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IMPLEMENTATION OF A SCIENTIFIC METROLOGY CLOUD KERNEL AS A BYPRODUCT OF THE DIGITAL TWINS

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Abstract – The Metrology Cloud has been described and implemented at some degree for several National Institutes of Metrology (NMI) or Designated Bodies, typically with emphasis in the Legal Metrology aspects, however, there is a lack of coverage for Scientific Metrology aspects. The paper first describes the situation at a specific NMI, then details the used procedure to find a solution and briefly provides examples for time conditioned properties, time dependent behavior, and virtual measuring instrument's simulated response, finally the results are revised, and future work is listed besides conclusion.

Keywords: digital transformation, digital twin, digital shadow, virtual instrument, middle ware, metrology cloud

1. INTRODUCTION

Digital transformation (DT) has been in the mind-set of industry and academia community for a decade by now [1], just recently it became the buzzword for the Information Technology and Metrology communities. The scope of DT for Metrology is both ways, the impact of DT on Metrology (DT4M) and the evolution of Metrology for DT to meet the future needs of a DT reality (M4DT). DT4M & M4DT has many faces and multiple edges, from the digital service certificate (calibration, proficiency testing, model approval, periodic verifications, etc.) and virtual measuring instruments (models, shadows, and twins) to new metrological services for smart devices [2]. Many of the topics are interrelated or even coupled. One of these key elements is the Metrology Cloud (MC) [3, 4, 5] which would serve as a platform and knowledge repository for the services and the measurements at least at some administrative level. While a lot of work has been done from the Legal Metrology's point of view [3, 4, 5], no work is known for the Scientific Metrology community needs in the scope of a National Metrology Institute (NMI) within the corresponding National Quality Infrastructure.

The digital calibration certificate (DCC) [6] is an ongoing project, with a plan that spans over several years. The implementation of DCC at Centro Nacional de Metrología (CENAM) of Mexico has been in progress since 2019. The need for exploring and analyzing data led us to implement some sort of Digital Twins of specific calibrated instruments, and in consequence to the development of a management environment for them. One of the problems we faced is the existence of many single calibration repositories, usually implemented in data acquisition programs and electronic spreadsheets, serving as separate calibration data storage repositories, with its corresponding data structure, data validation, data analysis, data visualization and so on. Also, there is a lack of an architecture to support easy access and search of related data, for example, finding all the calibration certificates for a single instrument, the instruments of the same client or owner, all the instruments of the same brand and model. The single calibration repositories are in most of the cases in isolated computers as a mean of keeping unauthorized users accessing the related data but making the data searchable increasingly difficult.

While the initial approach was to digitalize some instruments for digitally replicating the calibration certificate in mind as a DCC. It rapidly grew to assess the reported models that describe the instruments. To finally test for consistency in the long run, and to question the practices in place, some of them were traced back to ISO guidelines. In this paper I will present a scientific metrology database schema which is currently in development at CENAM.

2. USED METHODS AND PROCEDURES

The process started by studying and implementing a DCC, then recognizing the DCC is a data exchange standard for calibrations, to evolve into a structured database schema for storing the persistent data of the measuring instruments. The simpler structure of a point measurand was implemented and tested first, this is good for punctual characteristics of the item under calibration such as electrical resistance, gauge block length or the concentration of amount of substance in a chemical certified reference material. Later the system was extended to support a one-dimensional response function, it was implemented and tested, this is required for measurands that vary by an index-controlled variable, such as a microphone sensibility as a function of the controlled applied frequency, a balance indication as a function of controlled standard weights, or a thermometer indication as a function of the controlled temperature.

2.1. Time conditional response

The typical response of the virtual measuring instrument is built by assuming there are no time dependencies. This is done by using two independent models: an interpolation nominal response model and an interpolation uncertainty model.

Fig. 1 and Fig. 2 show the error (bias) model and the uncertainty model as functions of a new indication for an analytical balance, respectively. The error (bias) model is not statistically significant when considering the uncertainty attached to each observed point and the best estimate is the zero-error model. This is in accordance with the conclusion stated in [7].

The fitted models for bias and uncertainty conditioned on time and unconditional models were treated following the techniques described in [7].

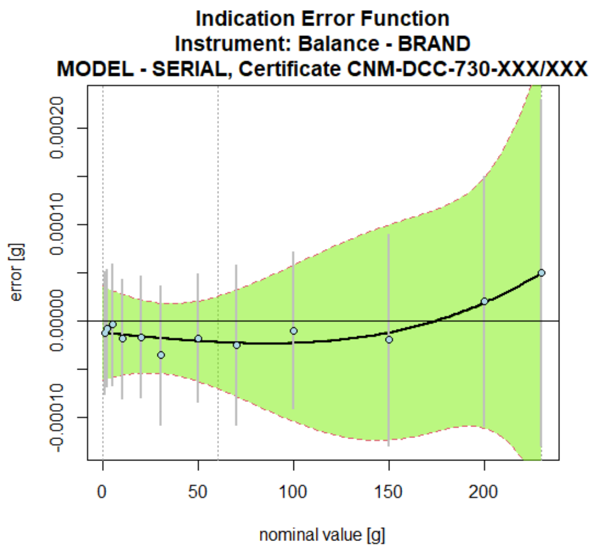

Figure 1. Error modelling as a continuous function of the nominal indication value. The discrete observed values are displayed as blue filled dots, the grey lines stand for the expanded uncertainty of the error. The black line is the predicted error, the dashed red lines represent the 95% probability confidence band of the error model.

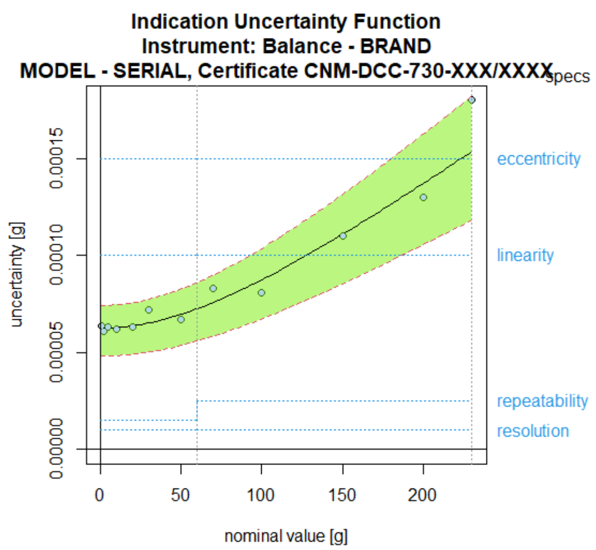

Figure 2. Uncertainty modelling as a continuous function of the nominal indication value. The discrete observed values are displayed as blue filled dots. The black line is the predicted uncertainty, and the dotted lines represent the confidence band. On the right side some of the device metrological characteristics as described in its specification.

A routine task while performing the data analysis and modelling the response either bias or uncertainty is the need to test for significant parameters. This task is well documented in the specialized literature however there is a lack of readily available tools for implementing these tasks. The developed environment considers a set of criteria for conducting these tests, such as the adjusted R square, the mean square error, and the Mallows' criteria [8]. Fig. 3 shows an example of the module for searching an optimal polynomial model.

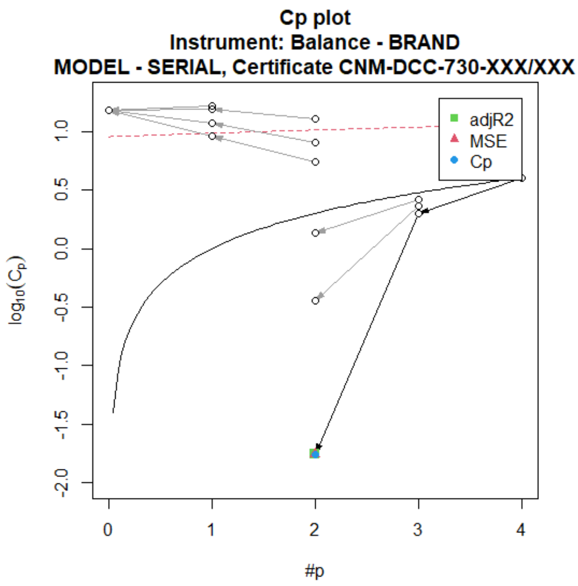

Figure 3. Searching for an optimal error modelling as a polynomial of the nominal indication value. The empty dots represent the evaluated criteria for the specific evaluated models. The x-axis shows the number of parameters used in the model. The black line is the expected value of the criteria and the doted red line represents the upper confidence band. The arrows start from a more complex model and point to a suggested reduced model due to the lack of evidence to support the starting model.

Much effort is spent in calibration processes to accomplish a good modelling for the response and its uncertainty of a measuring device. If a new indication is observed then some sort of interpolation is used to infer the error or correction and its associated uncertainty, in some cases the maximum of the nearest calibrated points (from above and below the observed indication) is used.

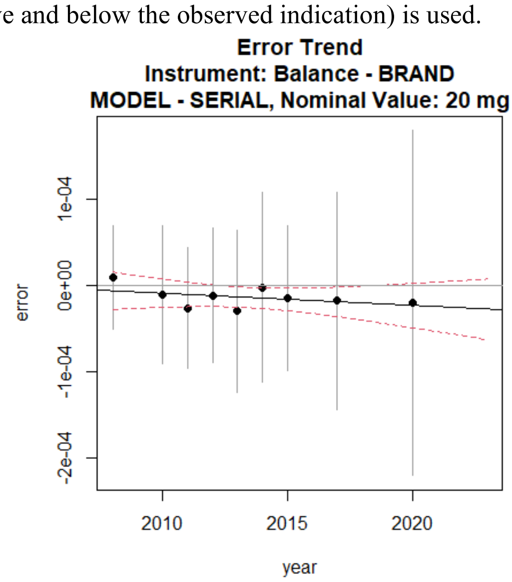

Figure 4. Combining drift information with extrapolated uncertainty to verify good operational conditions, filled dots

represent the error in grams, the grey bars represent the expanded uncertainty of the error with a coverage probability of 95% approximately, the black line represents the fitted line for a probable trend with dotted red lines representing the 95% confidence band for the model ignoring the uncertainty, the horizontal blue dotted lines stand for the estimated linearity uncertainty of the measuring instrument over time.

Statistical control charts can be tailored for each single measurand obtained with a measuring instrument. Fig. 4 shows a control chart for the analytical balance example at a nominal value. The Digital Twin Management System handles a basic mechanism for disclosing the sensitive data of the measuring instrument, as the current brand, model, and serial number.

2.1. Time dependent response

When data from the same measuring instrument is available over time, new time related analysis can be performed, such as statistical control charts, trend analysis, recalibration period estimation or even prognostic analysis and predictive maintenance. The statistical control charts usually assume the observed process is in stationary conditions and it is used to detect changes probably due to assignable causes. The later ones require modelling time dependencies as time functions.

While the time conditioned models tend to be used with interpolation techniques, the time dependent models tend to be used with extrapolation techniques. In general, a measuring instrument is calibrated at discrete points in time and used afterwards.

The first implementation to store the virtual representation of the measuring instrument was to simply stream the object to a file. This solution works fine for a single instrument; however, it offers no means to scale the analysis to a set or a family of instruments. The natural response to solve this problem was to design a structured database for storing the measuring instrument's data. Fig. 5 shows a simplified version of the tables and their main relationships as implemented in the digital twin management environment.

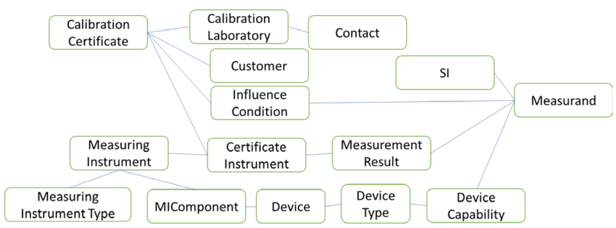

Figure 5. Database architecture schema.

There exists an administrative system for the calibration services at CENAM, so in fact the administrative shell information of the DCC is already digitalized. This is covered by the tables **Calibration Laboratory**, **Customer, Contact, Measuring Instrument**, and partially **Influence Conditions** as shown in Figure 5. Accordingly, to the International Metrology Vocabulary (VIM) [9], the database scheme considers the fact that a Measuring Instrument may be compound by several Devices, each of those have fixed measuring Device Capabilities for specific Measurands and that the Measuring Results are restricted to these Measurands. Also, the Influence Conditions are specified by other Measurands not necessarily covered by the Devices being part of the Measuring Instrument under calibration. We applied the well know theory of normal forms [10] to pursue an efficient storage and access to data. The proposed database schema is a superset of the current DCC, recognizing the DCC is designed for data exchange purposes only, in this sense the DCC can be thought as a specific view of the proposed database schema.

The data exploitation and retrieval ranges from simple measurement reports and charts to simulated response through the virtual measuring instrument. Measurement simulation follows the guidelines described in [11]. Fig. 6 shows an example of the measurement response of the virtual analytical balance [12, 13] while applying a weight standard with nominal value of 20 g, some months after the last calibration.

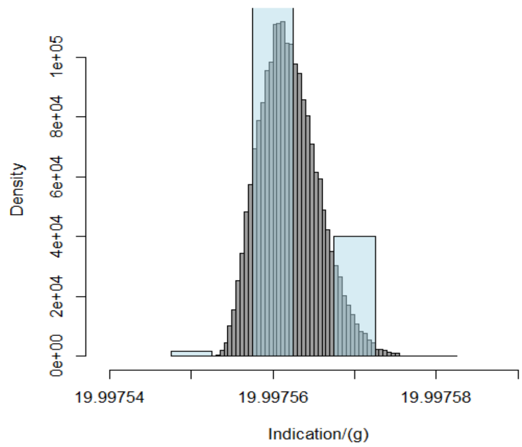

Figure 6. Response of a virtual analytical balance, in grey the simulated values on a specific nominal weight of 20 g and at a certain point in time after the last calibration. In transparent blue the filtered result considering the current resolution of the physical twin.

3. RESULTS

Calibration data become standard across different measuring instruments and measurands. This allows for several desired characteristics:

- Accessing, exploiting, and analyzing data is performed by using algorithms in common.
- Easy the communication between systems handling different measuring instruments and between laboratories.
- Reduces the time-consuming process to change or update the instrument-wise implemented systems.
- Fully supports the metrological traceability analysis.
- Stablishes a common platform to build on for future services.
- Easy the tutoring process to new metrologists and technicians as a tool to help understanding how the measuring instrument would behave as mirroring of a virtual instrument.

Table 1 lists the set of measuring instruments on which the database schema has been tested. As pointed out before, some instruments' measurands are point fixed such as a weight mass standard or a gauge block, while other instruments' measurands are described by a one-dimensional function.

Table 1. Tested measuring instruments.

Analytical Balance	Barometer
Weight Mass Standard	Platinum Resistance
Thermometer	Force Transducer
Hygrometer	Microphone Sensitivity
Gauge Block	

4. CONCLUSIONS

The experimental environment for handling Digital Twins of Measuring Instruments so far developed includes the kernel of a Scientific Metrological Cloud in the form of a general database schema to support detailed measurements and measurement results obtained with a set of measuring instruments during calibration.

The statistical tools provide an open architecture capable of supporting computer to computer communication, and human interface to computer communication.

The environment for Digital Twins Management is fully operable, however, the limited scope needs to be extended in future work, and some of the probable ways to extend it include:

- System's user access privileges and security (integration with administrative shell software and secure crypto signatures).
- Integration with DCC middleware.
- Integration with Metrology Procedures Modelling.
- Expansion to Physical Measuring Instrument data acquisition.
- Expansion to Physical Measuring Instrument Control Loop.
- Increase the coverage of types of measuring instruments to be managed.
- Update the development with the best practices by measurand/quantity.
- Harmonization with the RAMI 4.0 architecture [14].

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