Recent advances in Inmetro's Digital Calibration Certificates (DCCs) implementation

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Abstract. This paper presents recent advances in implementing a framework for Digital Calibration Certificates (DCCs) at laboratories within the Electrical Metrology Division of Inmetro. We developed an Application Programming Interface (API) using the Python programming language to generate DCCs from calibration data in JSON or Excel format. We also created an NI LabVIEW VI to read and extract calibration data from the DCCs to update the laboratory calibration database automatically. Using these newly developed tools, we were able to run a pilot of a fully automated calibration process, taking advantage of the machine-readability of DCCs to improve the automation of the whole calibration workflow.

Keywords: Digital Transformation, Digital Calibration Certificate, Automation, Database, Metrology 4.0

1. Introduction

"Digital Transformation" is an emerging topic in many areas, including metrology. One of the implications of the digital transformation of metrology is the shift from analog, paper-based Calibration Certificates to their digital counterpart: the Digital Calibration Certificate (DCC). In this context, when we add "D" (digital) to "CC" (calibration certificate), we are not simply converting the physical paper calibration certificate into a digital file (such as a PDF file, for example). The goal for a "true digitalization" is to use data structures that enable "machine-readability" of the calibration certificates, aiming for seamless integration to automated systems [1][2].

The concept of a Digital Calibration Certificate (DCC) was first proposed by Physikalisch-Technische Bundesanstalt (PTB) in 2017 [3]. One of the key features of the DCC is that it must be machine-readable. The concept proposed by PTB utilizes XML as the data exchange format, a machine-readable format that is also readable by humans. The XML format is also suitable for long-term storage, which is a crucial aspect, since the calibration certificates must still be legible for several decades. The XML format is also ideal for cryptographic methods (digital signatures), which are essential for the trust chain of calibration certificates.

In a previous work [4], we presented the development of the software framework *DCC Tools*, a set of open-source Python scripts for the generation of DCCs using the XML format, following the DCC Schema proposed by PTB [1][3]. Now we will present the recent advances in this development, including a pilot of a fully automated calibration workflow between two laboratories of Inmetro using DCCs.

2. DCC Generation

For the generation of the DCCs, we are using a set of software tools that we have implemented and presented in a previous work [4]. The software provides an Application Programming Interface (API) for generating DCCs. The API utilizes a simplified JSON schema for data input and is designed for integration with existing calibration/laboratory management systems that already incorporate some degree of automation. We also provide a user interface (web page) for users who prefer to upload an electronic spreadsheet (Excel) with the calibration data. This approach is more suitable for laboratories that rely on electronic spreadsheets for the calibration workflow, with or without automation. Figure 1 shows block diagrams for the endpoints of the API used to generate DCCs.

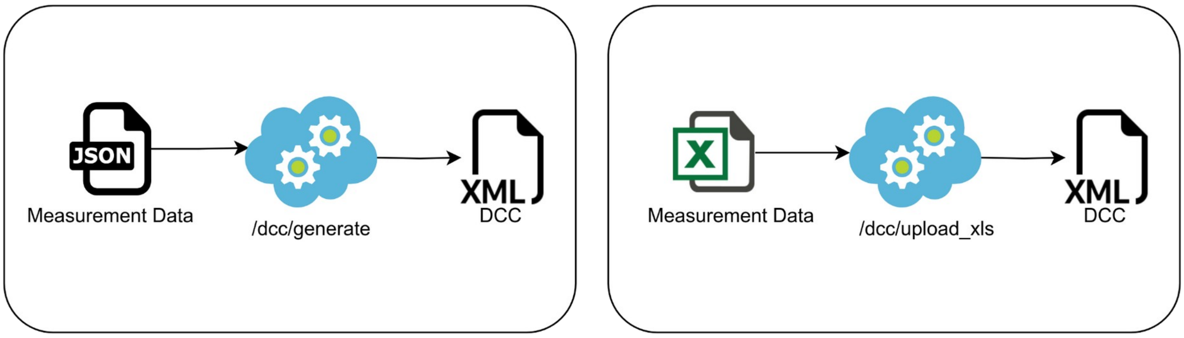

Figure 1. Application diagram. The route '/dcc/generate' accepts JSON data in an HTTP POST request and returns a DCC XML file. The route 'dcc/upload_xls' accepts an Excel spreadsheet file in an HTTP POST request encoded as multipart/form-data and returns a DCC XML file.

It is essential to point out that PTB already provides a tool for interactively building DCCs, the GEMMIMEG Tool [5]. However, as warned on its own welcome screen, the GEMMIMEG Tool is intended for educational purposes and testing, and is not recommended for use in a production environment. The software tools that we are proposing, on the other hand, are designed for integration with the existing calibration software, aiming for a seamless transition from paper (or PDF) based calibration certificates to DCCs.

We have improved the software tools to cover a wide range of calibration certificates, including multiple measurement points, multiple quantities, and refTypes [6][7]. We can see refTypes like a digital vocabulary, and they play a key role in the machine-readability of DCCs. We have also made some changes to the software architecture. We have designed the initial version of the software using cloud-based serverless architecture (AWS Lambda) [4]. Now, we also provide a Python Flask application, utilizing a more traditional client-server architecture, along with Docker scripts for quick and easy deployment. The application is available on GitHub [8]. We provide a simple user interface for testing purposes that can be accessed in a web browser, as shown in Figure 2. The user interface offers the user the option to download a working example.

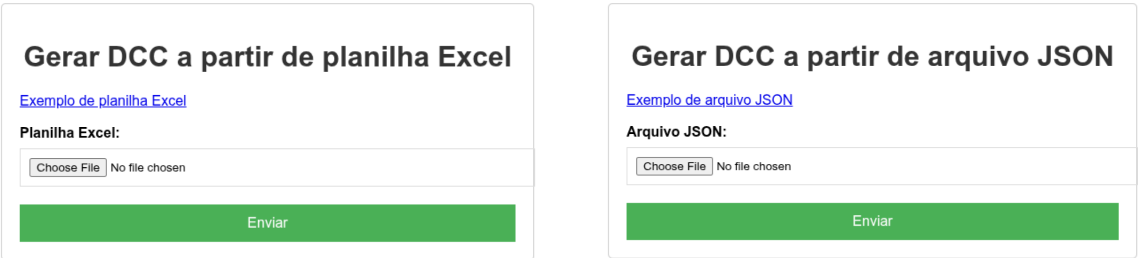

Figure 2. User interface for the API. The user can upload an Excel spreadsheet (on the left) or a JSON file (on the right).

2.1 Human-readable version

Initially, we have developed software tools to embed and extract the human-readable version of the calibration certificate (typically a PDF file) into the XML file by converting it to a base64 string, strictly following the PTB DCC schema (using the optional document section of the schema). In this approach, the calibration certificate is simply an XML file, and the issuing laboratory can include a human-readable version within it. On a technical point of view, this approach is more elegant, favoring machine-readability over human-readability. We can point out other advantages, such as a better adherence to FAIR principles (Findable, Accessible, Interoperable, Reusable) [9].

Nevertheless, considering a practical implementation in today's reality, with the current level of digitalization in the majority of calibration laboratories, this solution is not feasible. To overcome this limitation, we are developing an alternative approach that facilitates a seamless transition between conventional PDF certificates and DCCs: we are incorporating the DCC XML as an attachment within a PDF/A-3 file. With this approach, customers would still receive a digitally signed PDF calibration certificate, as they are used to, but now an XML file with the DCC is attached to the PDF file. With this approach, the machine-readable XML file is easily accessible within the PDF file, and customers with a more advanced information technology infrastructure could benefit from it. We also include a text file named SHA256SUM.txt with the SHA256 [10] hash sum of the attached file so that the customer can confirm the integrity of the attached XML file. This solution was based on the work developed by METAS [2] and, in our opinion, is more adequate for a smooth transition to digital calibration certificates. Figure 3 (left) shows the block diagram of the route provided by the API.

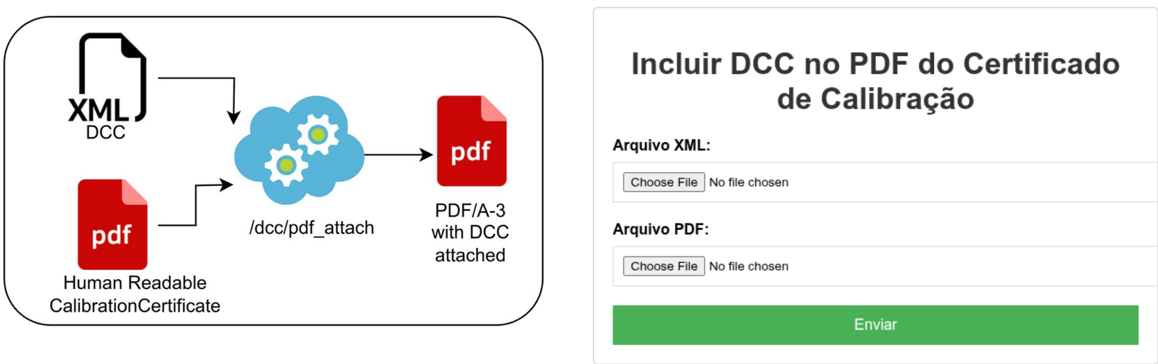

Figure 3. Block diagram of the route 'dcc/pdf_attach' (left picture). The route '/dcc/pdf_attach' accepts an XML and a PDF file in an HTTP POST request, encoded as multipart/form-data, and returns a PDF/A-3 file with the XML file attached. This function can be accessed directly via the '/dcc/pdf_attach' route or via the user interface (right picture).

Most PDF reader applications support attachments in PDF/A-3 files. Figure 4 shows how the attachments can be accessed in Adobe Acrobat Reader and in Mozilla Firefox.

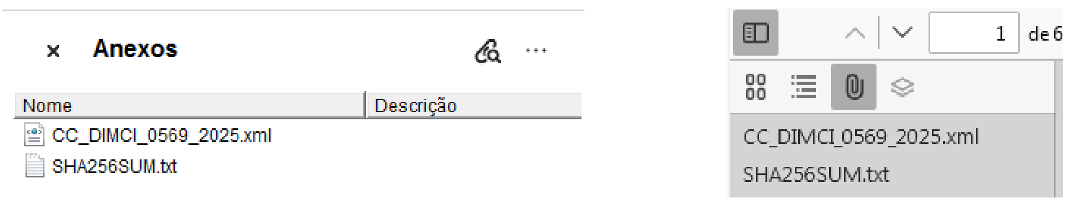

Figure 4. PDF attachments in Adobe Acrobat Reader (left) and Mozilla Firefox (right).

2.2. Simplified JSON schema

The PTB's DCC schema is quite complex because it aims to encompass nearly all possible calibration certificates, ranging from those issued by National Metrology Institutes (NMIs) to those from industries [6]. Initially, calibration laboratories may find it daunting to work with this schema due to the numerous optional fields and the effort required to translate their existing paper-based or PDF calibration certificates into the DCC format. It will take some time to understand how to navigate this structure fully.

To make the process of creating a DCC more suitable for Inmetro's laboratories, the first step was to map the data fields of our current PDF-based calibration certificate to a simple JSON structure (that can be translated directly to an electronic spreadsheet for a more accessible input format). Figure 5 shows the JSON representation of the administrative data of a calibration certificate issued by a calibration laboratory of Inmetro. We designed this JSON schema for a nearly direct correspondence with the data fields of the physical (PDF-based) calibration certificate model.

```json
{
 "nome_lab": "Laboratório de Metrologia em Padronização Elétrica",
 "sigla_lab": "Lampe",
 "nome_div": "Divisão de Metrologia Elétrica",
 "sigla_div": "Diele",
 "num_certif": "0856/2024",
 "num_processo": "0052600.003988/2023-06",
 "tipo_item": "Padrão de Transferência AC-DC",
 "fabricante": "Fluke",
 "modelo": "792A",
 "num_serie": "6515002",
 "cod_identificacao": "PT-030",
 "caracteristicas_item": "Função: Transferência Térmica de Tensão AC-DC",
 "data_calibracao": "2024-08-07",
 "data_emissao": "2024-08-07",
 "cmc": true,
 "chefe_div": "Edson Afonso",
 "chefe_lab": "Gean Marcos Geronymo",
 "tecnico_executor": "Gean Marcos Geronymo",
 "desc_tecnico_executor": "Técnico Executor",
 "cliente": {
  "nome": "Inmetro/Dimci/Diele/Lacel",
  "email": "lacel@inmetro.gov.br",
  "cidade": "Duque de Caxias",
  "pais": "BR",
  "cep": "25250-020",
  "uf": "RJ",
  "endereco": "Av. Nossa Senhora das Graças",
  "numero": "50"
 },
```

Figure 5. JSON representation of the calibration certificate administrative data.

We designed the first version of our software tools for simple calibration certificates of just one measurement result and its respective measurement uncertainty [4]. We have now improved the software to accommodate a more general case, featuring multiple measurement points (including various indexes, such as currents, voltages, and frequencies) and multiple quantities (for example, AC resistance, DC resistance, and time constant). Figure 6 illustrates the implementation of this solution.

The keys "mensurando" and "indices" can have multiple entries, allowing us to define various quantities and multiple indices for each quantity. For example, for the "acdc" quantity (AC-DC transfer difference), we can have multiple indices, such as range, voltage, and frequency. Finally, in the "resultados" key, we can send the measurement results, referenced to each quantity and each index, with their respective measurement uncertainty, as shown in Figure 7.

The simplified JSON schema was mapped to an Excel spreadsheet, allowing users with more basic information technology knowledge to also utilize the software to generate DCCs.


```
"mensurando": [
  {
    "label": "acdc",
    "name": "Diferença AC-DC em tensão",
    "col_name": "\\delta_u",
    "unit": "\\micro\\volt\\volt\\tothe{-1}",
    "unc_relativa": false
  },
  {
    "label": "rstdc",
    "name": "Resistência em Corrente Contínua",
    "col_name": "V.m.",
    "unit": "\\ohm",
    "unc_relativa": true
  }
 ]
```

```
"indices": [
  {
    "mensurando": "acdc",
    "label": "faixa",
    "name": "Faixa",
    "unit": "\\volt"
  },
  {
    "mensurando": "acdc",
    "label": "voltage",
    "name": "Tensão",
    "unit": "\\volt"
  },
  {
    "mensurando": "acdc",
    "label": "frequency",
    "name": "Frequência",
    "unit": "\\kilo\\hertz"
  },
  {
    "mensurando": "rstdc",
    "label": "current",
    "name": "Corrente",
    "unit": "\\ampere"
  }
]
```


Figure 6. JSON definition of multiple quantities (left) and multiple indexes (right).


```
"resultados": [
  {
    "mensurando": "acdc",
    "faixa": "0.022",
    "voltage": "0.002",
    "frequency": "0.01",
    "value": "-280",
    "unc": "44",
    "k": "2.13"
  },
  {
    "mensurando": "acdc",
    "faixa": "0.022",
    "voltage": "0.002",
    "frequency": "0.02",
    "value": "3",
    "unc": "37",
    "k": "2.28"
  },
```

```
  {
    "mensurando": "acdc",
    "faixa": "0.022",
    "voltage": "0.002",
    "frequency": "0.04",
    "value": "38",
    "unc": "36",
    "k": "2.21",
  },
  {
    "mensurando": "acdc",
    "faixa": "0.022",
    "voltage": "0.002",
    "frequency": "0.055",
    "value": "74",
    "unc": "51",
    "k": "2.65",
  },
```


Figure 7. JSON definition of the measurement results.

2.3 Integration with the laboratory's automation system

The pilot DCC implementation involved two laboratories of Inmetro's electrical division: the Laboratory of Electrical Standards (Lampe) and the Laboratory of Electrical Calibration (Lacel). Since Lampe provides metrological traceability to most of Lacel's standards, and both laboratories utilize automated, integrated systems to manage laboratory activities, this is a perfect use case where the machine readability of DCCs can be beneficial in improving the calibration workflow.

The laboratory Lampe uses an integrated web-based system (called SYS-LAMPE) to manage the calibration activities, including the generation of measurement reports and calibration certificates in PDF format [11]. SYS-LAMPE's database stores all the calibration data generated in different measurement systems, including in-house developed LabVIEW measurement software, C++ measurement software, and proprietary measurement software from Measurement International Limited. Since all the calibration data is already structured and stored in a SQL database, it was relatively easy to structure the data in JSON format and send it to the API to obtain a DCC in XML format. The next step was to embed the XML file generated by the API in the PDF-based calibration certificate produced by SYS-LAMPE. Figure 8 shows the integration between SYS-LAMPE and the developed API as a block diagram.

The laboratory Lacel adopts a similar approach, with variations in the data structures and development platforms used. Most measurement applications are developed using NI LabWindows and NI LabVIEW, with data stored in MS Access databases. A Microsoft Visual Basic application is responsible for generating the calibration certificates, using a dedicated MS Access database. An NI LabVIEW VI was developed to access the certificate database, convert the data into JSON format, and send it to the API that generates the DCC XML. This workflow is part of Lacel's automated calibration system and is presented in Figure 9.

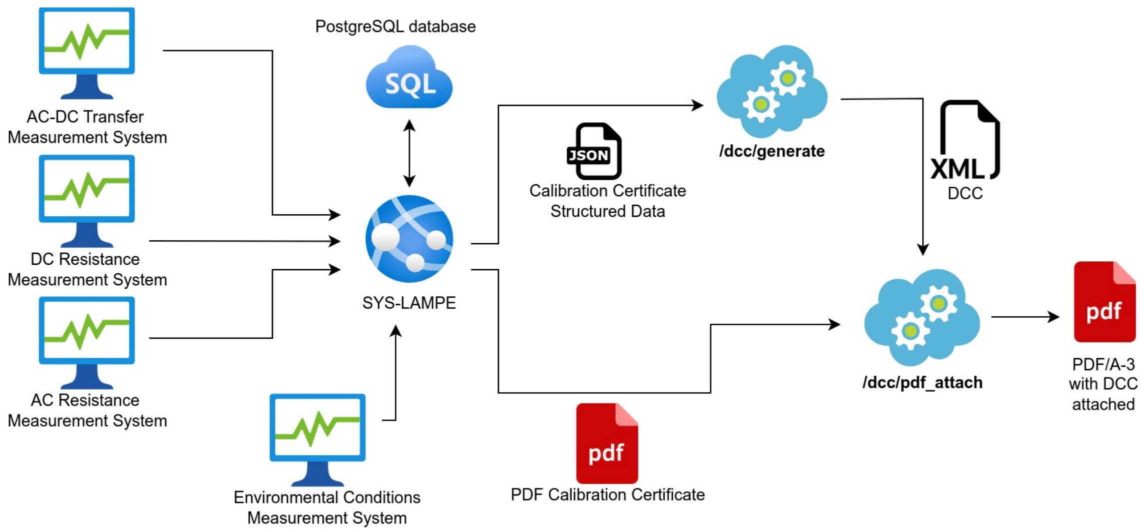

Figure 8. Integration with a laboratory’s calibration management system (SYS-LAMPE).

3. DCC Processing

For machine interpretability, DCCs provide context through their inherent structure and through attributes such as id, refId, and refType [12]. While id and refId are used within a specific DCC, refType attributes are designed to offer broader context, with certain refType sets requiring harmonization, including basic and community-specific namespaces [12]. For this initial version, we are using the harmonized refTypes provided by the German Calibration Service [13]. The basic refType encompasses terms commonly used across metrology domains, such as measuredValue or serialNumber [13].

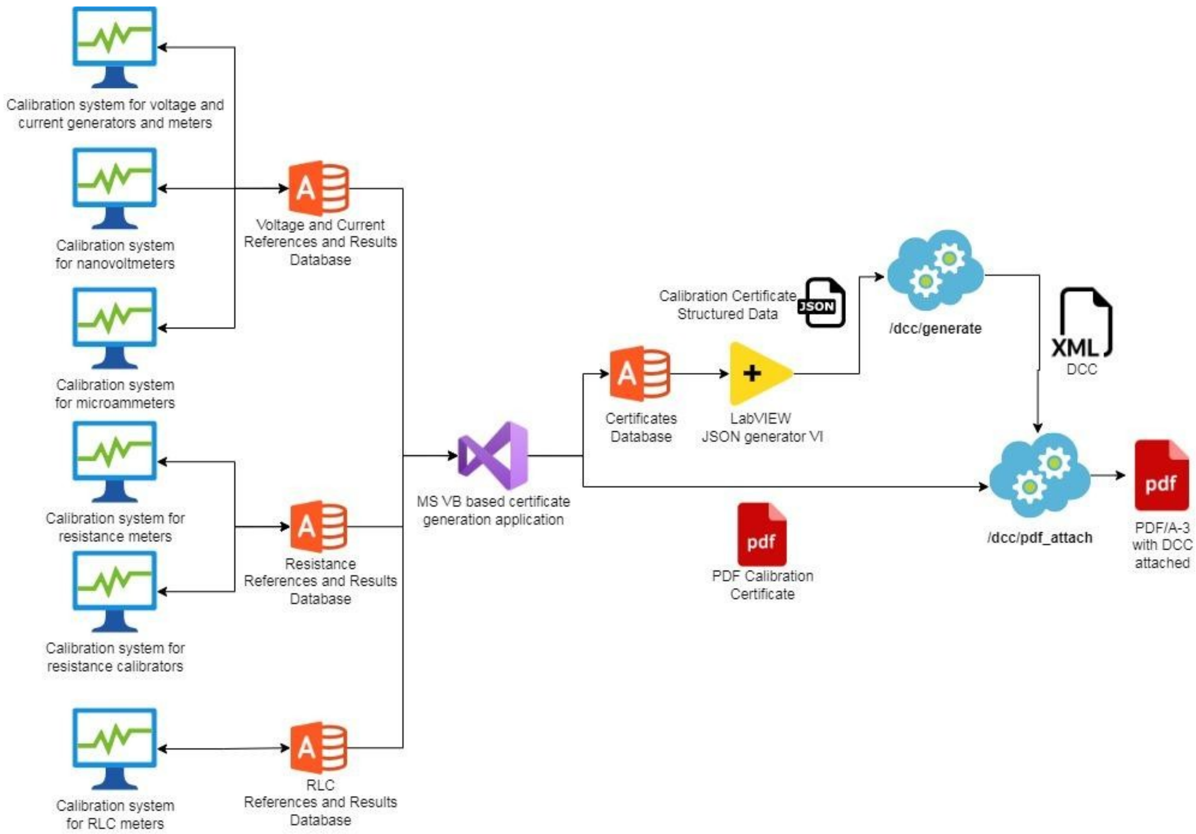

Figure 9. Workflow of the Interrelation Between Lacel's Systems.

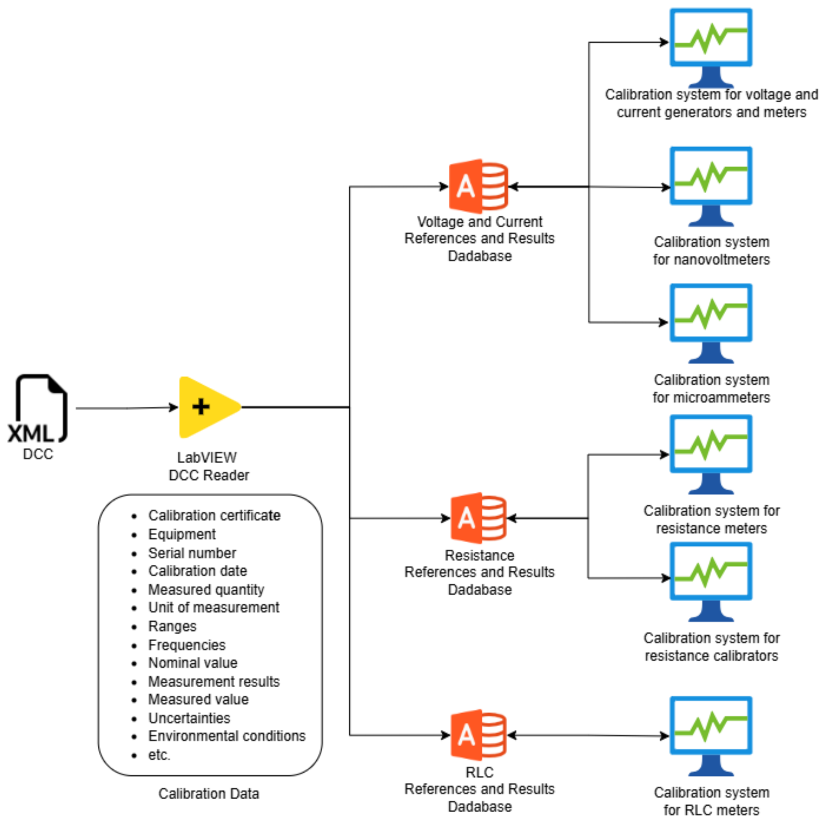

Figure 10. Workflow of the DCC Reader VI with Lacel's Systems.

The development of a DCC ontology is essential for a standardized framework that facilitates seamless interoperability and automated processing of calibration data. An ontology formally represents concepts, relationships, and properties within a domain, enabling the structured sharing of knowledge and the automation of reasoning [12]. Inmetro is working on the development of a DCC ontology that will be published as a publicly accessible database with permanent identifiers (PIDs). As soon as Inmetro's DCC ontology is available, we will update our software to reference the refTypes from that database.

For this pilot study, the first solution designed to connect DCCs with the automated measurement systems already in use at the Lacel laboratory was the creation of a single NI LabVIEW VI, capable of extracting the necessary data from the DCC and automatically updating the reference databases of standard equipment used in different measurement systems. We are also studying the use of the publicly available pyDCC library [14] for an alternative approach using the Python programming language.

4. Conclusion

This work presented the first pilot implementation of a fully automated calibration workflow using DCCs at Inmetro. Since it is a small-scale test for now, we cannot fully measure the productivity gain of using DCCs in this scenario at this moment. Still, it definitely opens up many possibilities for the future. The simple fact of avoiding the manual typing of calibration data from calibration certificates that can have up to 500 calibration points is a considerable gain of time and eliminates the possibility of transcription errors. The approach of maintaining a database with the calibration data of each standard may be replaced by a new approach where the calibration software reads the data directly from DCCs, implementing a nearly transparent traceability chain. The implementation of DCCs is a highly discussed topic at the moment, and it is a necessary step to take metrology into the digital age. However it comes with many challenges, especially on the technical aspect, regarding harmonization [15]. RefTypes play a key role in the harmonization and machine-readability of DCCs. For this moment, we are using the harmonized refTypes provided by the German Calibration Service [13], as stated in section 3, but, at this moment, this list does not provide refTypes for many areas, including electrical metrology, for example.

Up to now, the PTB DCC schema seems to be the most advanced initiative, but we do not have a commonly agreed international format yet. Currently, we have several working groups established to support the implementation of DCC, as the FORUM TG-H-DCC/DRMC [16], for example, whose goal is to develop a harmonized approach to DCCs and DRMCs (Digital Reference Material Certificate) that meets the international metrological requirements and standards. We also need to mention the BIPM's SI Reference Point [17], a set of tools designed to provide an authoritative digital reference to the SI, designed to be fully adherent to FAIR principles and machine-actionable [17]. A unique DCC format for worldwide use is utopian, but at least some harmonization should be achieved for large-scale worldwide adoption of DCCs. Initiatives like the FORUM TG-H-DCC/DRMC and the SI Reference Point are crucial for achieving this objective.

5. References

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