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DEVELOPMENT OF AN E-OPERATION FRAMEWORK FOR SOPC-BASED RECONFIGURABLE APPLICATIONS

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Abstract. *In recent years, due to the progress of information and Internet technologies, reconfigurable manufacturing systems have attracted a lot of attention over the fields of reusable SIP (Silicon Intellectual Property) and remote maintenance. Motivated by the need of information sharing and reuse, this paper aims to develop a conceptual framework for e-operations with the capability of e-maintenance, e-commerce and e-reconfiguring. The Web Services technologies are exploited as the communication infrastructure, which conveniently integrates the processes of e-diagnostic, SIP transactions and remote reconfiguring. In addition, the proposed framework can also meet various security requirements, such as basic authentication and authorization, XML signature and authentication. In particular, to increase the overall efficiency for system development, UML (Unified Modeling Language) is used as the tool to accomplish the object-oriented analysis and design (OOA and OOD) of system components in the proposed e-operation framework. Finally, to validate the convenience and effectiveness of the proposed framework, a reconfigurable controller for a virtual AS/RS (Automatic Storage/Retrieval System) is constructed as an application paradigm. The integration test results show that the proposed development framework can certainly comply with the design objectives. It is believed that the developed technologies and concepts can be applied to constructing new-generation remote maintenance systems for the future industry automation.*
Keywords: Web service, e-Maintenance, e-Commerce, e-Reconfiguring, SoPC, SIP

1. **Introduction.** E-Work was defined and described by the PRISM Center [1] as any collaborative, computer-supported and communication-enabled productive activities. In essence, e-Work is comprised of e-activities, namely, activities based on and executed through information technologies. To the advancement of information and Internet technologies, the concept of e-maintenance has been recently proposed in the field of industrial control. The e-maintenance system provides the experts of equipment supplier with the capability that allows remote linking to factory equipment through Internet with some remote actions, such as setup, control, configuration, diagnosis, de-bugging/fixing, performance monitoring and data collection/analysis. Accordingly, equipment can be rapidly repaired and maintained, and the equipment performance can be continuously improved.

Some remote maintenance systems were developed and applied in different industry applications. For example, Chen et al. [2] developed an e-maintenance embedded collaborative commerce system. Muller et al. [3] proposed the deployment and experimentation of a prognosis process within an e-maintenance architecture. Persona et al. [4] presented four industrial case-studies of the eMRO network organization to classify different e-maintenance systems and understand the relationships between the different members of the network. In order to facilitate proactive maintenance, a framework of multi-agent systems was introduced to make the information/knowledge exchange available [5]. In addition, hyperchaotic systems for chaotic encryption in remote monitoring systems were studied for product e-manufacturing and e-maintenance [6]. In [7, 8, 9, 10], some more applications in e-maintenance were described in detail.

Nevertheless, to achieve the automation of information integration, an e-maintenance system needs to integrate various heterogeneous data and systems on Intranet and/or Internet. A web service [11, 12, 13] framework has evolved to become an important paradigm for distributed computing. Currently, Web Services, capturing information and services from web sites, can successfully transmit the results to any device and perform integration in customized formats among cross-network, cross-platform and heterogeneous systems. Also, Web Services applies SOAP (Simple Object Access Protocol) as the communication protocol among application programs. By using HTTP (Hypertext Transfer Protocol) as the transfer protocol, the messages of Web Services can easily penetrate firewalls so that the interoperability problem among the cross-platform and distributed systems is solved. This type of information integration can break the barrier among Internet, operating systems, application programs, and various types of computing devices. In addition, clients can use the information provided by the Web Services at anytime, from anywhere, and on any device. In recent years, some e-maintenance systems have been developed for the purpose of different industrial applications by using the Web Services technologies, such as the DYNAMITE project [15], PROTEUS project [16], semiconductor factories [18, 19], remote multi-robot monitoring and control [20], and the E-learning implementation [21] and the B2B enterprise applications in a platform-independent manner [22].

In the tasks of industry automation, it is basically demanded to shorten the design cycle and increase the utilization efficiency. Accordingly, seeking for reusable and configurable processes or architectures is increasingly desired. Currently, MACH (Microprocessor Architecture with Configurable Hardware) is an active research area [23]. Among the researches in the field of MACH, SoPC (System on a Programmable Chip) is a device that a function kernel is realized in an FPGA (Field Programmable Gate Array) [24]. Due to the development of FPGA and SoPC, the realization of a reconfigurable-hardware machine controller becomes feasible. Based on an open-architecture scheme, reconfigurable machine controllers were developed to improve the flexibility of manufacturing systems. In response to new circumstances, the reconfigurable manufacturing system is designed to rapidly adjust production capacity and functionality by the rearrangement or change of components. Besides, a solution with embedded functional blocks has been adopted to fulfill some macro functions in a programmable chip so that the development cost and complexity can be reduced and the time-to-market can be shortened. Depending on the level of implementation, there are soft, hard, and firm blocks, where soft block is a synthesizable register-transfer-level (RTL) description or a netlist of generic library elements. About other descriptions of soft blocks, interested readers may refer to [25] for a review.

In this paper, the soft-blocks, also called the Soft-Silicon Intellectual Property (Soft-SIP), are used to accelerate the SoPC development. By using the SoPC and Soft-SIP, the software and hardware co-design is reprogrammable, and the co-design process can be parallelly processed in FPGA to increase the system performance and flexibility. In the past, the SIP users had to directly source from different SIP providers and through different intermediates to acquire all the required SIP solutions. Nowadays, users can purchase the SIPs through a single Web-based e-commerce mechanism [26, 27], called the SIP Mall [28, 29], and receive all SIP deliverables. Practically, based upon current business models, SIP Mall can provide not only business and legal services, but also technical supports including SIP integration, maintenance and applications [30]. In fact, the development of SIP Mall has been an emerging task around the world [31, 32, 33, 34, 35]. An e-commerce mechanism for SIP transactions aims to provide a well-established SIP database to deliver reusable SIPs and increase the efficiency of SIP transactions.

In order to leverage the advantages of SoPC technologies, improve the optimistic future of SIP e-commerce and achieve the automation of remote maintenance, a novel integrated framework must be developed. Furthermore, to maintain the efficiency of competitive factories, the following three factors: e-operations, SoPC technology and information technology, shown in Figure 1, must be considered. Simultaneously, the reuse concept must be emphasized in this conceptual framework as integrating the hardware and software modules. Therefore, this paper is dedicated to developing a conceptual framework which is helpful to study the relationships among those fundamental aspects addressed in Figure 1 and to constitute the effective scenarios of a novel industrial application.

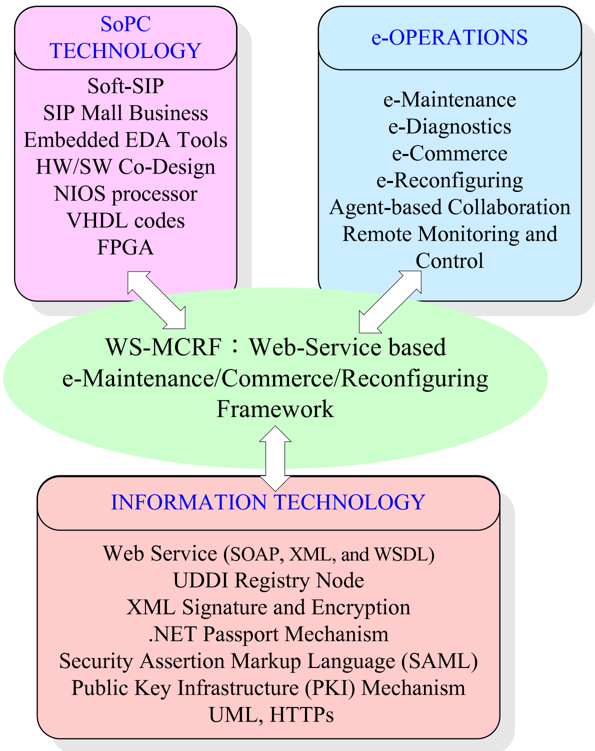

FIGURE 1. The framework construction concept by leveraging SoPC technology, e-operations, and information technology

In our previous work [19], a Web Service-based e-diagnostics/maintenance framework for semiconductor factories with security considerations had been developed. Under a secure communication infrastructure, the automation of diagnostic processes and the integration of diagnostics and maintenance information can be achieved. Based on the previous infrastructure, a new and novel e-operation framework for industrial equipment with SoPC-based controller is proposed in this paper. This new framework stands at the viewpoints of on-site engineers to find various services. These services are designed to meet the needs in the industry networks, including clarifying the importance of local/remote maintenance capability, emphasizing the impact from the developing trends of SIP Mall and rapidly redeploying and reconfiguring the devices. By utilizing the SoPC technology, SIP Mall business, and the Web Services, an e-maintenance system for virtual AS/RS appliances is also constructed as a paradigm application to verify the effectiveness of the proposed framework. The developed technologies and concepts in this research conform to the trend of reusable SIPs that can be easily applied to the devices and systems of factory automation.

The rest of this paper is organized as follows. Section 2 is the development design of the e-operations framework. The system components of the proposed framework are designed in Section 3. Section 4 describes the scenarios of the framework messages. Section 5 presents functional experimentations for the system components. Section 6 constructs a paradigm application of e-operation and describes the associated implementation and integration tests. Finally, the concluding remarks are given in Section 7.

2. **Design of e-Maintenance/Commerce/Reconfiguring Framework.** The proposed Web Services-based e-Maintenance/Commerce/Reconfiguring Framework (WS-MCRF) is shown in Figure 2, where the whole structure is divided into the factory side and the service supplier side. The factory side is composed of On-Site Maintenance and Security Server (OMSS), On-Site Engineering Database (OED) and Equipment with Reconfigurable Generic Controller (RGC). The service supplier side includes Remote Maintenance Server (RMS) and Global Maintenance Database (GMD) in equipment supplier, and e-commerce in SIP Mall. A Universal Description Discovery and Integration (UDDI) registry node [36] is included to provide functions of registering and searching Web Services for Internet users.

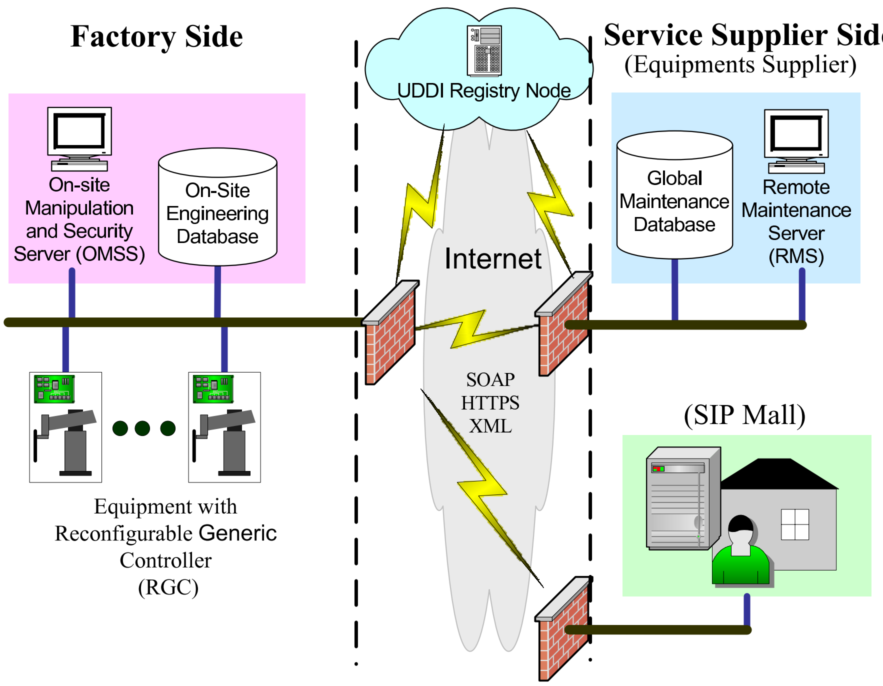

FIGURE 2. The proposed Web services-based e-MCR framework

In the WS-MCRF, each Reconfigurable Generic Controller (RGC) is designed to diagnose, monitor, and control at least one to several sets of equipment, such as AS/RS, robots and motion control platforms. Therefore, in a factory, there are many RGCs linked to various kinds of equipment to perform the tasks of monitoring and control. In addition, the

RGCs can collect equipment engineering data and exchange data with other system components by utilizing the SOAP as the messaging protocol to achieve the interoperability of cross-platform and distributed systems.

On the factory side, an OMSS is designed to contain the service components that can be used by local and remote maintenance systems with guaranteed security. Moreover, OMSS is responsible for handling the local maintenance process of equipment. For instance, when equipment error occurs, the diagnostics will be processed first by OMSS to provide the EGRC with the corresponding diagnostic solution from OED. Such diagnostics practices can save the network bandwidth and avoid the security threat resulted from the remote diagnostics services through Internet. Besides, OMSS is also responsible for handling the e-commerce of SIP and local reconfiguring process of RGC. When the functions of RGC need to be updated, the OMSS first can securely trade SIPs with the SIP Mall through Web Services. Then the administrators remotely reconfigure and upgrade the controller functions by downloading a new version of Soft-SIPs through network. For the sake of security, OMSS can perform the monitoring, recording and management of the operation statuses of the e-Maintenance/Commerce system to serve as the basis for the audit of system operations. In addition, OMSS provides the functions of unified authentication and authorization with a single sign-on capability so as to enhance the system security and reduce relevant maintenance costs.

On the service supplier side, there are Equipment Supplier and SIP Mall. The RMS is designed to provide professional diagnostics and maintenance services. For instance, when an equipment goes wrong, RGC can obtain diagnostics service information from OMSS through the secure process. Also, RMS can allow the experts of equipment suppliers to manually perform remote maintenance operations on the factory equipment through RGCs. In addition, RMS can remotely collect equipment engineering data through RGCs and then save them into the Global Maintenance Database (GMD). The SIP Mall provides a variety of SIPs for customers to order and also accept requests of customized SIPs. On the other hand, SIP Mall offers look-through services of all kinds of off-the-shelf SIPs for customers to choose. Customers can remotely trade with SIP Mall through Web Services.

In the security aspect, an outer firewall is installed between the Internet and the enterprise (factory, equipment supplier, SIP Mall) to protect the security of extranet information of the enterprise. The proposed framework adopts HTTPS, i.e., HTTP incorporated with Secure Socket Layer (SSL), to provide point-to-point security protection of data transmitted over the Internet. Meanwhile, the XML signature and XML encryption technologies are utilized to further protect the data contents of the transmitted messages, thereby achieving end-to-end data security protection. Since the Web Services technology is used to construct the communication infrastructure of the proposed framework, the OASIS Web Services Reliable Messaging standard (WS-Reliability) [37] can be used to achieve communication reliability. Therefore, as SIPs trading among the customers, SIP vendors and SIP Mall can be undertaken in a secure way. For the management of Web Services, the framework also involves a mechanism to register and find Web Services through UDDI technologies.

3. **Design the System Component Model.** The scheme of system components, shown in Figure 3, includes RGC, OMSS, RMS and SIP Mall. As described previously, several common functions, including SOAP communication, UDDI registration, security mechanism, and data exchange mechanism and database access, can be identified and put together to become the Web-Service Agent (WS-Agent).

RGC contains two parts, the hardware module and the software module. Regarding to the hardware module, the designer can compile and integrate various SIPs, such as

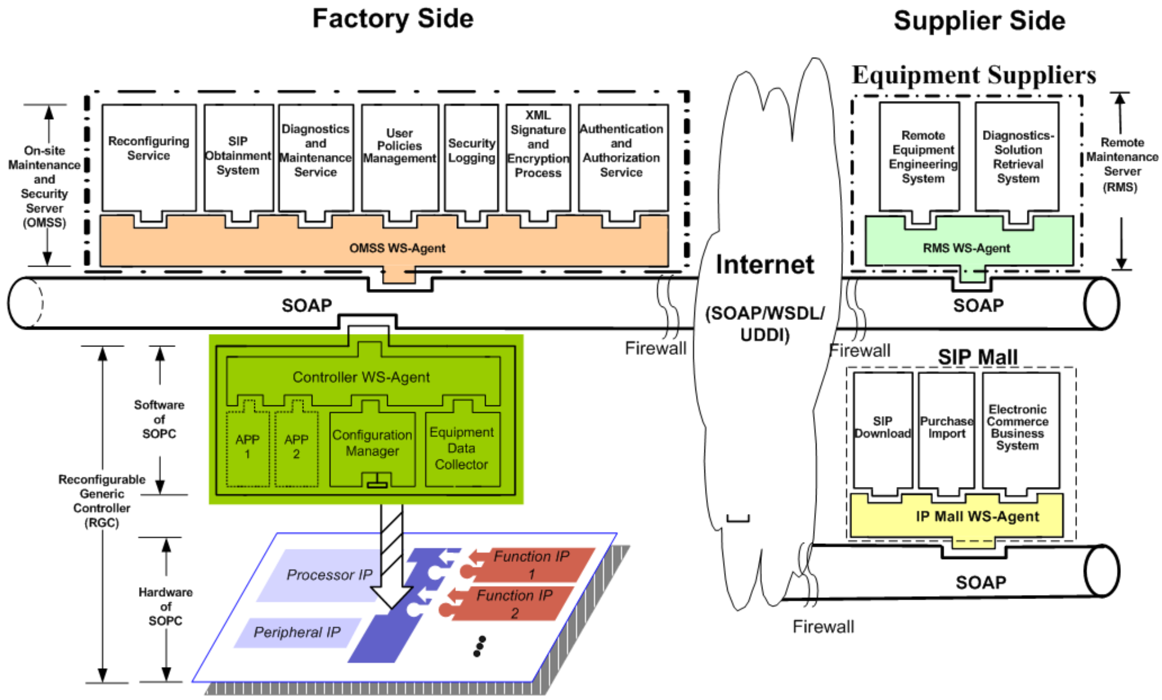

FIGURE 3. The scheme of system components

processor SIP, peripheral SIP, and certain specific function SIPs to achieve the functional requirements of the controller. Hence, by downloading the integrated SIP into the programmable chip through the software module, the designer is able to easily reconfigure the hardware to get the desired controller. On the other hand, the software module consists of Controller WS-Agent, Configuration Manager, Equipment Data Collector, and various pluggable applications. Among RGC, OMSS and RMS, the Controller WS-Agent is designed to be a communication agent to integrate various application components via Web Services protocols. The configuration manager is responsible for the reconfiguring processes of the software and hardware in the controller.

Various applications, such as collecting equipment engineering data and those are designed to be pluggable and removable, are used to realize certain specific functions of the controller. As manufacturing processes have become increasingly complicated, the more advanced e-Maintenance technologies, such as Prognostics and Virtual Metrology (VM) [38, 39], are required for current and future manufacturing industries. The core of a VM system is the VM model that contains various intelligent algorithms for conjecturing process quality, detecting equipment faults, or predicting the remaining useful life of equipment. Thus, in the proposed framework, various VM models containing intelligent algorithms can be created and stored in the OED. If a set of equipment needs VM functionality, a suitable VM model can then be downloaded to the RGC connected with the equipment in the form of a pluggable application. After the RGC is equipped with a VM model, it can acquire data from the equipment through the Equipment Data Collector, analyze and pre-process the obtained data, and then compute VM results, which can be used to support making dynamic decisions. Finally, other system components can use the functions provided by calling the methods in the Controller WS-Agent with SOAP. RGC can also exchange messages with other system components through SOAP. Additional generic capabilities can also be added in the future.

OMSS comprises equipment-engineering components, such as diagnostics/maintenance, reconfiguring and SIP transactions, to provide various functions and information required for the diagnostics, maintenance, and engineering operations of factory equipment. Besides, OMSS is responsible for providing the system with a unified mechanism of user authentication and authorization with single sign-on capability. The secure logging component manages the authentication and authorization of the login users. In addition, OMSS applies the technologies, XML signature and XML encryption, to authenticating the accuracy of the remote operation messages of equipment. OMSS also contains the functions of user policies and profiles management, which can collectively manage the information and authorization of the system users. Accordingly, the maintenance cost is reduced and the security is enhanced. Moreover, it provides the function of security logging that can monitor and record all the remote operation statuses of the system to provide evidences for the system security audit. These equipment-engineering components of OMSS are built on OMSS WS-Agent. Other system components can use the functions provided by OMSS WS-Agent with SOAP. In RMS on the equipment supplier side, professional diagnostics and equipment engineering components are designed to provide remote diagnostics and maintenance functions. Similarly, the functions provided by RMS are built upon RMS WS-Agent in the form of Web Services. Other system components can also use the functions provided by RMS by calling the methods in RMS WS-Agent with SOAP.

According to e-commerce mechanism for SIP transactions, the SIP Mall possesses several service components that are intended to support on-line SIP trading for electronic commerce with OMSS through Internet. The SIP transaction business provides functions for the users to browse off-the-shelf SIPs and make the purchases of SIPs. The purchase import component can accept client's purchase which contains relevant requirements of customized SIP designs from OMSS in XML format. As a customized SIP is completed, the SIP Mall will notify the client who makes that order. After passing certain agreements, the client can download the SIP through the functions of download component. By using these service components, OMSS can inquire, browse, and look for suitable ready-made SIPs. This paper does not make new contributions about business model in the area of SIP Mall. Interested readers may refer to [40, 41] for a review. Similarly, we also design a component, called SIP Mall WS-Agent, to integrate the functions in the form of Web Services. Other system components in Internet can then use the functions provided by SIP Mall by calling the SIP Mall WS-Agent via SOAP.

It is noted that WS-MCRF uses the Web Services as the communication infrastructure, which is loosely coupled and good expandability. In particular, to increase the overall efficiency for system development, UML (Unified Modeling Language) is used as the tool to accomplish the OOA and OOD of system components in the proposed scheme. Thus, all the system components of WS-MCRF can be integrated in plug-and-play fashion. In such a manner, other business components, such as Supply Chain Management (SCM), can also inherit the Web-Service Agent to interoperate with WS-MCRF components. In other words, if a new object-oriented component is implemented in the form of Web Services, it can be easily added to the system communication infrastructure to interoperate with other components.

4. **The Scenarios of the Framework Messages.** For the design of WS-MCRF to support generic applications, the framework messages, the communication messages among WS-MCRF system components should be defined to complete remote operation. According to the necessary system components in WS-MCRF, the scenarios of the framework

messages are defined and their associated methods and attributes can then be designed. The scenarios of the framework messages are defined in the following.

4.1. **e-Maintenance operation process.** The designed framework messages of e-maintenance operation, shown in Figure 4, are described as follows.

1. When a fault occurs, the equipment delivers the error message to RGC.
2. RGC passes the error message to OMSS.
3. OMSS searches for the diagnostic solution (checkpoint solution) in the OED (On-site Engineering Database).
4. OMSS responds to RGC with the checkpoint solution.
5. RGC itself with the aid of on-site engineers may troubleshoot the equipment based on the checkpoint solution.
6. RGC reports the diagnostic status to OMSS. This completes the local maintenance operation.
7. If no diagnostic solution for the occurring fault is found locally, or the fault cannot be remedied accordingly, then RGC delivers the error message to RMS.
8. RMS retrieves the diagnostic solutions (checkpoint solutions) from the GMD (Global Maintenance Database).
9. RMS responds to RGC with the checkpoint solutions, obtained from the Diagnostics-Solutions Retrieval System, which is a remote diagnostics system on the service supplier side.
10. RGC itself with the aid of on-site engineers may troubleshoot the equipment based on the checkpoint solution obtained in Step 5.
11. RGC reports the diagnostic status to OMSS.
12. OMSS saves the new case, including the information of the fault and the associated diagnostic solution, to OED to facilitate future local maintenance operations.
13. RGC reports the diagnostic status to RMS to complete the remote maintenance operation.
14. RMS stores the diagnostic status to the GMD for future references.

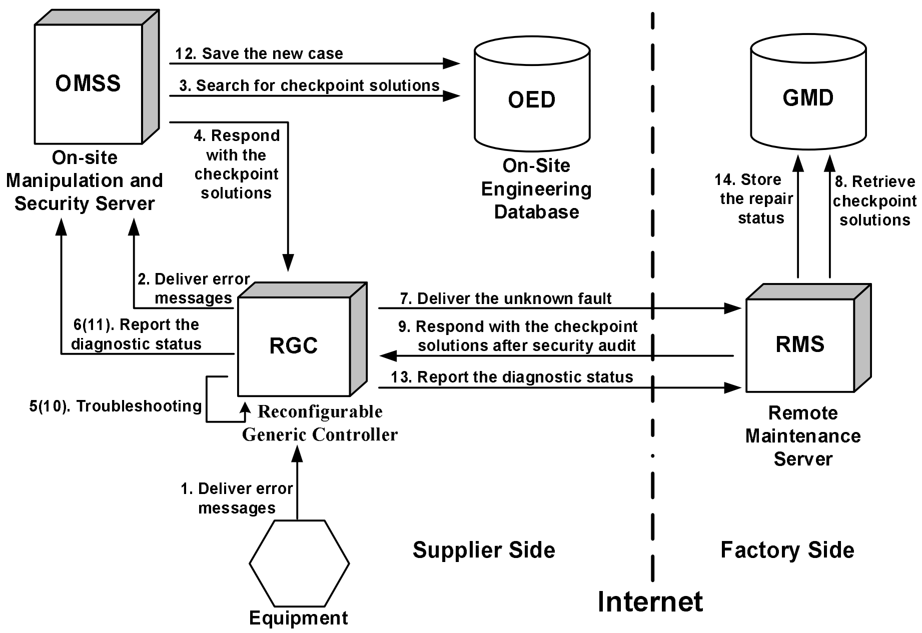

FIGURE 4. Example of framework messages for an e-maintenance operation

4.2. **e-Commerce transaction process.** When a fault occurs, the controller delivers the error message to OMSS. If administrator decides to modify or update the capability of the controller, OMSS searches Soft-SIP in the OED first. If no suitable solution for the requirement capability is found locally, then OMSS request reinforcements to obtain the Soft-SIP from SIP Mall. The process of e-commerce for SIP transaction is shown in Figure 5.

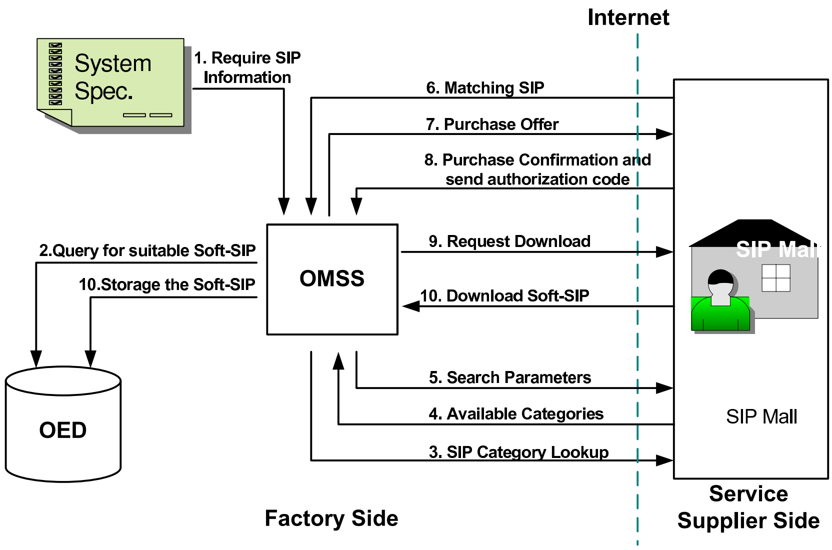

FIGURE 5. Example of framework messages for the e-commerce transaction process

1. When the controller needs to be modified, system specifications are delivered to OMSS.
2. Based on the system specifications, OMSS searches for the suitable Soft-SIP in OED.
3. If suitable Soft-SIP is not available locally, then OMSS performs a lookup on the desired SIP category from SIP Mall.
4. OMSS receives the list of available categories from SIP Mall. Each category has its associated set of search parameters that are specific to that category SIP and service representation.
5. OMSS uses these parameters to search for desired Soft-SIP.
6. OMSS receives the matching Soft-SIP.
7. When OMSS decides to make a purchase, OMSS issues a purchase confirmation request to the SIP Mall.
8. SIP Mall then confirms OMSS and sends the authorization code for downloading action.
9. OMSS requests to download Soft-SIP in accordance with the authorization code.
10. OMSS can download the transaction Soft-SIP through authenticating the sale confirmation and identity in the authorization code. OMSS saves the new SIP into OED.

4.3. **e-Reconfiguring process of RGC.** As shown in Figure 6, the framework messages for an e-reconfiguration and monitor procedure are described as follows.

1. Based on the need of system, the available SIPs are imported into OMSS from OED.
2. OMSS uses embedded EDA tool to complete the co-design of HW/SW of the control logics SIP by using the system specifications.
3. The executive codes are produced after the complete system is designed.

4. Through Controller WS-Agent, the operation and monitoring model in OMSS uploads the HW/SW executive codes to the configuration manager in RGC.
5. The information about the chosen programming space in the programmable chip is assigned to the configuration manager.
6. After receiving the complete HW/SW codes, the configuration manager will accomplish the HW/SW reconfiguring by allocating the codes in proper memory areas.
7. After OMSS performs state monitoring, the executing results and real-time statuses of RGC can be returned to OMSS.
8. The executive results and monitoring states and are saved to OED.
9. By using the Controller WS-Agent, the remote sites can import the parameter data and commands to the Controller WS-Agent on RGC through Internet. Also, the executing results and real-time statuses of RGC can be shown on the Web page for the purpose of monitoring.

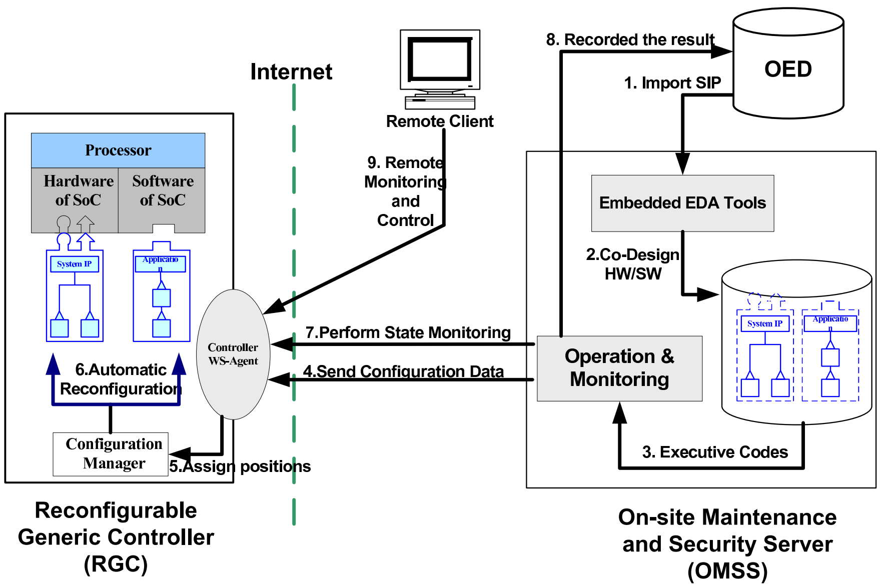

FIGURE 6. Example of framework messages for an e-reconfiguration operation

5. Functional Developments of System Components in WS-MCRF.

This section describes the analysis and design of system components in WS-MCRF. The development follows the procedure of the standard object-oriented system development. The functional requirements are analyzed first, and then the object-oriented analysis and design are subsequently performed.

5.1. Development of the on-site maintenance and security server.

5.1.1. *Analysis of functional requirements.* In this section, the functional requirements of OMSS are analyzed. The analyses include the following eight phases:

- *Single Sign-on Authentication and Authorization Service*

  All the components of the e-maintenance system have the access security problem. In the proposed framework, a single sign-on authentication and authorization service is required. As such, after users pass the authentication through the Web Services, a single integrated authorization process can be performed so that it is not necessary for the users to repeatedly perform login activities. Referring to .NET passport mechanism [42] and SAML (Security Assertion Markup Language) standard of OASIS [43], together with incorporating the PKI (Public Key Infrastructure) mechanism [44] to encrypt/decrypt the transmitted data, the single sign-on authentication and authorization service is implemented.

- *Confirmation of Data Accuracy and Assurance of Information Confidentiality*
  The application of XML signature [45] can ensure the integrity transactions of SOAP messages in Internet. Also, the receiving side of SOAP messages can authenticate the transmitter identity by authenticating the XML signature in the message. Consequently, the non-repudiation can be achieved as the basis for security auditing. However, the body of the signed SOAP message may still exist in plain-text format. Once unlawful parties intercept the message, they can easily use the content in the message. Therefore, the XML encryption technology is used to encrypt the body of the SOAP message. The application of XML encryption can not only ensure the confidentiality of the message content, but also assure that the message can only be applied by the properly authorized receiver.
- *Management of System Users*
  To avoid providing redundant authorization to users, a role-based authorization mechanism is applied to reducing the overall security of the system. According to the identities and the professional specialties of users, the role is classified into different user groups. Then, the users in different groups are granted with different authorizations. By setting up the user groups for obtaining proper authority of system components, the management of user authorizations is achieved.
- *Audit of System Operations*
  All e-operations in the WS-MCRF need to be recorded for the purpose of security auditing. The records in OMSS should include the requested operation, the user information, the execution time, and execution results. It is also desired that no matter the requested operation is authorized or not, the information security auditors can smoothly perform their tasks. Moreover, a graphic user interface is constructed to display the latest system operation records. At any time, the information security maintainer of the enterprise can monitor the system operation statuses through this graphic user interface to prevent any occurrence of system damages caused from unsecured behaviors.
- *Safety Guard and Communication Agent*
  Instead of practically performing requested operations, OMSS is mainly responsible for establishing the security functions for the system. Therefore, OMSS needs to possess the ability to pass the requested operations to other system components that actually perform the associated operations. For instance, in the operation that RGC requests remote diagnostics services from RMS, RGC actually sends the request to OMSS, and then OMSS passes the request on to RMS. Also, in the operation that RMS performs remote operations over RGC, RMS indeed transmits the operation commands to OMSS, and then OMSS passes the commands to RGC. By using the property that a Web Services component can integrate with other Web Services components to provide more complicated functions, a task enabling OMSS as the communication agent between RGC and RMS can be easily accomplished.
- *e-Diagnostics/Maintenance Capabilities*
  The framework should provide a networked connection between the factory and the supplier through Internet. Also, the remote functions, such as remote connectivity, collaboration, maintenance, equipment operations, performance monitoring, and data collection and storage, should be built for the development of e-operation systems.

- *SIP Obtainment Mechanism*

  The SIP obtainment mechanism contains two major functions: composing XML documents of SIPs purchase orders and decoding SIPs from base64-encoded data. The purchase orders from the OMSS to the SIP Mall and the purchased SIPs from the SIP Mall to the OMSS are transmitted in XML files. First, the OMSS uses data from the purchase form to compose XML documents of SIPs purchase orders through the XML Composer. Then, the OMSS sends the XML documents of purchase orders to the SIP Mall. After the SIP Mall confirms the orders, the requested SIPs, which are binary data, will be placed into an XML file using Base64 encoding and then downloaded to the OMSS. Next, the OMSS saves the new XML-based SIPs into the OED. If the engineers want to use the SIPs, these base64-encoded SIPs in the XML file need to be decoded to HDL (Hardware Description Language) files through the XML parser.
- *Execution of Remote Reconfiguring*

  Through network resources, OMSS is designed to simplify the design procedure of SoPC-based reconfiguration. In particular, OMSS possesses various EDA (Electronic Design Automation) tools that can edit, compile, integrate, and test the SIP functions. Then, users can remotely reconfigure and upgrade the functions of controllers.

5.1.2. *Object-oriented analysis.* After the required analysis of OMSS is completed, the use case diagram of OMSS can be drawn and shown in Figure 7. The actors and use cases of the diagram are described as follows:

Actors:

- Administrator: The information personnel of the factory that is in charge of the system management and maintenance.
- Account: The database in the system that stores user data.
- SIP Mall: The e-commerce platform for SIPs on the service supplier side.
- RMS: The remote maintenance server component that is located on the supplier side.
- RGC: The equipment with Reconfigurable Generic Controller that is located on the factory side.
- Global Certification Store: The Global Certification Manage Store of OMSS.

Use Cases:

- Manage User: Administrator can create, delete and modify user accounts and privileges.
- Format Purchase: Administrator transforms purchase into XML documents.
- Decode Operation: This operation is to restore the SIPs to HDL files.
- SIP Obtainment Mechanism: The OMSS possesses several service components that are intended to support on-line SIP trading for e-commerce with SIP Mall through Internet. This use case includes the use cases of *Decode Operation* and *Format Purchase* to increase the efficiency of SIP transaction.
- Reconfigure Controller: The remote reconfiguring procedure stored in the program area of factory is able to put the hardware and software codes in proper memory spaces within the SoPC-based controller.
- Stop Session: Through the OMSS, RMS notifies RGC that the relative remote operations are completed so that RGC can terminate the permission of remote operations.
- Request Session: Through the OMSS, RMS requests the permission from RGC to start the remote monitoring and control.

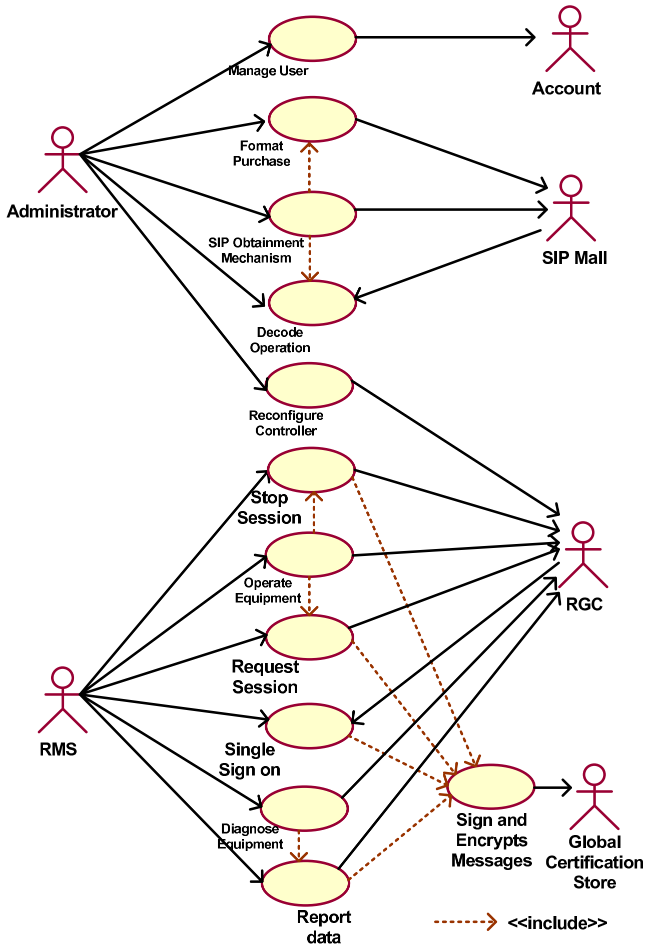

FIGURE 7. Use case diagram of OMSS for e-maintenance

- Operate Equipment: After obtaining the permission to start the remote operations, RMS can go through OMSS to perform remote operations over RGC. This use case includes the use cases of *Request Session* and *Stop Session* to strengthen the security guaranty of the equipment operations.
- Single Sign On: Before using the system, the system user needs to successfully login the single sign-on authentication and authorization service system provided by OMSS.
- Report Data: RMS can request RGC via OMSS to reply relevant equipment engineering data.
- Diagnose Equipment: When an equipment error occurs, RGC can request the equipment diagnostics service from RMS via OMSS. This use case includes the use case of *Report Data*, where the analysis of the equipment engineering data is applied as the basis for equipment diagnosing.

According to the use case diagram, each use case is further described to subsequently generate the corresponding scenarios. Then, based on the scenarios, the OOA of OMSS is performed to create the sequence diagrams and class diagrams of the OOA stage. Due to the space limit, here only the sequence diagram of the remote reconfiguration and monitoring of OMSS is demonstrated in Figure 8 and described as follows.

- Step 1: The administrator signs on with XML signature and encryption the interface of OMSS.

- Step 2: OMSSUserInterface sends the reconfiguring command to the WS-Agent of the selected RGC.
- Step 3: OMSSUserInterface uploads the HW/SW executive codes to the OMSSWS-Agent in RGC.
- Step 4: After receiving the complete HW/SW codes, OMSSWS-Agent assigns the codes to the reconfiguring positions.
- Step 5: OMSSWS-Agent begins to configure the SoPC-based device by the configuration manager in RGC.
- Step 6: The executing results and real-time statuses of RGC can be returned to OMSSUserInterface.
- Step 7: OMSSUserInterface sends the monitoring command to the WS-Agent of the selected RGC.
- Step 8: ControllerWS-Agent performs the status monitoring of RGC.
- Step 9: The real-time monitoring results of RGC can be returned to the administrator.

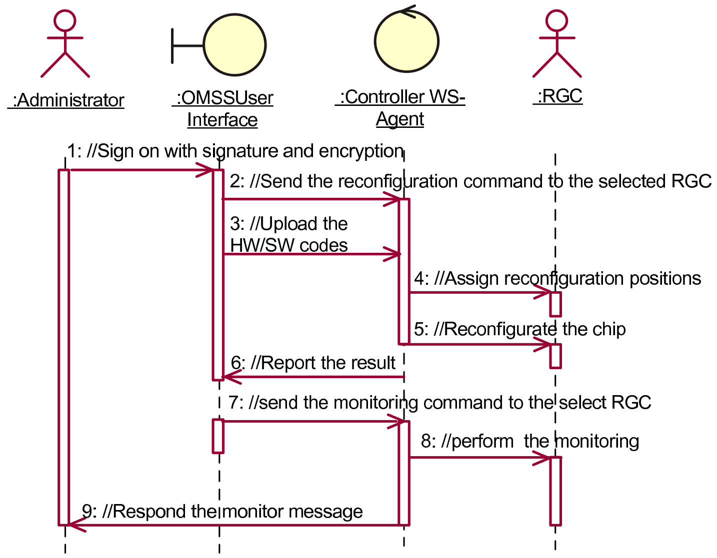

FIGURE 8. Sequence diagram of the remote reconfiguration and monitoring at the OOA stage

5.1.3. *Object-oriented design.* According to the sequence diagrams and class diagrams generated during the OOA stage, the OOD of OMSS can be performed in depth to produce the sequence diagrams and class diagrams of the OOD stage. Figure 9 shows the class diagram of OMSS at the OOD stage. From Figure 9, the static relationships among the constituent classes of OMSS can be observed, including OMSSWS-Agent, OMSSUserInterface, OnsiteEngineerDatabase, Account and GlobalCerticationStore. Among these classes, OMSSWS-Agent is the system component inside OMSS, implemented with the Web Services technology. The OMSSWS-Agent can use SOAP to perform relevant system operations through Internet. Also, OMSSWS-Agent can be used by other system components. OMSSUserInterface is responsible for all of the external communications of OMSS. GlobalCerticationStore is in charge of storing and handling all the certificate data. Account is responsible for storing and handling all the user information. OnsiteEngineerDatabase is used to store the Soft-SIPs and record all the system operations.

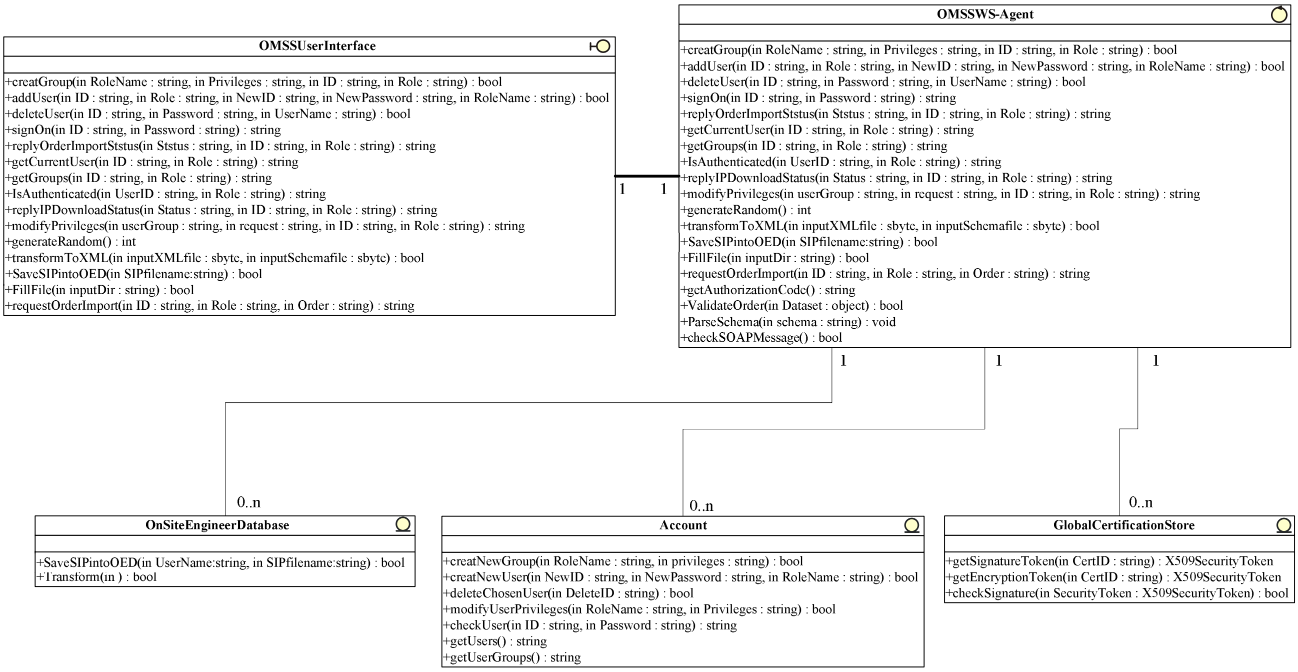

Figure 9. Class diagram of OMSS at the OOD stage

5.2. **Development of RMS and SIP mall.** The analysis and design of RMS and SIP Mall can be accomplished by using the same developing process as that described in the aforementioned OMSS development. First, the Web Services agents of RMS and the SIP Mall take care of the communication tasks for RMS and SIP Mall, respectively. Then, other specific functions are added to complete the design of RMS and SIP Mall. Due to the limit of space, the detailed descriptions of design are omitted here. Other system components can be developed in a similar way to benefit from the code reuse and increase the overall development efficiency.

5.3. **Development of SoPC-based RGC.** In this section, we will illustrate the hardware and software designs of the proposed RGC, respectively.

5.3.1. *The hardware module.* The hardware design of RGC is described as follows.

- *Design of Nios Processor SIP with Peripherals*

  Nios processor [46] is the core of a SoPC-based reconfigurable controller. Under the software environment of SoPC Builder, we can easily complete the design of the Nios processor, including the name, style, memory address, specified breakdown point, etc. Also, various kinds of peripheral SIPs can be integrated, such as RS-232 ports, Ethernet ports and general I/O ports.
- *Design of Control Function SIP*

  The design of the control function SIP is dependent on the controlled equipment. For instance, the AS/RS is composed of a set of storage equipment, movable mechanical arms, and a conveyer. There are nine storehouses in the storage equipment, where each storehouse has a limit switch at the bottom to detect whether there is a tow on it. The conveyer belt is divided into two sections, and each section possesses a reaction switch to detect whether there is a tow to be sent through. The above switches are all connected to the input ports of RGC for monitoring and acquiring the detected values. On the other hand, the output ports of the controller are used to drive the motors to move the mechanical arms to complete the storage and retrieval operations. According to the above hardware configuration, we can then develop the control function SIP for the AS/RS by utilizing programmed state machines. Specifically, we use Quartus II and VHDL to complete the design of control logics.

- *SIP Integration*

  After accomplishing the design of hardware SIP, we can proceed to make connection between the inputs and outputs of the graphic symbols of the processor SIP and the control function SIP according to the data flow. Finally, all necessary SIPs are integrated together and recompiled to accomplish the hardware code of the SoPC-based reconfigurable controller for the AS/RS.

5.3.2. *The software module.* In the software of RGC, we design a Controller WS-Agent based on embedded web server as the core for communication. The Controller WS-Agent can exchange information with OMSS through Internet. In particular, through the embedded web server, the users can use browsers to download and reconfigure the HW/SW codes of the controller, to acquire and analyze the system signals, and to monitor and control the system remotely. In addition, the drivers of the peripheral circuits are also included in the software. We adopt ANSI C programming language to design the software, and use GNUPro to compile and link the programs.

- *Peripheral Drivers*

  The application program needs to drive various interfaces of the peripheral circuits, which are connected to the processor SIP and the function circuit SIP. Because the Altera EDA tool has already developed the relevant drivers for peripheral circuits of the Nios processor with ANSI C programming language, we can easily include the desired peripheral drivers in the application program.

- *Web Programs*

  Without the support of the operating system, we use ANSI C programming language to design the Web Services, including several CGI programs. We also design various types of dynamic web pages, such as the ones for HW/SW reconfiguring, monitoring and control. Besides, we design some static web pages that are stored in flash with the form of images to provide static information of the controller, such as the introduction of controller structure and the procedure of controller reconfiguring.

6. **Implementation and Integration Test.** Based on the proposed framework, a paradigm application for a virtual AS/RS, shown in Figures 2 and 3, has been successfully implemented and tested. The details of system implementation and testing are described below.

6.1. **System implementation.** This prototype system adopts Windows XP as the development platform to develop the system components such as OMSS, RMS and parts of SIP Mall for SIP transaction. The C# language is applied for the implementation of all system components, and the CLR (Common Language Runtime) of Microsoft .NET is used as the execution environment. The resource of the embedded OS (Operation System) for RGC is restricted; thus we use ANSI C programming language to design its execution environment. This implementation has also proved the interoperability of the proposed information integration framework under heterogeneous execution environments and different programming languages.

The software tools of the system implementation for OMSS, RMS and SIP Mall include Microsoft Visual Studio.NET, Microsoft Internet Information Services, Microsoft SQL Server 2000, and Microsoft Web Services Enhancement. Besides, the GUNPro and Quartus tools are applied to developing the software and hardware of RGC, respectively. On the other hand, the hardware for system deployment uses three sets of Pentium IV

PCs, where OMSS, RMS and SIP Mall are individually installed in different PCs. Finally, the Altera Nios development board is adopted as the development platform for the HW/SW circuits of RGC.

6.2. **Construction of virtual AS/RS.** Owing to validating of the convenience and effectiveness of the proposed framework, a virtual AS/RS system is constructed as an application paradigm in a simulation environment, shown in Figure 10. By using ADVENTECH Studio software tool and ADAM5000 series Input/Output module [47], a virtual AS/RS platform is successfully implemented. As already explained in Section 4.3, we have designed the control function SIPs for the function requirements of an RGC-controlled automatic storage/retrieval system. The virtual AS/RS system is implemented with an IBM PC running Windows XP with Pentium IV core processor running at 2.33 GHz, 4GB DDR2 RAM and Asus EAH4870 series graphics card. Finally, the AS/RS control system by ADAM5000 module with RGC is implemented to reach interactive operation of simulation.

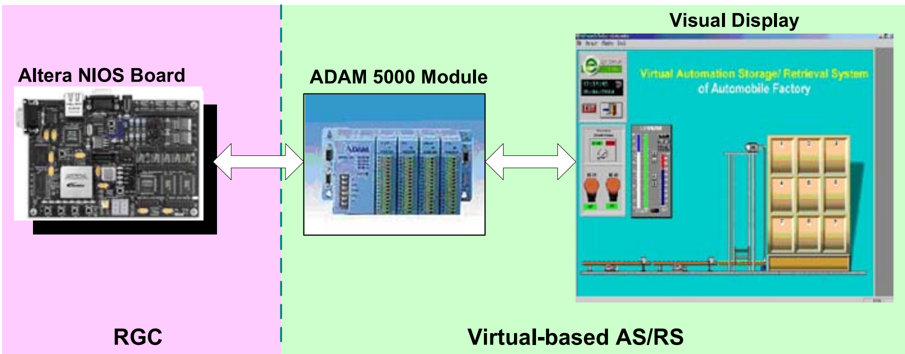

FIGURE 10. Development of the virtual AS/RS platform with RGC

6.3. **Integration test.** A snapshot of the integration test of the paradigm WS-MCRF is shown in Figure 11. The designs of OMSS, RMS and SIP Mall all have graphic user interfaces for the convenience of system operations. In this prototype system, the equipment is substituted with the virtual system that complies with AS/RS specifications. First, we test every constructed component in the system to assure that each function can meet the design specifications. Then, we design necessary testing scenarios to perform integration tests to validate the practicability and effectiveness of the proposed framework. Two major scenarios are adopted to test the system, which are described as follows.

- *Remotely Diagnose Equipment through OMSS and RMS*
  1. When an equipment error occurs, RGC delivers the error messages to OMSS.
  2. The administrator of OMSS searches for the relevant diagnostic solutions from the OED according to the error messages. If a proper diagnostic solution is available, the OMSS administrator executes the suggestion and repairing the equipment.
  3. If a proper solution is unavailable, the RGC will ask RMS for the diagnostic services from advanced experts.
  4. The expert of equipment supplier, after completing the relevant security handling with OMSS, can perform remote operations to diagnose and repair the equipment through Internet via OMSS.
  5. In case the RGC detects any unreasonable remote operation, the remote operation can be immediately stopped.

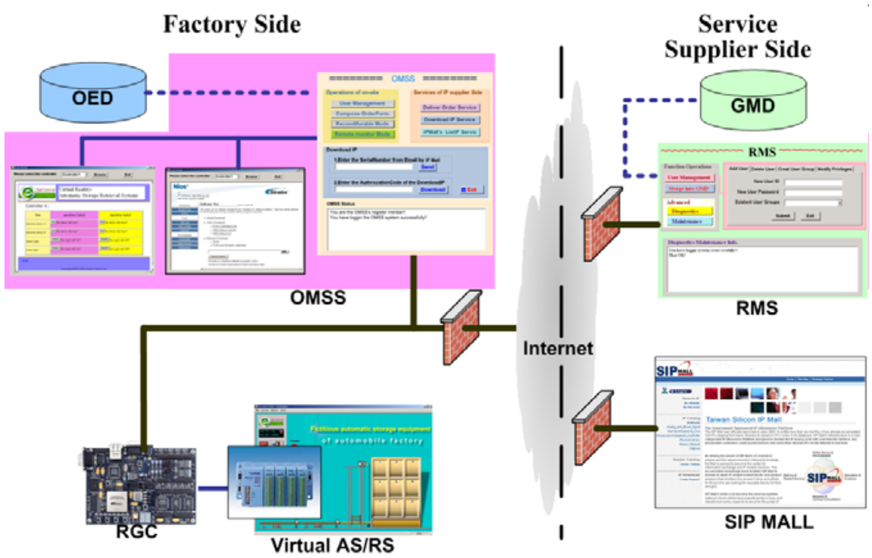

FIGURE 11. The snapshot of system integration and tests

6. The equipment expert on the service supplier side stores the repair status to the global maintenance database (GMD) for future references.

- *Remotely Reconfiguring and Monitoring*
  1. OMSS obtains the desired function SIP through OED in the factory and sends it to the EDA tool for formatting and verification.
  2. According to the system hardware configuration, the HW/SW codes of RGC are designed and produced.
  3. The operation and monitoring module of OMSS obtains the HW/SW codes.
  4. The operation and monitoring module of OMSS requests RGC to download the remote reconfiguring service. Then, the HW/SW codes are uploaded to the web server through the web page via HTTP.
  5. After receiving the HW/SW codes, the web server passes them to the reconfiguring manager for reconfigurable controller.
  6. The reconfiguring manager automatically allocates the HW/SW codes to proper memory areas to accomplish the reconfiguration of the controller.
  7. After the controller is set up and ready to run, the users on OMSS and other remote sites can then monitor and control the statuses of the controller through the Internet.
  8. If there is an operational mistake or a function that does not reach the requirements, Steps 2-7 are repeated.

The test results indicate that the proposed development framework for SoPC-based reconfigurable controllers can certainly comply with the design objectives and its effectiveness is demonstrated and verified.

6.4. **Capability comparisons.** To illustrate the advantages of the proposed framework, we compare the capabilities of the proposed framework and other e-Diagnostics/e-Maintenance and e-Commerce frameworks in Table 1. Generally, the e-Diagnostics or e-Maintenance frameworks, such as those in [18, 19], are dedicated to support diagnostics and maintenance operations through network, whereas some advanced e-Maintenance frameworks, such as that in [39], support conjecture functions using intelligent VM models. The general e-Commerce frameworks, such as those in [48, 49], mainly support delivering e-commerce data, such as purchase orders, WIP data, demand forecasts and shipping plans. [48], as well as engineering data [49], over the Internet.

On the contrary, the proposed framework can support diagnostics/maintenance operations through network and provide conjecture or prediction functions through pluggable VM models in RGCs. Besides, the proposed framework possesses the e-Commerce capability that mainly supports SIPs transactions between the SIP Mall and the factory side through the Internet. In addition, reconfigurable generic controllers based on SOPC technology are included in the proposed framework. The engineers are allowed to remotely reconfigure and upgrade the functions of controllers for different types of equipment by downloading new SIPs into SOPC through network. From the above comparisons, it is obvious that the proposed framework is more versatile than other related frameworks.

Table 1. Capability comparisons of the proposed framework and other e-Diagnostics/e-Maintenance and e-Commerce frameworks

	Proposed Framework	e-Diagnostics or e-Maintenance Frameworks [18, 19, 39]	e-Commerce Frameworks [48, 49]
e-Diagnostics /e-Maintenance Capability	1) Support diagnostics and maintenance operations through network. 2) Support conjecture or prediction functions through pluggable VM models in RGCs.	1) Support diagnostics and maintenance operations through network [18, 19]. 2) Support conjecture functions using VM models [39].	N/A
e-Commerce Capability	Support SIPs transactions between the SIP Mall and the factory side through the Internet.	N/A	Deliver general e-commerce data, such as purchase orders, WIP data, demand forecasts and shipping plans. [48], as well as engineering data [49], through the Internet.
Reconfigurable Capability	1) Possess reconfigurable generic controllers based on SOPC technology. 2) Allow engineers to remotely reconfigure and upgrade the functions of controllers for different types of equipment by downloading new SIPs into SOPC through network.	N/A	N/A

7. **Conclusion.** In this paper, based on the technologies of SoPC, Soft-SIP, and the emerging Web Services, an e-Maintenance, Commerce, and Reconfiguring framework for industrial equipment with reconfigurable generic controllers is proposed. The proposed framework can successfully resolve the information integration problem among cross-network, cross-platform, and heterogeneous systems of remote operation environments. The developed scheme has full operational capabilities such as automatically integrating diagnostics and maintenance information through Internet, web-based e-commerce service for SIP transaction and remotely executing reconfiguring operations for SoPC-based controllers. In addition, the proposed framework can meet various security requirements, such as the authentication and authorization of users, the protection of information confidentiality, the safeguard of data transmission security, and the monitoring of system operations.

The addressed system is developed with an object-oriented approach. After the system requirements are analyzed, the system framework is designed, and the system component model is sketched. Then, the object-oriented analysis and design, together with the system implementation, integration and testing, are sequentially performed. To validate the convenience and effectiveness of the proposed scheme, a SoPC-based controller for a virtual AS/RS is constructed as an application paradigm. The integration test results show that the proposed conceptual framework can certainly comply with the design objectives. It is believed that the proposed framework and concepts can meet the requirements of e-operation systems for the future industry automation.

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