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INDUSTRIAL AUTOMATION SERVICE TEMPLATES FOR PROVISIONING OF CLOUD SERVICES

P.Priya [1], M.Mohanapriya [2]

P.G. Student, Dept. of MCA, VSB Engineering College, Karur, Tamilnadu, India

Asst.Professor, Dept. of MCA, VSB Engineering College, Karur, Tamilnadu, India

Abstract : **New cloud services are being developed to support a wide variety of real-life applications. In this paper, we introduce a new cloud service: industrial automation, which includes different functionalities from feedback control and telemetry to plant optimization and enterprise management. We focus our study on the feedback control layer as the most time-critical and demanding functionality. Today's large-scale industrial automation projects are expensive and time-consuming. Hence, we propose a new cloud-based automation architecture, we analyze cost and time savings under the proposed architecture. We show that significant cost and time savings can be achieved, mainly due to the virtualization of controllers and the reduction of hardware cost and associated labor. However, the major difficulties in providing cloud-based industrial automation systems are timeliness and reliability. Offering automation functionalities from the cloud over the Internet puts the controlled processes at risk due to varying communication delays and potential failure of virtual machines and/or links. Thus, we design an adaptive delay compensator and a distributed fault tolerance algorithm to mitigate delays and failures, respectively. We theoretically analyze the performance of the proposed architecture when compared to the traditional systems and prove zero or negligible change in performance. To experimentally evaluate our approach, we implement our controllers on commercial clouds and use them to control: (i) a physical model of a solar power plant, where we show that the fault-tolerance algorithm effectively makes the system unaware of faults, and (ii) industry-standard emulation with large injected delays and disturbances, where we show that the proposed cloud-based controllers perform indistinguishably from the best-known counterparts: local controllers.**

Index Terms—Cloud Computing, Industrial Automation, Delay Compensation, Fault Tolerance, Feedback Control

1 INTRODUCTION

Cloud computing is proving to be an important area that requires further research and development to accommodate more applications [24]. It has attracted significant interest from academia, industry, governments, and even individual users not only because of the promised cost savings, but also because it can improve existing computing services, e.g., video streaming [13]. In addition, cloud computing offers opportunities to create new services, e.g., robotics [8, 21] and manufacturing. In this paper, we introduce a new cloud service: industrial automation. We show that the proposed service reduces the time and cost incurred in deploying new systems since current industrial automation systems are complex and require large human effort to build [26]. Further, we address how to migrate vital automation functionality to the cloud without compromising the system performance. It is noteworthy that the work proposed in this paper fits

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an ongoing trend that evolved several decades ago when digital computers were first introduced to control systems around the year of 1960 in the form of Direct Digital Control (DDC). Ever since, evolution of control system has been associated with the advancement of computing devices [34]. Several functionalities, e.g., monitoring, logging, optimization, and asset management, have been added on top of the core direct digital control functionality, forming an *automation system*. As a result, a current industrial automation system is indeed a multi-tiered architecture entailing several hierarchical layers of computation, communication, and storage [33]. With such history, we see a great potential in studying the application of an evolving computing model, such as cloud computing to industrial automation systems, which could provide several benefits to end users, including cost saving and agility.

2 RELATED WORK

Kumar *et al.* [21] proposed an approach for assisting autonomous vehicles in path planning based on cloud collected remote sensor data. Chen *et al.* [8] proposed "Robot as a Service" or RaaS where the service is available in both hardware and software. Also, Wu *et al.* [35] explored "Cloud Manufacturing", which is a cloud-based manufacturing model that is service-oriented, customercentric, and demand-driven. RaaS and Cloud Manufacturing focus on planning and optimization, while we consider the whole automation hierarchy and focus on direct digital control, which is much more challenging in terms of timeliness and reliability. Several researchers/enterprises employed feedback controllers to manage their computing systems, e.g., [1, 23, 29]. The employed feedback controllers can be acquired as a service through our proposed cloud-based feedback control approach. It has been recently proposed to offer certain industrial automation components through the cloud. First, enterpriselevel (L4) asset management applications, such as SAPr, are now offered through the cloud. Second, plant optimization (L3) can easily be offered through the cloud. For example, Honeywell AttuneTM [31] offers cloud-based services for energy optimization. Although, it is mainly offered for building automation, the plant version is conceptually the same. Third, HMI/SCADA (L2) is now offered in a virtualized fashion as it is the case with Invensys Wonderwarer System Platform 2012 [19], which indicates that offering L2 as a cloud service is only a matter of moving the virtual machines (VMs) to the cloud. Finally, moving direct digital control (L1) to the cloud is challenging due to timeliness and reliability requirements. We are not aware of any commercially available system that offers direct digital control through the cloud, although researchers have partially addressed some of these challenges as we present in the following paragraph.

Yang *et al.* [36] designed two predictive compensators for Internet delays in the feedforward and feedback directions, while Chen *et al.* [9] proposed a single compensator block for the feedforward path only. Yoo *et al.* [37] proposed the use of Smith Predictor with constant buffer, which can unnecessarily increase the settling time because it inserts delay inside the control loop to keep the delay at its maximum possible value. In contrast, our proposed delay mitigation approach requires only one remote component that adaptively compensates for the whole roundtrip delay without affecting the

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original controller design or requiring additional support from the controlled system.

Most fail-stop failures in digital controllers are handled through redundancy [7]. For example, Yokogawa FFCS [18] employs double redundancy, and Invensys Triconex Tricon [20] employs triple redundancy. While the former is used for direct digital control, the latter is used for safety and emergency shutdown control of mission-critical processes, e.g., nuclear power plants. Our extensive literature review did not yield any work where redundant controllers are remote to both the process and the primary controller as we propose in this paper. In summary, we are not aware of any work that proposed an architecture for the whole industrial automation hierarchy, including its most demanding layer of direct digital control. Further, we did not come across any work that analyzes cost/time saving when using cloud computing in industrial automation, as we do in this paper. Furthermore, we have not come across any work that addressed fault tolerance through redundant software controllers when running on loosely coupled machines that are far away from one another. Thus, in the evaluation section, we compare the performance of our approach to the best known counterpart: local, physical, and tightly coupled controllers.

2.1 EXISTING SYSTEM

Controllers communicate with sensors/actuators over a network with mostly deterministic communication delays that are negligibly. Whereas in our design, communication occurs over the Internet, which adds large and variable delays to the control loop. Therefore, straightforward migration of direct digital control algorithms to the cloud may affect the functionality of the control loop or even make the system unstable, and thus jeopardize the theoretical performance guarantees offered by traditional controllers. Existing automation systems a control room is a complex environment loaded with servers, workstations, network switches, and cables.

2.1.1 Disadvantage

- Requires more hardware and wiring, making it a tidier environment
- Control room is a complex environment loaded with servers.

2.2 PROPOSED SYSTEM

The use of Smith Predictor with constant buffer, which can unnecessarily increase the settling time because it inserts delay inside the control loop to keep the delay at its maximum possible value. In contrast, our proposed delay mitigation approach requires only one remote component that adaptively compensates for the whole roundtrip delay without affecting the original controller design or requiring additional support from the controlled system.

2.2.1 Advantage

- Maximum possible value.
- Unnecessarily increase the settling time.

3. PROPOSED ARCHITECTURE OVERVIEW

In our proposed approach, we move all computing functions of the automation system into the cloud in order to provide full automation as a service. This makes it easier, faster and less costly for users to deploy, maintain, and upgrade their automation systems. Moreover, our design supports switching to a different cloud automation providers since all VMs

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can be group-migrated to a different provider. Some components are not movable to the cloud, such as sensors, actuators, and safety/emergency shutdown control functions. Our proposed approach relaxes the existing systems layers. To connect sensors and actuators to the cloud, we use field-level protocols that run on top of TCP, such as Modbus/TCP and Profibus/TCP, which are either built in the devices or provided through separate I/O modules. For cases where advanced functions, such as security and messagelevel scheduling are required, we dedicate a gateway server, which could be replicated for more reliability. In our approach, direct digital control algorithms (L1) run on cloud VMs instead of real hardware in the control room. Also, in existing automation systems , controllers communicate with sensors/actuators over a network with mostly deterministic communication delays that are negligibly. Whereas in our design, communication occurs over the Internet, which adds large and variable delays to the control loop. Therefore, straightforward migration of direct digital control algorithms to the cloud may affect the functionality of the control loop or even make the system unstable, and thus jeopardize the theoretical performance guarantees offered by traditional controllers. As a result, more components are needed to mitigate the variable Internet delays and the lack of reliability of Internet links and VMs, which we design in this paper. We propose providing the HMI/SCADA layer, L2, and all the way to L4, through Platform or Software as a Service (PaaS and SaaS) models. Thus, we provide engineers and operators with access to the control room applications through thin clients. In existing automation systems, a control room is a complex environment loaded with servers, workstations, network switches, and cables. In our proposed design, a control room is comprised of a number of thin clients, which requires less hardware and wiring, making it a tidier environment [26]. In a manner similar to the field gateway server, we propose a control room redundant gateway server to reliably carry on advanced functions, such as security and message scheduling.

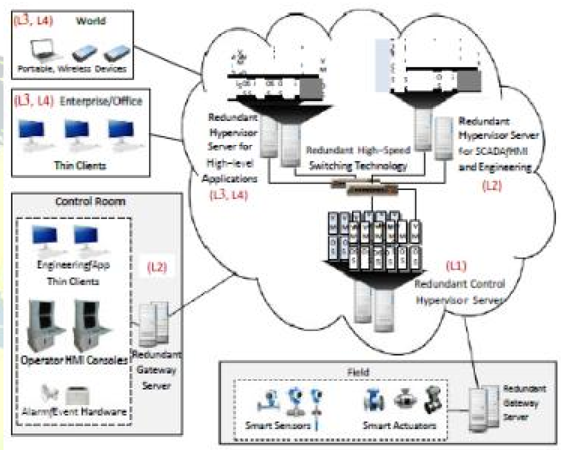

Fig. 3. Overview of the proposed architecture.

3.1 MODULES DESCRIPTION

1. Admin Module/Organization.

2. File Uploading Process

3. Broker Module

4. Encrypted

5. Co-Ordinator Module.

6. File Transferring

Admin Module:

The admin module in our project manages the account information about the data owner. The admin only have the authorization to create new data owners.

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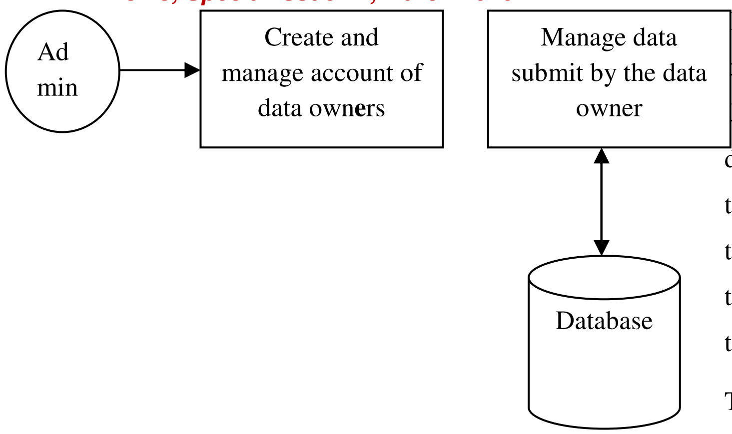
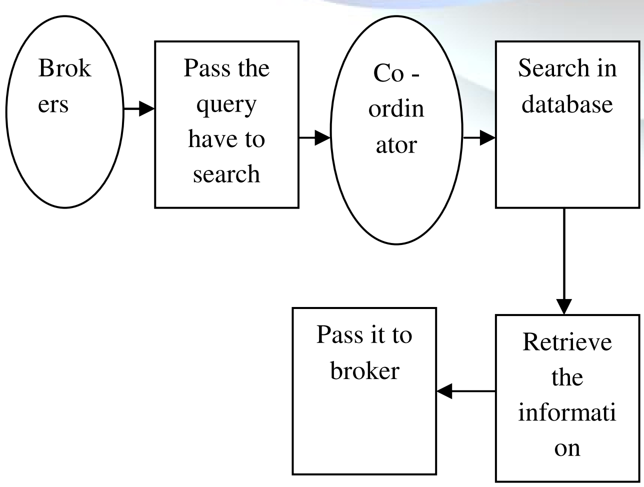


Co-Ordinator Module:

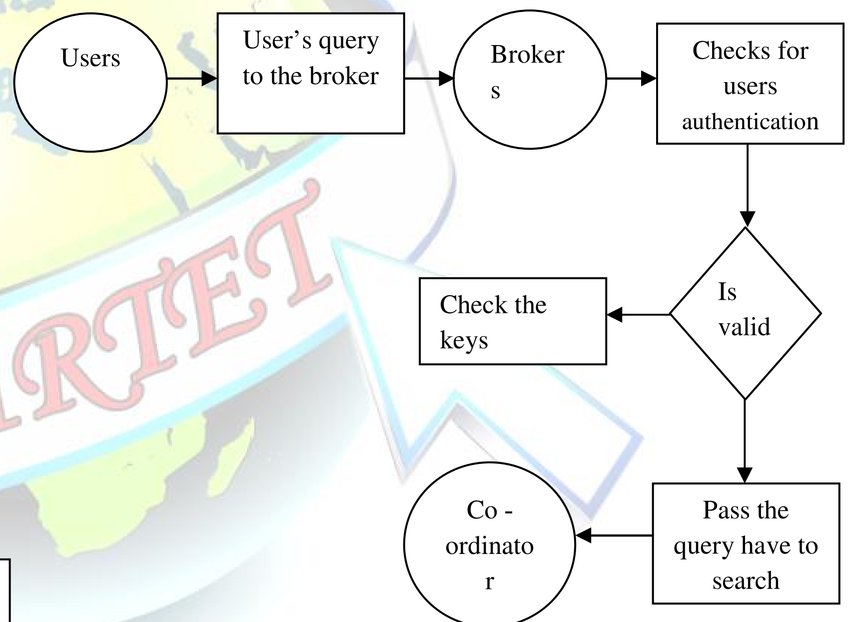
The process carried on this module is to provide a global service between the brokers and the database. The coordinator gets the query from the brokers in an encrypted manner. The coordinator is responsible for search the query into the database and retrieves the relevant information.) In this module, the co-coordinator performs the global service between the two end users. Initially the Data Owner needs to submit the details of the patient in the server. Data Users needs to search the data which is stored in the servers and they give request for the data and the co-Ordinator sends the key to the Data users and the Data will be passed by the broker Way.



Broker Module:

In this module, the broker performs the role who can act between the Co-coordinator and the data Users. The request which is all submitted from the data user will be verified and thus it will be passed to the co-coordinator. The data will be passed from the co-coordinator and thus it will be submitted to the End Users(Data Users). The broker module acts the role between the coordinator and the data users.

The broker is the main responsible for users authentication and the query forwarding. The brokers forward the query to the co-ordinator and returns the required information to the user.



Encryption Modules

The first module in this project is file encryption module. This module is designed for encrypt the file before outsourcing the file into cloud service providers. The encryption process done by the dynamic data owner to prevent their data from the unauthorized users. During the encryption time the secret key for the file to decrypt the file is

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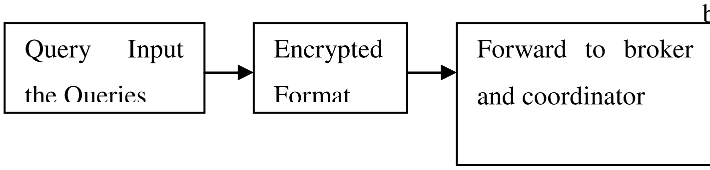
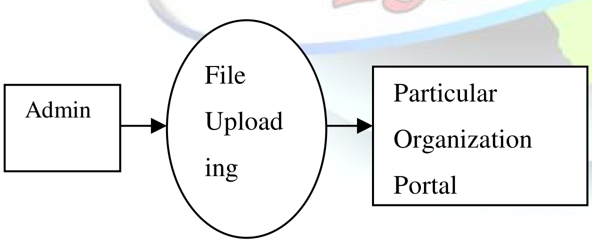
produced. The owner have to keep the secret key. When they are retrieving the data from the cloud service providers the data will be in encrypted form. So this module plays an important role in our project.



File upload Module

Transferring data from one remote system to another under the control of a local system is **remote uploading**. Remote uploading is used by some online file hosting services . It is also used when the local computer has a slow connection to the remote systems, but they have a fast connection between them. Without remote uploading functionality, the data would have to first be download to local host and then uploaded to the remote file hosting server, both times over slow connections.



FILE TRANSFERRING

The **File Transfer Protocol** (**FTP**) is a standard network protocol used to transfer computer files between a client and server on a computer network. FTP is built on a client-server model architecture and uses separate control and data connections between the client and the server.[1] FTP users may authenticate themselves with a clear-text sign-in protocol, normally in the form of a username and password, but can connect anonymously if the server is onfigured to allow it. For secure transmission that rotects the username and password, and encrypts he content, FTP is often secured with SSL/TLS (FTPS). SSH File Transfer Protocol (SFTP) is sometimes also used instead, but is technologically different.

4. CONCLUSIONS & FUTURE ENHANCEMENTS

Cloud computing is proving beneficial to many real-life applications, including industrial automation. We proposed architecture for offering industrial automation as a cloud service, which simplifies automation system design and saves time and cost. We focused on satisfying the timeliness and reliability requirements for feedback control as the most challenging industrial automation component. We presented and theoretically analyzed novel delay mitigation and distributed fault tolerance algorithms. We evaluated our proposed approach using a physical model of a real-life plant, and deployed its controllers on the Amazon cloud. Our experimental results revealed that the approach can effectively make the controlled plant unaware of controller/link failures, even when controllers are thousands of miles away from the plant. Further, we conducted emulation experiments with the purpose of injecting random and deterministic delays and disturbances.

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