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Development of a novel cloud-based multi-tenant model creation service for automatic virtual metrology

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ABSTRACT

AVM (Automatic Virtual Metrology) is the highest-level technology for VM (Virtual Metrology) applications from the perspective of automation. Its various automatic capabilities could facilitate fast factory-wide deployment and operations of VM systems. AVM systems have been successfully applied to the semiconductor, TFT-LCD, solar-cell, and machining industries for on-line monitoring the production quality of workpieces. However, in its past industrial applications, the model creation (MC) functionality of the existing AVM system encountered several limitations, such as being a standalone application and confined to be used in situ in a factory, no support for multiuser model creation, wasting computing resources, etc., which could diminish the applicability of the existing AVM system in current global and distributed manufacturing environments. Thus, this paper is dedicated to tackling the problem of how to systematically and effectively overcome MC-related limitations of the existing AVM system so that it can robustly support multiple users across factories to create their VM models simultaneously in distributed manufacturing settings. By leveraging the advantages of cloud computing and several IT technologies (including virtualization software, XML, Web Service, Multi-tenancy technique, and HTML5), this paper proposes a novel cloud-based multi-tenant model creation service (i.e., CMMCS) for AVM. The proposed CMMCS contains a cloud-based system architecture, functional frameworks of its key components, several functional mechanisms, and HTML5-based Web GUIs. Testing results in an industrial case study that creates VM models using the CMMCS for CNC machine tools in machining wheel rims of automobiles in a factory in Taiwan demonstrate that the CMMCS can allow multiple users from different tenants to simultaneously create their VM models, while enabling the MC cloud services to be more robust for processing MC requests, having higher CPU-usage rates in the underlying virtual machines, and achieving better cross-platform usage, compared to the original MC functionality. This paper has provided a feasible solution to systematically and effectively remedying the MC-related limitations of the existing AVM system. The existing VM-related literature mainly focused on the development of VM models. To our knowledge, no papers have coped with issues addressed in this paper by leveraging cloud computing. The results of this paper can be a useful reference for industrial practitioners to construct AVM systems which support multi-tenant or multiuser model creation.

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1. Introduction

In equipment engineering, measurement of workpieces (e.g., wafers in semiconductor manufacturing and glasses in TFT-LCD manufacturing) is an essential measure to know the conditions of production equipment and processes. The high-tech industries (e.g., Semiconductor, TFT-LCD, and Solar-Cell manufacturing industries) usually adopt sampling measurement approach (i.e., only measuring some sample workpieces) to monitor the manufacturing processes for saving cost and time in workpiece measurement. However, there is a metrology delay (about a few hours) from the completion of processing workpieces to the measurement of them. Thus, the anomalies of equipment or processes occurring during the metrology delay cannot be timely detected, which could result in producing many flawed workpieces, causing significant production losses [1].

Virtual metrology (VM) [2–4] allows the production quality of a workpiece to be known instantly right after the processing of the

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workpiece is completed, without measuring it physically. Thus, VM can achieve the objective of timely and online quality monitoring of every workpiece. In recent years, it has become a viable approach to conduct online monitoring of production equipment and processes in high-tech manufacturing industries [5–9]. VM has also been applied to predict the machining precision of workpieces in the machining industry [10].

The underlying principle of VM contains two stages: off-line model creation followed by on-line virtual metrology. First, at the off-line stage, algorithmic methods (e.g., neural network and regression techniques), as well as the historical process data and the corresponding metrology data of processed workpieces, are used to create VM models for the monitored production equipment or process. Then, at the on-line (i.e., production) stage, once the processing of a workpiece is completed, the VM models, taking the process data related to the processed workpiece as input, could timely predict the production quality of the workpiece. Therefore, how to create VM models effectively and accurately is an extremely important issue for VM applications to be successful. Hereafter, creating VM models is referred to as model creation (MC) for short.

There exist a lot of VM-related works, such as [1–20], which mainly focused on developing algorithms or mathematic methods to create VM models for production equipment or processes, together with showcasing the prediction accuracy, fault-detection capability, or run-to-run application of the VM models. On the other hand, some existing works, such as [21,22], addressed the issue about how to create VM models in an automatic and systematic manner. Specifically, Cheng et al. [21] proposed the concept of automatic virtual metrology (AVM) and developed an AVM system which possessed several automatic capabilities, such as automatic data acquisition, automatic data quality evaluation, automatic model fanning out, and automatic model refreshing, which could save a significant amount of time in data quality evaluation and model creation and could facilitate fast factory-wide deployment and operations of VM systems (i.e., applying VM to all pieces of equipment in a factory). Hung et al. [22] developed an AVM system implementation framework so that the complex AVM system could be constructed in a systematic and easy manner.

Fig. 1 shows the architecture of the AVM system in [21,22], which is referred to as the existing AVM system in this paper and introduced briefly below. The VM server is responsible for collecting data from process equipment and metrology equipment. The collected process and metrology data are then transmitted to the model creation server (i.e., MC Server) for creating the base VM models of the process equipment, which are then stored into the central database (i.e., Central DB). Afterward, the VM client can command the VM manager to fan out (i.e., copy and deploy) the base VM models to other VM servers connected with the same type of process equipment. Subsequently, each of these VM servers could generate its own VM models for the connected equipment by tuning or retraining the base VM models using the measurement data of new processed workpieces and the corresponding process data. After that, the VM client can activate the VM servers via the VM manager to start the on-line VM computation for the newly-processed workpieces, and the VM results are stored into the Central DB and displayed onto the GUI of the VM client.

The AVM system is the highest-level technology for VM applications from the perspective of automation. However, in its past industrial applications, the model creation (MC) functionality of the existing AVM system encountered several limitations, which are briefly described as follows. First, the model creation function of the existing AVM system was designed to be a standalone application and deployed in a factory so that it was confined to be used in situ in a factory, instead of being used across factories. Second, the existing AVM system utilized only a MC server to undertake model creation so that it could only perform a MC task at a time. Thus, it could not allow many users who may be in the same factory or different factories to create VM models simultaneously. Thirdly, because the underlying intelligent algorithms for model creation were implemented in MATLAB and could not run in parallel, the MC server had a low average CPU-usage rate (only about 30%) in model creation, resulting in wasting computing resources. Fourthly, the MC server lacked fail-over and load-balancing mechanisms for processing incoming MC requests. Therefore, it could not robustly handle a large number of simultaneous MC requests. Fifthly, the Web GUIs of the existing AVM system were developed based on proprietary RIA (Rich Internet Application)

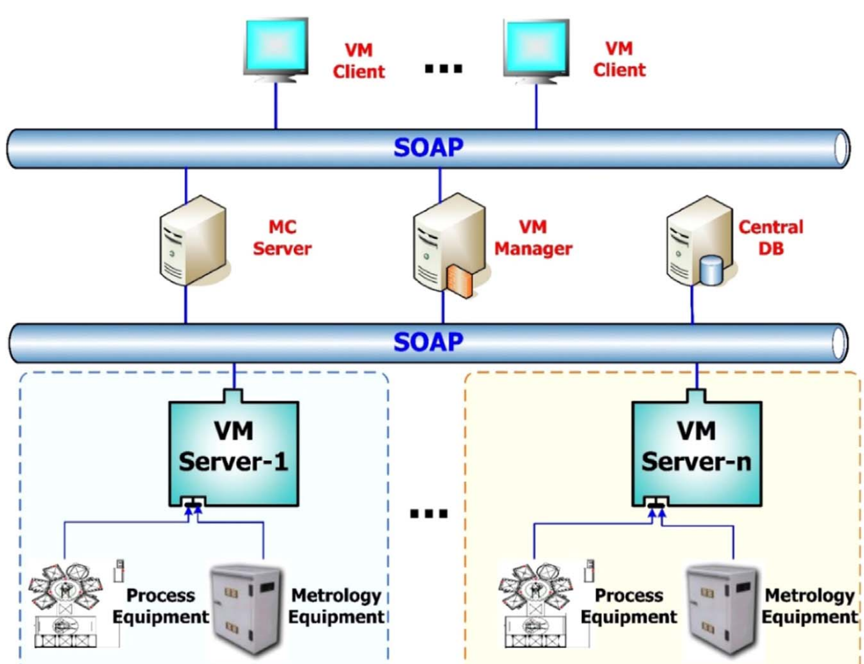

Fig. 1. Architecture of an existing AVM system [21,22].

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