest in the project is the improvement of temperature measurement accuracy and related issues, including: techniques and methods for contact temperature measurement (point measurements using selected thermocouple sensors and resistance temperature sensors) and non-contact measurement (measurement of temperature fields using liquid crystal thermography and thermal imaging methods). The activities include the characterisation of temperature sensors for solids and liquids and the application of calibration methods for instruments used in the above-mentioned measurement techniques. The application aspect of the project is also important, with plans to use the calibrated sensors to carry out heat transfer and diagnostic tests, as well as practical calibration of sensors in real air-conditioning, heating and ventilation systems. Validation and comparative analysis of the results obtained from the experiments within the project tasks will be carried out. The collected results will be integrated into the digital Thermometry Platform being developed within the Laboratory of Boiling Heat Transfer and the newly established Laboratory of Thermometry. In addition, promotional and information activities are being carried out to increase the dissemination of knowledge about thermometry and its socio-economic impact.

III. Digital Certificate System (SCC) - a new proposal

The sixth edition of the Implementation PhD programme is another area of cooperation between the Central Office of Measures and the Kielce University of Technology. The opportunity was provided by the Holy Cross Laboratory Campus of the Central Office of Measures, which is under final stage of construction. It will include a stand dedicated to the development of the System of Digital Certificates (SCC). The proposed system will support the implementation of monitoring of measuring instrument monitoring. This supervision consists in certification and periodic control of correctness of operation within the tools of legalisation of measuring instruments subject to legal metrological control. The designed system will help to confirm the reliability of the measurement, which is based on physical safeguards of the invariability of the construction and metrological parameters and periodic inspections. It has been assumed that it is possible to create a digital surveillance system, which, through the analysis of data read from measuring instruments (information about the instrument, measurement data, configuration parameters and event registers), combined with the analysis of environmental conditions, will enable automatic supervision and control of the legalisation status, ensuring the reliability of the results of measurements made using the measuring instruments.

Digital certificates will be implemented as part of a pilot project in the Central Office of Measures and in selected laboratories of the Faculty of Mechatronics and Mechanical Engineering of the Kielce University of Technology - in the Department of Mechanics and Thermal Processes (Laboratory of Boiling Heat Transfer, Laboratory of Thermometry and Laboratory of Vibration and Vibroacoustics). The assumptions of the designed system include the remote use of a cloud service. The future implementation of the market use assumes the possibility of making the developed solution available to the market, which will allow users of measuring instruments to verify the inclusion of a particular instrument in the certificate of verification and will enable verification of the statement of homogeneity conditions of the measuring instrument with the tested batch.

The functions provided for in the SCC assume its operation to enable the reading from the built-in database of the complete set of data contained in the calibration, calibration and validation certificates, both individual and those carried out using the statistical method, issued by the Central Office of Measures or authorised bodies, respectively.

The design of the digital certificate system is shown in Figure 3.

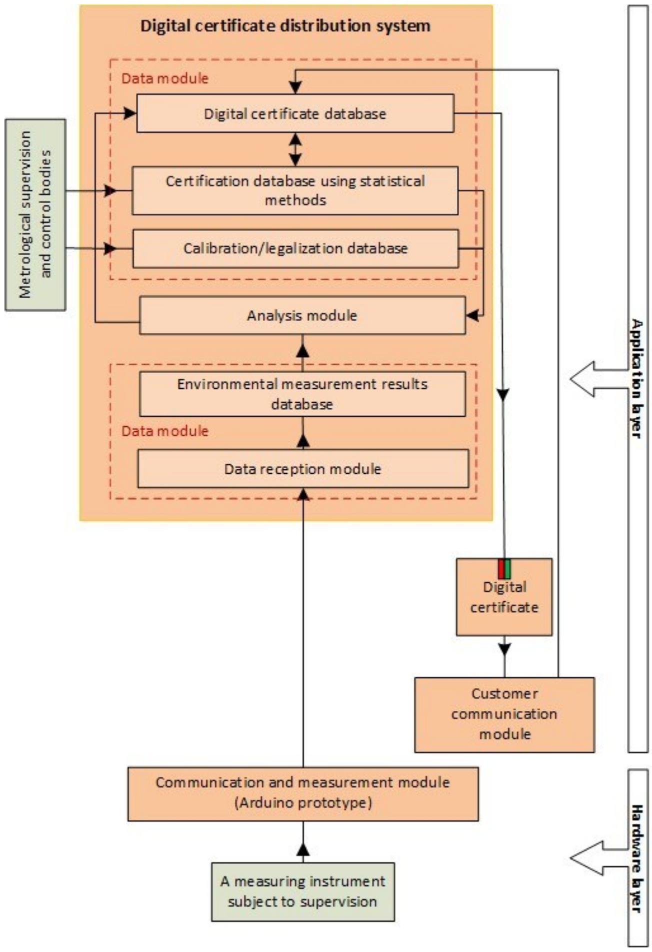

Fig. 3. General proposed concept for the use of the SCC to provide user-dedicated information on the certification of a measuring instrument. Source: own elaboration.

The SCC project consists of five main modules:

- communication and measurement module - the main task of this module is to read data from instruments and the measurement environment;
- data reception module - the task of this module is: to receive measurement data from the communication and measurement module and to transfer the data to the database (database recording);
- data module - a module containing certification data and data obtained from the data reception module;
- analysis module - its purpose is to analyse the correct operation of the measuring instruments, i.e., analyse data from the database module and assess the correct operation of the measuring instruments on the basis of these data;
- customer communication module.

A. Communication and measurement module

The following subsections describe the design of the individual SCC modules. The communication and measurement module in the prototype implementation based on the Arduino Nano 33 BLE Sense Rev2 [13] will include a number of sensors, memory blocks and modules to measure the environmental conditions around the measuring instrument. These measurements will be controlled during both measurements being carried out and during their transport and storage. The measured values of the individual quantities will be tagged with metadata enabling them to be linked to a specific piece of the measuring instrument. In the prototype version, it is envisaged that the measured values of the specific measurands can also be transferred for analysis.

B. Data reception module

This module is designed to receive data from the communication and measurement module remotely. Ultimately, data will be received via an internet connection, and bluetooth or wifi communication will be used for prototype tests. The data thus acquired will be transferred to an environmental measurement database.

C. Data module

The data module consists of a number of databases to collect input data and resources to be made available to interested users. The statistical certification and calibration/legalisation database will contain the necessary information on the calibration and legalisation of the measuring instruments subject to performance analysis. On the other hand, the database of environmental measurement results will contain acquired information from measurement sensors. The data from the measurement sensors will be transferred by the communication and measurement module to the data receiving module and then transferred to the environmental measurement results database. The data from the results database will be analysed by the analysis module.

D. Analysis module

The analysis module is a module for analysing correct or incorrect operation of a measuring instrument, responsible for carrying out an impact assessment of circumstances that may affect the correctness of the indication of the measuring instrument. This process will be carried out using tools based on machine learning mechanisms. On the basis of this analysis, decisions will be made about the correct operation or violation of the conditions for correct operation of the instrument. Which, in further steps, will support the decision-making process for analysing device operation. An electronic document (CC) will be issued if the correct or incorrect operation of the measuring instrument is found. The document will contain information about the calibration, legalisation and established correct and incorrect operation of the measuring instrument.

As a result, automatic mechanisms will be set up to declare a single measurement invalid and, in extreme cases, it will refer to indications of expired legalisation, calibration or calibration itself. The above result will be returned to the data module and from there to the customer via a web application module communicating with databases. Such an action will reduce the number of erroneous measurement results that are analysed or involved in the disciplinary and penalisation processes.

E. Customer communication module

The Customer Communication Module is a web-based application used to transmit the information collected by SCC from the measuring instrument data module to the customer. This information is the issuance of a digital certificate document for the measuring instrument, including the expiration date of validation or calibration certificates, information on correct or incorrect operation of the measuring instrument detected by SCC for the instrument at a given time. The application will allow the customer to gain control over the correct operation of the instrument, support the decision-making process by analysing the operation of the measuring instrument, and then support quality management systems.

IV. LABORATORIES COLLABORATING ON PROTOTYPE TESTS

The laboratories cooperating in the testing of the SCC prototype are the Laboratory of Boiling Heat Transfer, the Laboratory of Thermometry, and the Laboratory of Vibration and Vibroacoustics of the Kielce University of Technology. Measurement instruments located in the laboratories will be used for testing. A set of necessary data on the instruments will be defined and analysed at a later stage to determine the correctness of their operating conditions.

The feasibility of using the SCC to support measurement instruments of various types is assumed. The development and implementation of communication methods with selected measuring instruments of Laboratory of Thermometry and Laboratory of Boiling Heat Transfer and the Laboratory of Vibration and Vibroacoustics of the Kielce University of Technology will be a representative sample to determine the appropriate way of analysing the collected data to optimise the usability of the SCC for particular types of stakeholders.

As part of the digital certificate system under development, it is planned to use the digital Thermometry Platform (under construction) at Laboratory of Boiling Heat Transfer and Laboratory of Thermometry of the Kielce University of Technology to launch a pilot system for the supervision and management of measuring instrument operation. Based on the communication and data exchange with the measuring instruments, the feasibility of using selected instrument models capable of working with the SCC was assessed. In both laboratories, several devices were selected for the implementation of temperature measurements by various methods, including temperature calibrators, precision thermometers, infrared cameras, and additionally a Coriolis mass flow meter.

Temperature calibrators and precision thermometers will be equipped with a communication and measurement module that collects information on ambient temperature and humidity to assess the influence of these parameters and other factors on the accuracy of operation and measured values. Changes in the position of the instruments will be detected based on readings from the IMU (Inertial Measurement Unit) BMI270 contained in the module, which contains a 3-axis gyroscope and a 3-axis accelerator used for prototyping smart solutions. The FLIR infrared camera will be tested for temperature, humidity, the inclination at which it is used and the time it will be moved from an outdoor environment to room temperature. In addition, due to the position sensitivity of the Coriolis mass flow meter, the communication and measurement module will be placed on its housing in a configuration equipped with an IMU - BMI270 unit to monitor acceleration and changes in position of the instrument. It should be emphasised that the apparatus components given are examples selected for the planned tests.

Depending on the quantities being measured, measuring instruments can be sensitive to various environmental factors. Such instruments can be, among others, acoustic instruments, that very often work in outdoor environments measuring acoustic and vibroacoustic hazards. This makes their correct operation highly dependent on the conditions in the external environment, as well as on the type of measurand being measured. The Laboratory of Vibration and Vibroacoustics of the Kielce University of Technology, due to the measuring instruments present in this laboratory, will therefore be a suitable place to check the suitability of the SCC and to dedicate the SCC to such instruments as well. The SCC under construction will allow for the verification of operation as intended and thus the system's ability to work in real conditions. The realisation of the digital certificate system project will shed new light on the innovative methods of legalisation marking in the area of legal metrology, thus guiding potential changes in legalisation marking methods.

As part of the cooperation with the Laboratory of Vibration and Vibroacoustics, the Nor-140 sound analyser, which will be equipped with a communication and measurement module, will be supervised as a first step. The tests will measure and analyse temperature, humidity, vibration, pressure levels, risk of fall, and the impacts to which the instrument has been subjected. Analysis of the collected data using various state-of-the-art methods of analysing the above data will indicate the optimum method[14] for automatically detecting inappropriate operating, storage and transport conditions affecting the instrument's measurement accuracy.

Implementation of the system is planned at the Holy Cross Laboratory Campus of the Central Office of Measures in Kielce.

V. Cooperation between the Traditional and the Proposed SCC

The traditional system for distributing the validation certificate involves transmitting the document in paper form in accordance with the applicable regulations. Information on the validations performed using the statistical [15] method is published on the website [16]. These data, as well as information on individual verifications for the instruments selected during the SCC construction phase, will be entered into the data module being developed. The data from the data module will be analysed by the system. As a result of this analysis, the SCC will make a certificate available in digital form by the SCC. The certificate will confirm the legalisation of the instrument to which the customer's enquiry to the SCC relates. In addition, for monitored instruments, the result of the analysis of the environmental conditions will be included, confirming the correctness of the measurements carried out by the measuring instrument.

VI. Summary

The main objective of this paper is to present methods to support the certification and legalisation of measuring instruments in selected European countries and to present a new proposal for a System of Digital Certificates (SCC). The development of network technologies has meant that it is now possible to obtain a remote solution to verify and maintain the certification of measuring instruments. This paper presents proposals for the SCC, which is the first remote digital proposal that uses state-of-the-art technology to check violations and validate certificates. Such a solution will support the protection of measuring instruments from damage, damage due to the impact of often unfavourable environmental conditions, but most importantly it will protect against the acquisition of erroneous measurement readings. The proposed SCC will identify the unfavourable operating environment in which the measuring instrument is located and which may cause erroneous measurements provided by the instrument. The review of the literature and the normative documents carried out indicates that the SCC is a response to the new requirements of normative regulations and the expectations of market consumers. The established SCC may become a model for other certification and verification bodies. Future work will outline the next steps involved in establishing this system.

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