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UNCERTAINTY CALCULATION-AS-A-SERVICE: AN IIOT APPLICATION FOR AUTOMATED RF POWER SENSOR CALIBRATION

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Abstract – Providing automated and networked solutions on the cloud will remarkably facilitate ongoing digitalization efforts in Metrology and the calibration industry. The AutoRFPower application was developed to automate the RF power measurement process and uncertainty calculations. This study presents our ongoing research on moving this application to a cloud environment and adapting it to perform power sensor calibrations. The cloud-based application initiates communication with calibration equipment, transfers test points to the client computer to perform measurement activities locally, and finally transfers the measurement data back to the cloud. Uncertainty calculations are performed on the cloud by a service. The calibration process produces a digital calibration certificate again on the server-side. The structure of the cloud-based application conforms to our previously proposed Internet of Measurement Things architecture, paving the way for digitalization and standardization in Metrology and the calibration industry.

Keywords: automated power measurement, digital calibration certificate, internet of measurement things, uncertainty calculation-as-a-service

1. INTRODUCTION

Ever-growing technology and globalization escalate the requirements for every industry, including reducing costs, speeding up business processes, and saving human resources. Metrology and the calibration industry are experiencing a digital transformation to keep up with the necessities of the new era. Provision of automated and networked solutions and formulation and dissemination of data standards are essential aspects of this transformation. In this regard, AutoRFPower was developed as a desktop application to automate RF power measurements in our previous work [1]. The application can communicate with the calibration equipment, obtain measurement data from the setup, and perform the uncertainty calculations according to the Guide to the Expression of Uncertainty in Measurement (GUM) [2] and its Monte Carlo Simulation (MCS) method description. However, it is difficult to serve all stakeholders at the desired level with a desktop application. Moreover, it is not easy to use and enforce standards for data and processes having separate copies of services that can be used in common. Therefore, we are adapting AutoRFPower to the cloud environment in the context of the Industrial Internet of Things (IIoT). Our previous work, the Internet of Measurement Things (IoMT) architecture [3], is chosen as a guide for this transformation. The IoMT architecture is a specialized IIoT architecture that identifies the layers of physical equipment, cloud-based services and commonly used data, and applications. In this work, our ongoing efforts to adapt AutoRFPower to the IoMT architecture is presented. In our vision, initiating the calibration process through a cloud service, collecting data from the calibration setup and performing uncertainty calculations on the cloud-side, and publishing a digital calibration certificate (DCC) will be possible, once the migration of the application to the cloud completed. Furthermore, having the IIoT perspective is promising to increase productivity and efficiency: commonly used services are accessible through the cloud, data is stored conforming to the certain standards, and applications are available through internet connection.

A similar work making uncertainty calculations available on the internet is the NIST Uncertainty Machine (NUM) [4]. This web-based application calculates measurement uncertainty based on GUM and the MCS methods. NUM is similar to our proposed work in performing calculations on the server-side. However, our approach has a holistic view in the IIoT context covering physical equipment and their communications with the uncertainty calculation service and producing DCC at the end of the process. Another handy tool is *Metas.UncLib* for uncertainty calculations [5]. This application easily handles complex-valued and multivariate quantities; therefore, it can be used for complex metrological problems. *Metas.UncLib* is a desktop application; hence, it is different than our proposed approach.

The rest of the work is structured as follows: The AutoRFPower application and the IoMT architecture are summarized in the Background section. The subsequent section describes the proposed cloud-based application in detail by explaining its functionalities, components, workflow, and how the application fits the IoMT architecture as an IIoT implementation. Then, the current and possible future advantages of using the application are discussed, along with the potential research topics.

2. BACKGROUND

2.1. *AutoRFPower Application*

AutoRFPower is a desktop application that allows users to perform automatic power measurements on a setup consisting of an RF signal generator, a power sensor, and a power meter [1]. The communication between these devices and a personal computer (PC) used for the measurement is handled using SCPI (Standard Commands for Programmable Instruments) [6] for each device through GPIB (General Purpose Interface Bus) [7].

The application incorporates an SQL database to store device and measurement data. Operators are obligated to register their devices to the system before performing measurements. In the registration phase, necessary information for measurements and uncertainty calculations are collected from the operators including certificate information, supported frequency/power range, connector type(s), and device identifiers. This information is used to validate the parameters set for a measurement process to check the compatibility of the devices/ranges in the measurement setup.

The application is capable of performing uncertainty calculations based on GUM and MCS methods utilizing the automatically collected measurement data. The results of these calculations are presented to the operators as a report and can be exported to their workspace.

2.2. *Internet of Measurement Things Architecture*

The IoMT architecture is proposed for calibration and Metrology applications based on the IIoT concept [3]. The layered nature of the architecture adheres to the reference architecture of the Industrial Internet Consortium [8].

The architecture contains three layers, namely the *physical layer*, the *cloud services layer*, and the *application layer*. The physical layer contains equipment setups and physical configuration in calibration labs. The cloud services layer hosts services for metrology and calibration applications. Relational databases and file storage also reside at this layer to save measurement data, equipment data and specifications, and documents such as DCCs and the scope of accreditation. The application layer hosts applications that use the services and data stored in the cloud services layer. The business logic of the applications is generally handled by cloud services. Therefore, the application layer mostly includes the user interface (UI) parts of applications.

The proposed IoMT architecture aims to help digitalization efforts in Metrology and the calibration industry by moving commonly used services to the cloud and increasing standardization of data such as schemas for units of measure, DCCs, and accreditation scopes. Thus, automation for different kinds of applications can be achieved easier than developing individual solutions. To this extent, a Scope of Accreditation (SoA) editor was developed [9]. Then, the necessary steps to implement a cloud-based SoA editor are explained in [10].

3. PROPOSED CLOUD APPLICATION

Our ongoing work aims to meet the AutoRFPower application with the IoMT architecture. Microsoft's Azure cloud computing service is chosen for the deployment of services and data to the cloud services layer of the IoMT architecture. Note that dependence on a particular cloud provider can be avoided by adopting container technology, such as Kubernetes [11].

Besides keeping the existing functionalities of the desktop version of our application, new functionalities will be added to the cloud version. The uncertainty calculations module of the desktop application will be transformed into a web service. Moreover, the cloud version of the application will have power sensor calibrations capabilities and a DCC generation module as some important extensions. We are aiming to take advantage of the PTB DCC experience [12] through available publications and services whenever possible during the DCC service development. Furthermore, we will also use the existing knowledge of the Metrology community to enrich DCCs from other aspects: For example, DCC results will be tagged with appropriate taxons from the Metrology taxonomy [10] put forth by Metrology Information Infrastructure.

Figure 1 illustrates the AutoRFPower application on the IoMT architecture. The physical layer of the architecture hosts calibration and measurement setups. Mostly, these setups include a PC connected to the internet. Therefore, the data transfer between the physical equipment and the cloud is conducted through this PC. The cloud services layer contains the uncertainty calculation service and the DCC service. Besides, common data to be used resides in this layer, such as device communication libraries. Measurement data obtained from the calibration setup, results of the uncertainty calculations, relevant device data allowing automated calibration, and produced DCC after the calibration are kept inside databases deployed to this layer. The application layer contains the UI-related parts of the application. Possible users of the application, namely calibration laboratories, and accreditation bodies are depicted above the application layer in Figure 1. The arrows in the figure indicate two-way communication between the adjacent layers.

The IoMT architecture illustrates the separation of concerns in terms of different layers. Deployment of the components is planned to be shared between the cloud and client machines. For instance, the AutoRFPower UI component refers to the UI for uncertainty calculations and the DCC generation on the web. At the same time, it indicates the application UI that runs on the physical setup.

Figure 2 provides system components to be used when the application is deployed to the Azure environment. IoT Hub collects calibration and measurement data from the calibration setup. Devices communicate directly with a PC where an instance of the AutoRFPower application is running. The same PC is assumed to be controlled by operators/technicians and acts as a field gateway that commu-

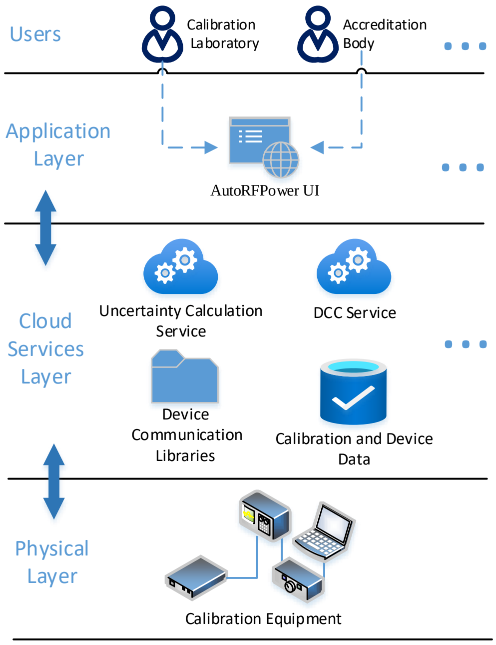

Fig. 1: AutoRFPower application in the context of the IoMT architecture.

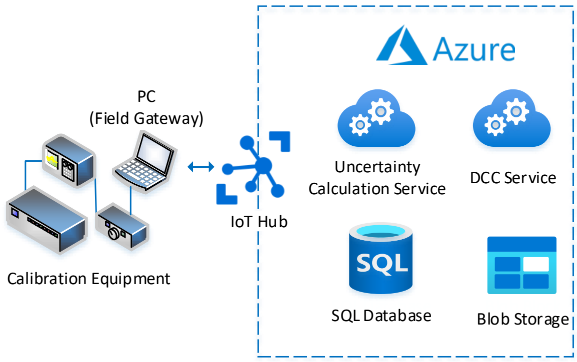

Fig. 2: The proposed system with the Azure environment.

nicates to the cloud environment allowing edge computing capabilities if needed. SQL Database keeps device, measurement, and uncertainty calculations data. Blob Storage stores the produced DCC files and device communication libraries. The uncertainty calculation service and the DCC service are employed as user-defined services on Azure.

Figure 3 illustrates the general workflow of the system that comprise of local and cloud components interacting both internally and externally. The process starts on the cloud UI with the end-user (operator) managing the devices to be used in that specific measurement. If there are device(s) that are not registered to the system, the registration process starts and the operator enters required information such as device specifications/configurations, certificate details, product identifiers etc.

When all devices are registered to the system, the operator enters the parameters to be passed to the devices in the measurement process. These parameters include frequency/power ranges that will be measured (test-points), number of repetitions, the delay between frequency changes/test-points etc. Device data and measurement parameters are saved in SQL storage on the cloud, ready to be exported to the local workspace. Then, the operator selects and imports the SQL file downloaded from the cloud and starts the measurement process on the local workspace running the application. The application running on the local environment handles the interactions among the devices allocated for the measurement and gathers the measurement results to be saved in an exportable format.

Finally, measurement results are transferred to the cloud and uncertainty calculations can be performed on virtual machines. At this point, DCCs can be created since all of the required information is already stored in the cloud.

4. DISCUSSION

AutoRFPower allows operators to perform automated RF power measurements in a reliable, fast, and precise fashion while making the process less error-prone. Nevertheless, deploying such applications fully or partially to the cloud will provide particular opportunities for accessibility, usability, security, and promoting standardization. Moreover, the confidentiality of data can be protected by using the facilities offered by the cloud service provider.

Cloud applications have a distinctive accessibility advantage since any interested party can use them with an internet connection. Furthermore, developers take advantage of diagnosing and resolving problems on the server-side instead of dealing with local copies for each user improving maintainability. The flip side is the measurement setups must be connected to the internet for a cloud application to work.

Users can back up their device data, and measurement/uncertainty results on the cloud, protected from probable misfortunes, such as hardware failures and data loss. Also, having all of the resources required to calculate the uncertainty and create digital certificates on the cloud makes the whole process more reliable while reducing dependency on another environment. Especially, MCS is known to be consuming system resources in terms of computational power and time. Running these processes on the cloud reduces workload on the user-side.

Having measurement data on the cloud opens the door for machine-based learning applications. Optimizing calibration intervals is a problem that machine learning techniques may help with. However, using customer data may not be possible if the data is confidential. In such a case, federated learning techniques [13] may satisfy user requirements on confidentiality and make the learning on a large scale possible. The algorithm can be trained on the edge devices that our system architecture includes. Then all local nodes contribute to form the global model.

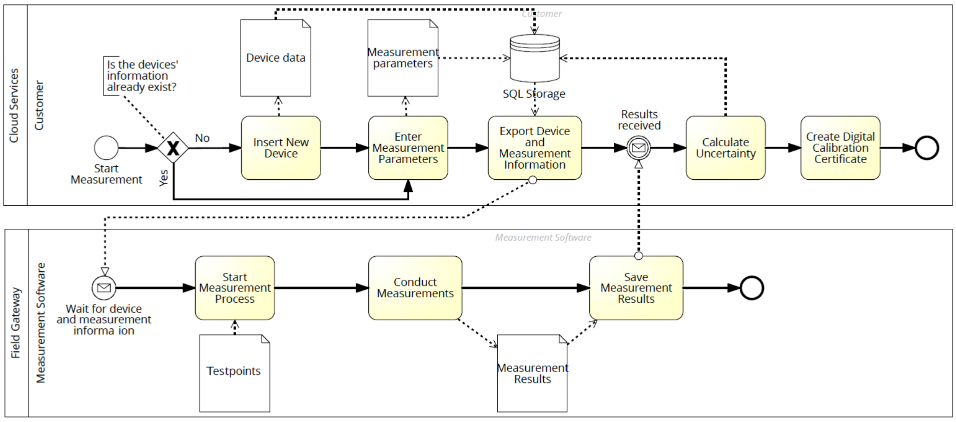

Fig. 3: The process model representing the workflow of the system.

5. CONCLUSIONS

This work presents our ongoing work on deploying our automated power measurement application to the cloud environment based on the IoMT architecture. Besides, we are extending the current version of the application to provide a full cycle for a calibration process: performing measurements on calibration setup, calculating uncertainty, and producing a calibration certificate. We explain how this process is conducted by the different components of the application. Microsoft Azure services that are needed to run the proposed application is described.

The next step is to make the proposed application available to the Metrology community. Applying machine learning techniques to the gathered data on the cloud is a possible future work: E.g., for calibration interval optimization.

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