IMEKO TC6 International Conference on Metrology and Digital Transformation
September 19 – September 21, 2022, Berlin, Germany

SMART INFRASTRUCTURE FOR DEVELOPING DIGITAL CALIBRATION CERTIFICATES AT SASO-NMCC

Khaled M. Ahmed [a,b,*], *Abdullah S. AlOsaimi* [a], *Khalid M. Amin* [c]
[a] *National Measurement and Calibration Center (NMCC), SASO, PO Box 3437 Riyadh 11471 Saudi Arabia.*
[b] *National Institute for Standards (NIS), PO Box 136 Giza, Code No 12211, Egypt.*
[c] Department of Information Technology, Faculty of Computers and Information, Menoufiya University, Egypt
* Corresponding author. E-mail address: k.abdelftah@saso.gov.sa / khaled55eg@gmail.com

Abstract – Nowadays, digital solutions are dominant in almost all industry related activities and applications, especially in the metrology domain. Digital Calibration Certificates (DCCs) will soon replace both paper and electronic calibration certificates. This is due to the fact that electronic files can be communicated instantly and securely to the customer and are machine readable. However, DCCs require a digital security and software infrastructure to fulfill the current ‘analogue’ processes of authentication and validation that secures traceability of the measurements. In this work, we present the efforts at SASO-NMCC of Saudi Arabia towards modifying its work processes for replacing analog calibration certificates with the modern DCCs. A smart e-infrastructure for issuing DCCs is proposed. The system communicates with customers and national standards communities via metrology clouds (e.g. SASO Cloud and GULFMET cloud). Our proposed system is also able to be compatible with recent artificial intelligence applications, the Internet of Things (IoT) and future completely digital metrology.

Keywords: DCC, Digital Transformation, Metrology Cloud, Digital SI, Machine-readable, AI, Digital metrological services

1. MOTIVATION

The introduction of increasingly affordable processing power and memory, as well as interconnected networks, has ushered in a huge change in how information technology affects our lives over the last decades [1-4]. A secure and thriving economy and society are built on innovation and trust in a high-quality infrastructure. Metrology is the science and practice of measurement, hence the ability to gather correct data based on high-precision measurements is one of the objectives of metrology, is the foundation of an effective quality infrastructure. The economy and society of the 21st century are undergoing a comprehensive digital transformation, with the goal of securely establishing the foundation for success in the digital arena, which is the cornerstone for the economy and society's progress in the digital era. The process of digitization has been ongoing for several years [5-6]. The exponential growth of computing and storage capacities, as well as the increasing speed of data exchange and the affordable availability of versatile sensors that can be used flexibly, have opened up completely new possibilities for creating networks between objects and exploitation of the data and information stored [7-12].

The increased number of measuring equipment, sensors, and sensor systems and networks, as well as the restricted time available for doing metrological work, necessitate a large rise in metrological activity efficiency. Calibration of measuring instruments is one of metrology's most significant duties [13-14]. Currently, the method for calibrating measuring equipment concludes with the issue of a calibration certificate, which is normally in the form of a paper certificate or a PDF file certified by an electronic digital signature. In response to the problems of the digital economy, the Digital Calibration Certificate (DCC) idea is being developed alongside the Digital International System of Units (D-SI) paradigm [12]. As previously stated, the significant increase in the number of calibrations necessitates automation of both the calibration technique and machine-readability for automatic analysis of issued calibration certificates [13, 15-18].

On the other hand, through a variety of recognized protocols, legal metrology relies on a set of tests, calibrations, and method assurances. Calibrations are sometimes done by hand. A type evaluation authority, or in some situations, a manufacturer, conducts in-house tests and subsequently submits a data set to a type approval authority for certification [3-4]. The type evaluation authority then stores the certificates in digital form and makes them publicly available through online access. When a legal metrology instrument is modified, the type evaluation may be revised as well. State agencies or registered service groups conduct field tests, with the results reported in a variety of ways that differ from country to another. Paper documents, hard copy files, file scans, and digital files saved locally or remotely on a cloud-like system are all examples. Overall, there is a lot of variation in how data is acquired, stored, preserved, and managed. In conclusion, switching to the DCC becomes crucial, and the above mentioned changes motive the NMIs to work on setting optimum software protocols for data storage, manipulation, and secure transfer of those data as well as planning and implementation steps for issuing DCCs, which should be a step-forward of the current available facilities and electronic management systems that currently available, to save the efforts while keeping the compatibility with the electronic management systems in hand. The following are the most frequently mentioned benefits of switching to DCC, among others:

1. DCC enables simultaneous access and use in several locations at the same time.

2. DCC's machine-readability enables for the automated verification of certificate availability, validity duration, and content information.

3. Data from the DCC can be instantly downloaded to the instrument without the need for human interaction. This reduces errors caused by manual data entry.

4. As instruments get increasingly complicated, the amount of information required in a calibration certificate grows. Because this data is available in digital form, it is easier to interact with it both manually and automatically during the measurement process.

5. The application of DCCs in practice will allow machine learning methods in artificial intelligence and IoT systems to analyze calibration data.

A digital calibration certificate (DCC) is used for electronic storage, authentication, encryption, and signing of calibration findings, as well as standard interpretation. Because the data gathered during calibration is time-consuming and error-prone, the analogue calibration certificate has rarely provided a surplus value for a corporation. The DCC compensates for this important flaw in its analog cousin. Digitally assisted manufacturing and quality monitoring processes benefit substantially from its machine readability. For a corporation that uses the DCC, this adds significant value. In addition to the DCC's structure, unique framework constraints for its transfer must be established. Cryptographic protection measures are among them. They ensure the integrity and authenticity of the DCC's contents, as well as their electronic transmission. Metrology institutes do not have the fundamental capability for acceptable processes. Previous results and outside knowledge will be utilized for this. The framework criteria, on the other hand, are set by metrology institutions, taking legislative requirements into account. The goal is to produce a DCC format that is universally recognized. In the entire field of metrology, this will be established as an exchange format. Exchange formats in legal metrology, for digital type evaluation, and for the "digital twin" (DT) should be established based on the DCC.

The general structure of a DCC is subdivided into four layers: first, Administrative data that contains information of central interest; usually found in the first page of any analogue calibration certificate. Second, measurements and calibration results. Third, any additional comments. Finally; optional version of the calibration certificate stored in PDF format, as shown in figure 1. Figure 2 also presents a demonstration to show worked example of analogue calibration certificate versus its DCC counterpart excerpt. Figure shows that the mistakes that might happen in the analogue certificate, e.g. due to OCR, is all impossible to be happened in the DCC

2. AVAILABLE E-INFRASTRUCTURE

Current e-infrastructure for processing and managing the calibration process until the issuance of the paper based and PDF calibration certificate at SASO-NMCC is based on Laboratory Information Management System (LIMS) software. The work on developing an electronic system for the creation and storage of electronic calibration certificates was carried out at NMCC (NMI of Saudi Arabia), including the development of a program that was developed as a java-applet running in a browser, with the purpose of creating an electronic calibration certificate with LIMS software e-infrastructure. The program's certificate satisfies all of the standard "ISO/IEC 17025:2017".

The brief of the steps of processing of calibration request since it is placed by the customer until the issuance of the paper certificate or PDF version is shown in figure 3(a).

Currently, the method for calibrating a measuring equipment concludes with the issue of a calibration certificate, which is normally in the form of a paper certificate or a PDF file certified by an electronic digital signature and recently with added unique QR code (figure 3 b). There are several methods for putting such files, sometimes known as electronic calibration certificates, into action. The need to adopt the so-called DCC is considered with the usage of the paper certificate as a standard and the gradual introduction of electronic calibration certificates towards developing the DCC.

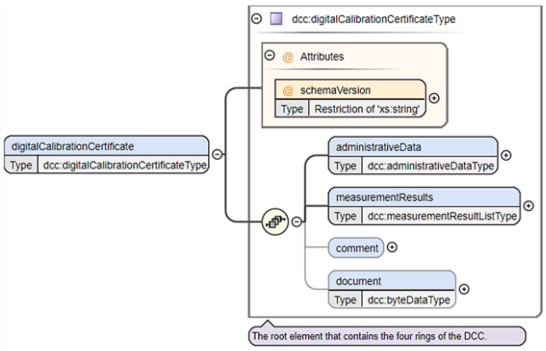

Figure 1. DCC structure, layers and type as concluded by PTB (Source: https://ptb.de/dcc) [13]

3. SASO-NMCC METHODOLOGY FOR ISSUANCE OF DCC

3.1. International reference standards for DCC

Many efforts are pushing today towards a unified structure for the DCC. The international standard ISO/IEC 17025, which deals with the general requirements for calibration laboratories, is the reference document used by reference laboratories around the world, like the Physikalisch-Technische Bundesanstalt (PTB), the Instituto Nacional de Metrologia, Qualidade e Tecnologia (INMETRO), and the National Institute of Standards and Technology (NIST), among others [1-6, 14, 15]. The items 7.8.2 and 7.8.4 - titled "Common requirements for reports (test, calibration or sampling)" and "Specific requirements for calibration certificates" - are objective in defining what is required on a calibration certificate, and item 8 adds minimal requirements for management system for assuring the quality of the laboratory results. The ISO GUM, Guides to the Expression of Uncertainty in Measurement, defines, among other references and standards, the vocabulary to be used in documents that deals with expressing uncertainty in measurement [1-3, 8, 12, 14]. Such documents are used to guide the requirements for what needs to be implemented in our software tools.

VDI/VDE-2623 establishes a rigid Extensible Markup Language (XML) data structure with both required and

Figure 2. Example of analogue calibration certificate and its DCC counterpart excerpt. Figure shows that the mistakes that might happen in the analogue certificate, e.g. due to OCR, is not possibly happen in the DCC.

optional fields. While some of the data covered by this standard may not be applicable in every situation, using the work already conducted in developing the data structure is ideal for moving this effort forward in a meaningful way [14-15].

3.2. Data structure

Data format, storage, delivery, and operating techniques requirements for DCC can be summarized as follows, among others:

1. The data format must be unique and internationally recognized, 2. When transferring, DCCs must maintain readability, integrity, consistency, and authenticity; there should be no linkages or pathways in the data. That may be dependent on the system in which it was implemented and created, and the data interpretation should be unambiguous, 3. Should include a qualified/advanced electronic signature that is appropriate for internal transactions (electronic authentication, identification) and the Regulation on Trust Services), which uniquely identifies the signatory, as well as his organization and proof of the document's consistency, 4. The user's digital certificate should be valid at the time of signing with an electronic signature, as well as the identity of the signatory, his role, and affiliation with a specific organization, 5. Should be able to ensure that personal data is kept private when working with and keeping it, 6. The capacity to communicate data across different applications should be interoperable, 7. The possibility to automate conversions to different application formats should be available, 8. Allow for the replacement of entire services or tools as well as individual components, 9. Should allow for safe operation without the requirement for specialized knowledge, 10. Data controllability when working with them is protected, 11. Data validation and verification should be provided, and 12. Should have scalability and modularity qualities, i.e., the ability to supplement, change, and replace with unambiguous identification of all alterations and, in the case of a complete replacement, an unambiguous reference to the original document.

3.3. Possibilities for used programming language

We looked into numerous different formats for implementing this standard data structure. While XML is a common structure that is used by the VDI standard, we discovered that an alternative, External Machine Interface (EMI); which is an extension to Universal Computer Protocol (UCP), may offer a more flexible use case. Although EMI is generally utilized in Short Message Service (SMS) applications, its string-based structure is more versatile and could be used to generate any other format. Hexadecimal or ASCII encoding is used by EMI, which means it is based on known common technology. It would also be encryptable, which is another advantage [14].

3.4. Proposed digital infrastructure system

Our system starts with accepting calibration requests from any customer via our website. The request is processed by the LIMS software which controls the documentation of all processes starting from registering of the equipment up to issuance of electronic calibration certificate. Different types of data are exchanged from the LIMS database and also, as per our proposal, from SASO/GULFMET clouds and fed into the DCC issuance software in the future. As an optional part of DCC, the PDF version of the output certificate should be reviewed by the calibration engineer and finally should be digitally signed.

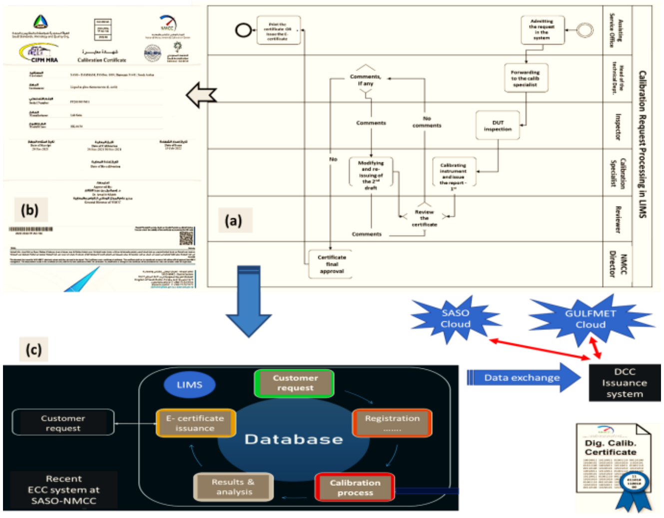

Figure 3. (a) Calibration request processing within the current e-infrastructure (LIMS-based) until issuing the PDF certificate, (b) sample calibration certificate generated by the system with QR code and (c) proposed smart e-infrastructure system for developing DCCs.

3.5. *Worked example*

In Figure 4, an example of the calibration section of a digital certificate in a XML format, with information regarding calibration result, ambient conditions, traceability, used technical procedure, among others. This pieced of code is used to produce the PDF file without reducing the quality of figures, even for high quality printouts.

```xml
<calibration>
  <inspection_plan>
    <id>PP1234</id>
    <description>Bloco Padrão 150 mm</description>
    <calibration_procedure>PT1010011501</calibration_procedure>
    <characteristics>
      <character>
        <supplier_character_id>A17300</supplier_character_id>
        <buyer_character_id>1</buyer_character_id>
        <class>000</class>
        <designation>Erro de medição</designation>
        <type>002</type>
        <nominal_value>0</nominal_value>
        <upper_limit>30.2</upper_limit>
        <lower_limit>-30.5</lower_limit>
        <unit>4H</unit>
        <result_value>20</result_value>
        <uncertainty>10</uncertainty>
        <unit_uncertainty>4H</unit_uncertainty>
        <compliance>001</compliance>
        <remark>4H código comum para µm</remark>
        <attributes>
          <attribute>
            <class>001</class>
            <designation>temperatura ambiente</designation>
            <value>20.5</value>
            <upper_limit>21.5</upper_limit>
            <lower_limit>19.2</lower_limit>
            <unit>CEL</unit>
            <remark>CEL código comum para temperatura em graus Celsius</remark>
          </attribute>
          <attribute>
            <class>001</class>
            <value>22</value>
          </attribute>
        </attributes>
        <traceabilities>
          <traceability>
            <id_number>PN98656782</id_number>
            <test_equipment_notation>Conjunto de 10 partes</test_equipment_notation>
            <last_calibration_date>2018-02-28</last_calibration_date>
            <last_calibration_certificate_number>K5987720</last_calibration_certificate_number>
```

Figure 4. Example of a digital certificate in a XML format.

We believe that all calibration labs should use standard capabilities and tools from PTB [1] as well as the programming environment of Excel for the visual generation of a DCC in an Excel workbook [2]. The basic structure schema of the Excel tool supported by PTB is shown in figure 5. Moreover, the first lines of the dcc.xsd file, version 2.3.0. is shown in figure 6 [2].

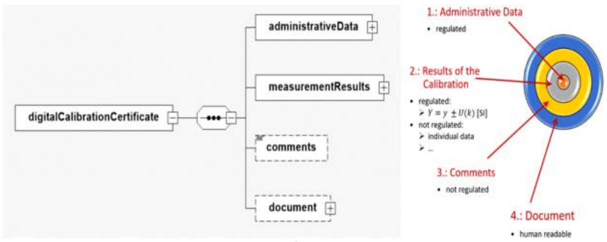

Figure 5. The basic structure of the DCC generation tool (Source: https://dccwiki.ptb.de/en/root).

```xml
<?xml version="1.0" encoding="UTF-8"?>
<xs:schema version="2.3.0" xmlns:xs="http://www.w3.org/2001/XMLSchema"
           xmlns:dcc="https://ptb.de/dcc"
           xmlns:si="https://ptb.de/si"
           targetNamespace="https://ptb.de/dcc"
           elementFormDefault="qualified">

   <xs:import
          namespace="https://ptb.de/si"
          schemaLocation="https://ptb.de/si/v1.3.0/SI_Format.xsd"/>
...
   <xs:complexType name="digitalCalibrationCertificateType">
       <xs:sequence>
          <xs:element name="administrativeData" type=
          "dcc:administrativeDataType"/>

          <xs:element name="measurementResults" type=
          "dcc:measurementResultListType"/>
```

Figure 6. the first lines of the dcc.xsd file, version 2.3.0. as represented by [10].

4. CONCLUSIONS

The transformation towards digital metrological services starts with a DCC. In this work, we described the proposed system for issuing DCC at SASO-NMCC. Our system gets its basic information from our e-certificate infrastructure which was built based on LIMS software. The system communicates with customers and national standards communities via metrology clouds (SASO Cloud and GULFMET cloud). Moreover, the system can communicate with recent artificial intelligence applications and Internet of Things (IoT). We believe that there are many other steps required for complete digital metrological activities. we also believe that additional standardization discussions regarding the formatting and representation of measurement data and metadata are required towards machine actionable DCCs.

REFERENCES

[1] Siegfried Hackel, Frank Hartig, Julia Hornig, and Thomas Wiedenhofer, *The Digital Calibration Certificate*, PTB-Mittelungen 127 (2017), Heft 4.

[2] Metrology for the digitalization of the economy and society, German Government Report, 2017.

[3] OIML webinar on “Digital Transformation of Metrology”, May 5th 2021.

[4] Katya Delak, Bob Hanisch, and Chuck Ehrlich, Why the Recent Global Attention on Digital Transformation in (Legal) Metrology?, Measurement Matters, VAOL. 11, Issue 4, October 2021.

[5] Pavel Neyezhmakov, Stanislav Pivneko, and Sergei Zub, Electronic Calibration Certificate, XXI IMEKO World Congress, “Measurement and Research and Industry”, Prague, Czech Republic, 2015.

[6] Pavel Neyezhmakov, Stanislav Zub, Stanislav Pivnenko Preliminary E-infrastructure for Digital Calibration Certificate, Measurement: Sensors 18 (2021) 100332.

[7] Gregor Boschung, Michael Wollensack, Markus Zeier, C´edric Blaser, Christian Hof, Manuel Stathis, Peter Blattner, Florian Stuker, Nina Basic, Federico Grasso Toro, PDF/A-3 solution for digital calibration certificates, Measurement: Sensors 18 (2021) 100282.

[8] F. Thiel, et al., A Digital Quality Infrastructure for Europe: The European Metrology Cloud, *Metrologie für die Digitalisierung von Wirtschaft und Gesellschaft*, 2017, p. 83.

[9] EURAMET, TC IM, Development of Digital Calibration Certificates, 1448. https://www.euramet.org/technical-committees/tc-projects/details/project/development-of-digital-calibration-certificates .

[10] Dirk R¨oske, A visual tool for generating digital calibration certificates (DCCs) in Excel, Measurement: Sensors 18 (2021) 100175.

[11] T. Bruns, J. Nordholz, D. R¨oske, T. Schrader, “A demonstrator for measurement workflows using digital calibration certificates (DCC)”, Submitted to *XXIII IMEKO World Congress*, 30 August – 3 September 2021, Yokohama, Japan.

[12] D-SI schema definition [accessed 01 March 2021], https://ptb.de/si/v1.3.0/SI_F ormat.xsd.

[13] DCC schema definition [accessed 01 March 2021], https://www.ptb.de/dcc /v2.3.0/.

[14] A Proposal for a Standard Calibration Data Format, Fluke White Paper.

[15] https://github.com/ericoporto/DistributedDigitalCalibrationCertificate.

[16] B.D. Hall and D.R. White, Digital representation of measurement uncertainty, Measurement: Sensors 18 (2021) 100074.

[17] Andre Schaefer, A high-precision measurement chain for reference purposes, Measurement: Sensors 18 (2021) 100085.

[18] B. D. Hall and M. Kuster, Metrological support for quantities and units in digital systems, Measurement: Sensors 18 (2021) 100102 .