New Intelligent Equipment Monitoring Architecture Based on Cloud Computing

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Abstract - In recent years, cloud computing has become a new trend of Internet applications and can potentially bring benefits and new business models for various industries. In this paper, we propose a new intelligent equipment monitoring architecture (IEMA) based on cloud computing, which mainly consists of three parts: v-Supplier, v-Machine, and v-Client. The v-Supplier provides various equipment monitoring related services on the cloud, such as cloud computing services of data acquisition, historical data storage and inquiry, model creation and management, and remote equipment monitoring. The v-Machine is connected to equipment on the premises for providing functions of data acquisition, data preprocessing, indicators computation, real-time equipment monitoring, and production quality prediction. The v-Client contains various Web-based GUIs based on lightweight application architecture and rich interactive application (RIA) technology. The proposed new IEMA also provides several data security mechanisms to protect the system. Based on the proposed intelligent equipment architecture, various prediction models can be created on the cloud and then downloaded to the v-Machine for performing yield rate prediction, machining precision conjecture, and remaining useful life prediction on line.

Keywords - Cloud Computing, Intelligent Equipment Monitoring, Prediction Systems.

I. INTRODUCTION

Equipment is the most capital asset in manufacturing factories [1]. However, there is too much time during which the equipment is either idle or under the routine/non-routine maintenance. Therefore, how to effectively increase the equipment effectiveness and availability has become a very important task to be dealt with in the semiconductor factory. It is also one of the key factors for gaining profits for manufacturers.

Due to the flourishing development of Internet and information technologies, the e-diagnostics [2] had been proposed to allow the experts of equipment suppliers to remotely conduct actions on equipment through Internet, such as remote connectivity, remote control and operation, performance monitoring, data collection and analyses, and fault diagnosis, together with self-diagnostics and predictive maintenance.

Since virtual metrology (VM) [3][4] can conjecture the process quality of every workpiece (such as wafers or glasses) using process data of the production tool and can turn sampling inspection into real-time and on-line total inspection, VM has now become an important measure of advanced equipment/process monitoring and control in high-tech manufacturing industries, such as Semiconductor, TFT-LCD, and Solar-Cell industries. Figure 1 shows an equipment monitoring system with automatic virtual metrology (AVM) capabilities [5]. The VM Server is responsible for collecting data from the connected process equipment and metrology equipment. The collected data are then transmitted from the VM server to the Model Creation (MC) server for creating the base model, for the process equipment. The created base model is then stored into the Central Database (Central DB). Afterward the VM Client can command the VM Manager to fan out (i.e. copy and deploy) the base model to other VM Servers of the same type of process equipment. Then, through retraining or tuning the base model, these VM Servers can generate their own conjecture models of the connected process equipment. After the VM Servers are equipped with their respective conjecture models, the VM Client can activate the VM Servers via the VM Manager to start the computation of VM, and the VM results are stored into the Central DB and displayed onto graphical user interfaces (GUIs) of the VM Client.

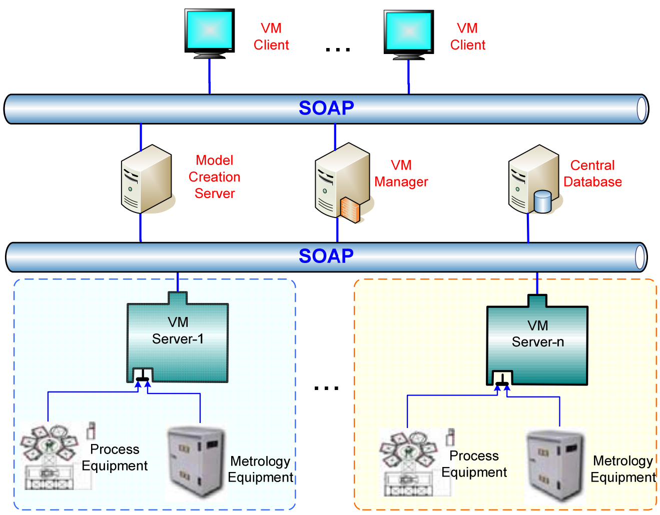

Fig. 1 An equipment monitoring system with AVM capabilities [5].

Once the number of equipment becomes large, traditional Internet-based equipment monitoring systems (EMSs), such as those in [2][5][6], may encounter the problem of computing and storage capability shortage, thereby reducing the system performance. In recent years, cloud computing [7][8] has become a new trend of Internet applications and can potentially bring benefits and new business models for various industries. For leveraging the advantages of cloud computing to improve the computing and storage capability shortage problem of traditional EMSs, this paper introduces a new intelligent equipment monitoring architecture (IEMA) based on cloud computing.

Traditionally, we deploy the core functional servers of an EMS into the manufacturing factory. The proposed new IEMA deploys the core functional components of the EMS, such as Data Acquisition, Model Creation, Model Evaluation, Model Management, Model Repository, and Historical Data Repository, into cloud servers. By adopting such a new EMS architecture, the manufacturer not only can reduce the construction cost of information hardware in a factory to minimum, but also can get the required computing and storing resources on demand from the cloud for creating and storing VM conjecture models and VM data. Also, the equipment suppliers can leverage this architecture to create new business models for gaining profits.

The rest of the paper is organized as follows. Section II introduces the proposed new IEMA. Section III presents the major operational scenarios of the new IEMA. Section IV describes the system implementation and testing results of a paradigm EMS. Section V is the conclusions of this paper.

II. New Intelligent Equipment Monitoring Architecture

The proposed new IEMA based on cloud computing is designed as shown in Fig. 2, which consists of three parts: v-Supplier, v-Machine, and the client side.

A. V-Supplier

In the new IEMA, we deploy core functional components of the EMS in the cloud, including Data Acquisition, Model Creation, Model Evaluation, Model Management, Model Repository, and Historical Data Repository. Furthermore, we adopt Web Services technologies to wrap these functions to form the Intelligent Prediction Cloud Services (IPCS), which can serve as a virtual provider (v-Supplier), so that other systems or users can easily access these services through the Internet. The v-Supplier also contains a cloud Web server that hosts a variety of GUIs for the clients to operate the v-Supplier services.

B. V-Machine

We design a type of virtual machine, called v-Machine, which can monitor various kinds of equipment. The v-Machine consists of five parts: Generic Communication Interface (GCI), Pluggable Algorithm Module (PAM), Virtual Machine Kernel (VMK), Generic Data Acquisition Driver (GDAD), and Local Database (Local DB).

The communication functions of GCI are built in the form of WCF (Windows Communication Foundation) services. The GCI can allow the v-Machine to communicate with other systems, such as cloud computing services, the diagnostics system of the equipment supplier, etc., through the Service Broker using multiple protocols, including SOAP and REST. The PAM can host diverse algorithms and prediction models for performing real-time monitoring and prediction of equipment and manufacturing processes.

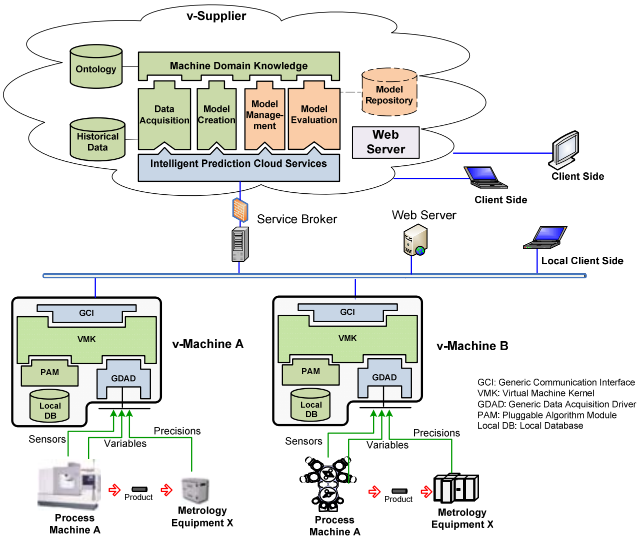

Fig. 2 Architecture of the proposed cloud computing-based intelligent equipment monitoring system.

The VMK is responsible for controlling the messages and data handling and configuration setting of the v-Machine. The VMK contains a data pre-processing module that can process and filter the raw process or sensor data and compute the corresponding indicators. Then, these indicator data can be uploaded to the v-Supplier for creating conjecture models or fed to the pluggable algorithm module (PAM) for the usage of various real-time prediction applications, such as conjecturing the process quality, detecting equipment faults, estimating the remaining useful life of equipment, and so on. The GDAD can collect data from various types of equipment. The Local DB is used to store the indicators and the VM results.

C. Client Side

We adopt the newest Web technologies, such as Silverlight and Ajax, to construct a variety of graphical user interfaces (GUIs). The GUIs contains the following category: user login, data collection, model creation, model management, cloud services management, alarm management, equipment monitoring, user management, and historical data search.

By such system architecture, the equipment supplier can utilize v-Machine to acquire data from process equipment and metrology equipment, respectively. Next, the v-Machine preprocesses the process and metrology data and then uploads the preprocessed data to the v-Supplier through the Service Broker for creating the prediction models in the cloud. Afterwards, the engineers in factories can download their desired prediction models from the cloud (v-Supplier) to the target v-Machines. Following that, the v-Machine equipped with the downloaded prediction model can proceed to perform monitoring, conjecture, fault diagnostics, or predictive maintenance on equipment or processes in real time.

III. *OPERATIONAL SCENARIOS*

This section presents several operational scenarios of the proposed new IEMA, including scenarios of data acquisition, model creation, model download, and process monitoring.

A. Data Acquisition

The operational scenario of data acquisition is shown in Fig. 3 and described as follows.

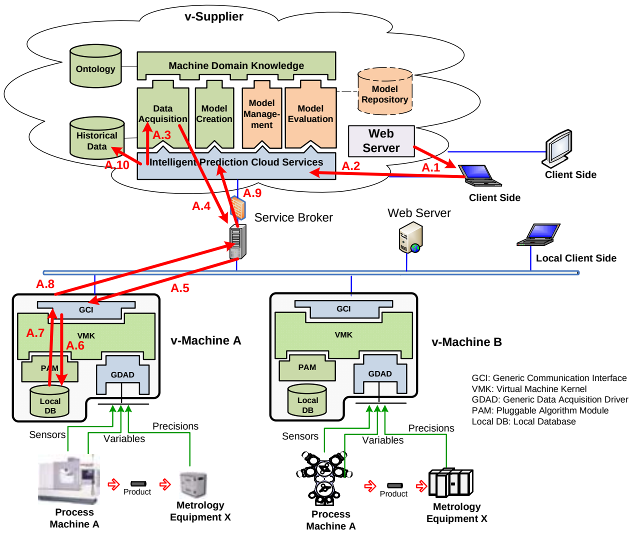

Fig. 3 The operational scenario of data acquisition.

Step A.1: The user logs in the v-Supplier system and downloads the data acquisition (DA) GUI from the cloud.

Step A.2: The user starts the DA operation by operating the DA GUI, which then calls the DA service of the IPS.

Step A.3: The DA service of the IPS calls the DA method of the Data Acquisition module.

Step A.4: The Data Acquisition module calls the DA service of the Service Broker.

Step A.5: The Service Broker calls the DA service on GCI of the v-Machine.

Step A.6: The GCI accesses the local database in v-Machine.

Step A.7: The local database sends indicators to GCI.

Step A.8: The GCI forwards the indicators to the Service Broker.

Step A.9: The Service Broker sends the indicators to the IPS.

Step A.10: The IPS stores the indicators into Historical Data database.

B. Model Creation

The operational scenario of model creation is shown in Fig. 4 and described as follows.

Step B.1: The user logs in the v-Supplier system and downloads the model creation (MC) GUI from the cloud.

Step B.2: The user starts the MC operation by operating the MC GUI, which then calls the MC service of the IPS.

Step B.3: The IPS calls the MC method of the Model Creation module.

Steps B.4 & B.5: The Model Creation module retrieves data from the Historical Data database in the cloud.

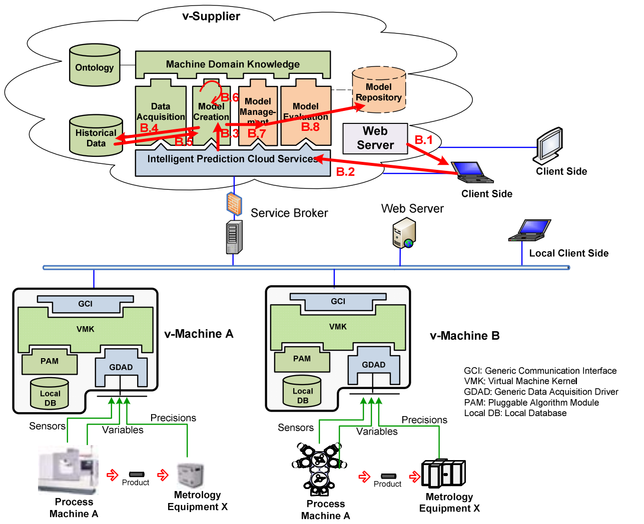

Fig. 4 The operational scenario of model creation.

Step B.6: The Model Creation module activates the MC procedure.

Step B.7: The Model Creation module sends the created model to the Model Management module.

Step B.8: The Model Management module stores the model into the Model Repository database.

C. Model Download

The operational scenario of model download is shown in Fig. 5 and described as follows.

Step C.1: The user logs in the v-Supplier system and downloads the model management (MM) GUI from the cloud.

Step C.2: The user starts the MM operation by operating the MM GUI, which then calls the MM service of the IPS.

Step C.3: The IPS calls the MM method of the Model Management module.

Step C.4: The Model Management module retrieves the desired VM model from the Model Repository database.

Steps C.5-C.7: The Model Management module downloads the VM model to the PAMs of the target v-Machines through the Service Broker.

Step C.8: The PAMs receive and confirm the VM model.

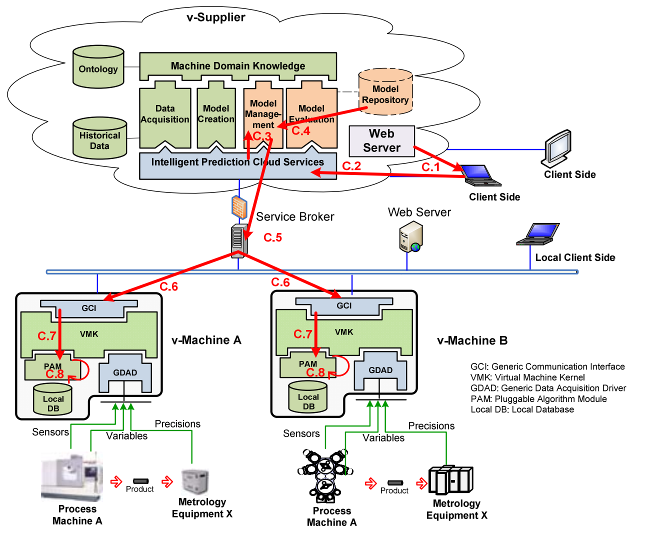

Fig. 5 The operational scenario of model download.

D. *Process Monitoring*

The operational scenario of process monitoring is shown in Fig. 6 and described as follows.

Step D.1: The local user logs in the v-Machine system and downloads the process monitoring (PM) GUI from the local Web server.

Step D.2: The user starts the PM operation by operating the PM GUI, which then calls the PM service on the GCI of the v-Machine.

Step D.3: The GCI activates the GDAD to collect data from process equipment and metrology equipment.

Step D.4: The GDAD receives data from process equipment and metrology equipment.

Step D.5: The GDAD sends the received data to the VMK for computing indicators which are then inputted into the PAM for computing VM results.

Step D.6: The PAM saves the VM results into its local database.

Step D.7: The PAM sends the VM results to the local client through the GCI for displaying on the PM GUI.

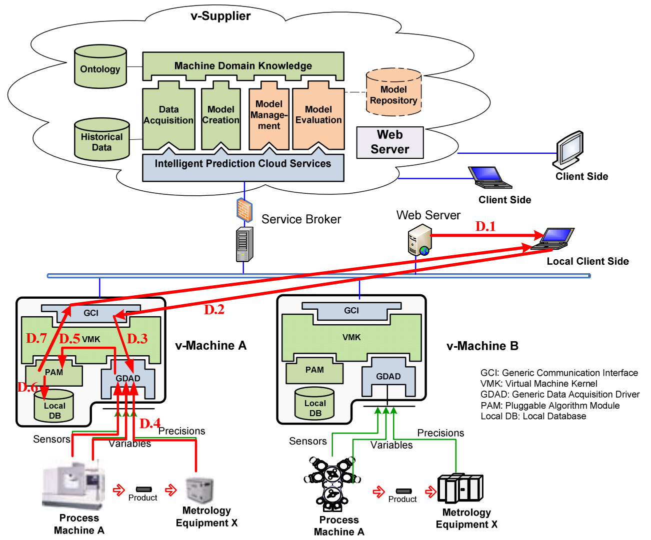

Fig. 6 The operational scenario of process monitoring.

IV. *SYSTEM IMPLEMENTATION AND TESTING RESULTS*

Based the proposed new IEMA, we have constructed a cloud computing-based equipment monitoring system (CCEMS) for the CNC machinery industry. We deploy the v-Supplier and the Web GUIs in the Windows Azure [9] public cloud, whereas deploying the v-Machine in the factory of our cooperative CNC tool manufacturing company. The historical data (indicators) are stored in Windows SQL Azure, while Windows Azure Blob is adopted to store the created VM models.

We have also conducted several testing scenarios, including the above-mentioned scenarios of data acquisition from the cloud, model creation in the cloud, model download from the cloud, and real-time production precision prediction in the v-Machine, to validate the effectiveness of the proposed new IEMA. Testing results show that the paradigm CCEMS for CNC tools works smoothly and has an expected performance. Fig. 7 shows a GUI snapshot of the production precision conjecture results.

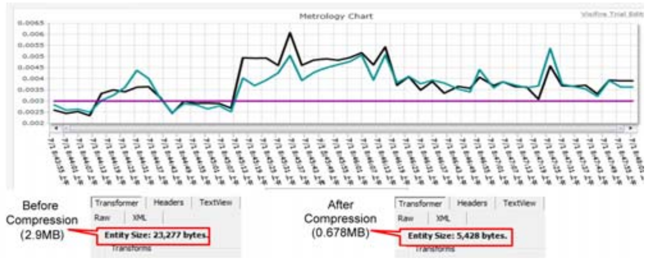

Fig. 7. GUI snapshot of the production precision conjecture results.

V. *CONCLUSIONS*

For leveraging the advantages of cloud computing to improve the computing and storage capability shortage problem of traditional EMSs, this paper introduces a new intelligent equipment monitoring architecture (IEMA) based on cloud computing. By adopting the new IEMA, the equipment supplier can create prediction models in the cloud. The engineers in factories can download their desired prediction models from the cloud to the target v-Machines. Then, the v-Machine equipped with the downloaded prediction model can perform monitoring, fault diagnostics, or predictive maintenance on equipment or processes in real time. Several operational scenarios, such as data acquisition, model creation, model download, and process monitoring, have been tested in a CNC tool manufacturing factory to validate the effectiveness of the new IEMA. This paper can be a useful reference for constructing cloud-computing-based equipment monitoring and prediction systems.

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