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Article

G-Cloud Monitor: A Cloud Monitoring System for Factory Automation for Sustainable Green Computing

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Abstract: Green and cloud computing (G-cloud) are new trends in all areas of computing. The G-cloud provides an efficient function, which enables users to access their programs, systems and platforms at anytime and anyplace. Green computing can also yield greener technology by reducing power consumption for sustainable environments. Furthermore, in order to apply user needs to the system development, the user characteristics are regarded as some of the most important factors to be considered in product industries. In this paper, we propose a cloud monitoring system to observe and manage the manufacturing system/factory automation for sustainable green computing. For monitoring systems, we utilized the resources in the G-cloud environments, and hence, it can reduce the amount of system resources and devices, such as system power and processes. In addition, we propose adding a user profile to the monitoring system in order to provide a user-friendly function. That is, this function allows system configurations to be automatically matched to the individual's requirements, thus increasing efficiency.

Keywords: green computing; manufacturing system; cloud computing; user profile; factory automation; monitoring system

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1. Introduction

Designers of the manufacturing systems in factory automation are in constant search of new principles, new mechanisms, applications, services and tools to enable faster and more efficient performance for today's systems. Consequently, the structure of automated factories, their resources and processes have to be adapted and continuously developed and improved. Furthermore, in recent times, factory development has become more oriented towards strategic objectives and continuous operation without any jams or errors, while maximizing economic efficiency [1]. For this purpose, optimizing the design of manufacturing systems [2–4] in the factory environment can be very important work.

Computer systems are continuously undergoing a process of improvement in terms of their information processing capability. In addition, computer technology is increasingly becoming integrated with our daily lives to enhance comfort and convenience [5]. Recently, application and information technology has changed. A designer or developer who wants to improve the efficiency of manufacturing systems in the factory designs functions to control and manage the systems using the network. Through this work, the machine's user or manager is able to see and analyze the system's status anytime, anywhere. However, it is difficult for them to simultaneously control and manage many manufacturing systems in real time. In accordance with this new trend, the area of factory automation is attempting to apply this new technology for more efficient work and good quality production. To this end, the application of cloud computing and sensor networks in factory automation can be useful.

Cloud computing is a new paradigm that is changing the behavior of the consumption and delivery of information technology services [6,7], and it is fast becoming a popular computing trend. Cloud computing technology is the new Internet-based IT services that increase the use and delivery model to provide flexible, dynamic, scalable and, often, virtualized resources. A specific feature of this model is that computation, hardware and software resources are provided as services [6]. Therefore, system developers within cloud computing who want to provide interactive services, including hardware and software resources, do not require finances for a large or long-term development project [8].

It also can be an adaptable technology for many organizations with its dynamic scalability and usage of virtualized resources as a service over the Internet [9]. In the cloud computing environment, system software applications and processes can be executed or maintained as a service and that includes infrastructures, system resources, platforms, and so on. Furthermore, the advantages of applying cloud computing technology to manufacturing systems includes significant cost reductions in terms of system development and management, on-demand resource provision, supporting legacy codes, service reliability, easy management and so on [6,10].

When it comes to storage service, cloud computing enables users to remotely process and store their data in the cloud, so as to receive services on-demand [9]. That is, it can provide massive storage facilities catering to large data storage requirements, such as those of complex services and application environments [11].

In spite of the many advantages of the cloud computing application, it lacks the research necessary to provide user-oriented service processes and methods and to analyze what it is that users want. A user profile can be a solution, and user characteristics are regarded as some of the most important factors to be considered in the software and product industries [12–14]. It is a technique based on the user's experience, knowledge and needs. Therefore, to develop a manufacturing system in the factory, a cloud computing and user profile-based system is needed.

Furthermore, the recent trend of system development and environment has been focusing on how to reduce system energy and process resources. We call this technology green computing. With this technology, we can reduce the global CO_2 emissions from system use [10].

In this paper, we present a model to provide a cloud monitoring system for manufacturing systems in the factory. In addition, we propose green computing technology for monitoring, controlling and management within the overall process of the manufacturing system. In order to provide user-friendly functions for system monitoring, we also propose a user profile for the system. This would allow the system to quickly search for and process functions in accordance with user preferences and requirements, thus reducing system power usage. To evaluate the performance for the proposed system, we recruited 124 participants as a sample, and all of them took a pre-test using existing methods and a post-test using the proposed method for satisfaction for system operation. The responses were recorded via a questionnaire. According to our results, the proposed system can provide higher satisfaction to users across the five factors measured.

The remainder of the paper is organized as follows. Section 2 shows related works, including factory automation, cloud computing, monitoring systems and green computing technology. Section 3 shows the proposed system process for a cloud monitoring system within the green computing environment. Section 4 shows the experiment result, and finally, Section 5 presents a discussion and conclusions for this research.

2. Related Works

In this section, we describe factory automation and manufacturing systems, cloud computing and monitoring systems, as well as green computing.

2.1. Factory Automation and Manufacturing System

A new industrial paradigm featuring high technology and networking is now essential in order to improve efficiency, effectiveness and guarantee competitiveness within a sustainable business environment. In terms of manufacturing systems, it is becoming progressively clearer that the future generation of factories needs to be modular, scalable, flexible, open, agile and knowledge-based to allow for real-time adaption to continuously changing market trends and demands, technology options and regulations. In addition, this future generation of factories should be able to integrate each model and strategies capable of adapting their production system to the market's needs, of accelerating system design and of optimizing production [15].

Within the manufacturing strategy literature, structural decisions are made regarding automation without any errors, customer-oriented services and more efficiency. On the other hand, decisions regarding user models are considered an infrastructural decision within the manufacturing strategy formulation [16]. In Figure 1, Morgan *et al.* [17] depicted how strategic integration activities create system information and communication flows related to the manufacturing plant (system).

Figure 1. Four types of strategic integration.

According to their framework, a manufacturing system's process can be influenced by the acquisition of technical knowledge and planning (system) information from external sources, including suppliers, customers, product-process technology developers and corporate strategy managers. The need for a regular review of manufacturing strategies has been emphasized by Hayes and Wheelwright [18], as well as by Platts and Gregory [19], all of whom addressed the manufacturing strategies that should not only be consciously developed, but also should be subject to regular review. Consequently, automation is described in the human resource literature, where frequent problems mentioned are linked to human issues with respect to using, controlling and managing the automated system: attention problems, perception and cognition. Thus, automation in the manufacturing area often refers to the automation, mechanization, integration and communication of sensing for environmental data.

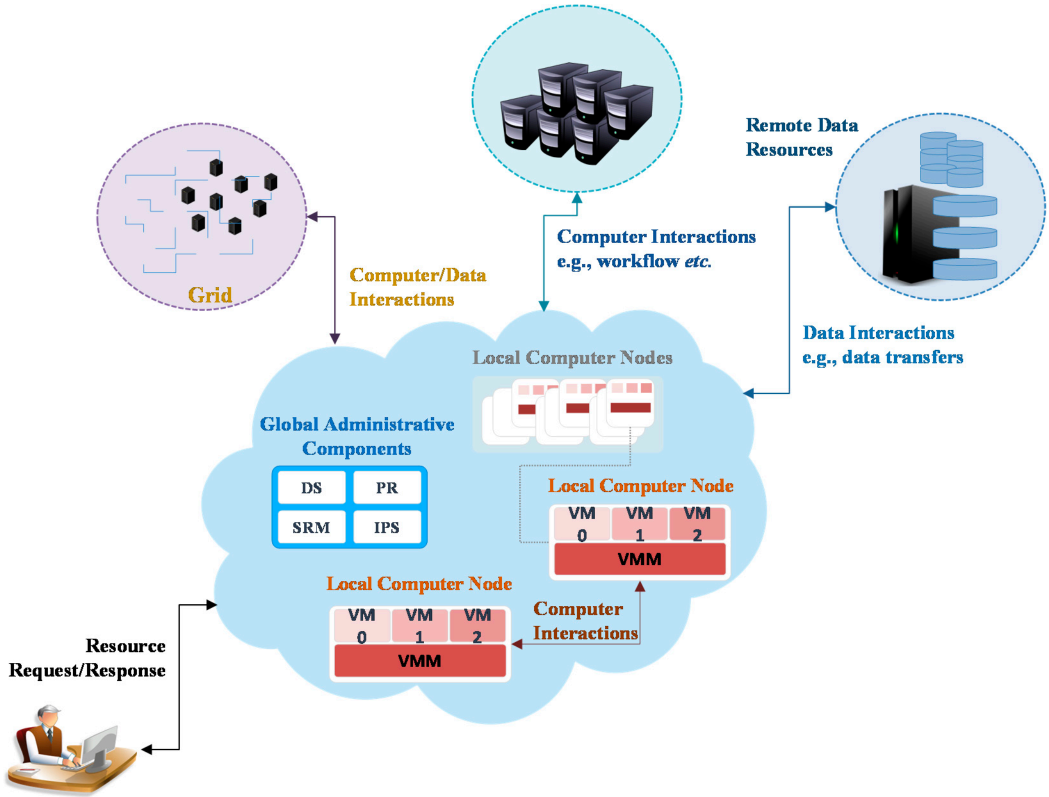
However, the focus is on the complex interaction between humans (users) and technology, which, when combined, is referred to as automation [4]. In the factory automation area, the method for system development requires new techniques for more efficient processes, such as cloud computing.

2.2. Cloud Computing and Monitoring System

Cloud computing provides materials, such as hardware, software, infrastructure, platforms, and so on, as their services. For example, it can involve a software program and a process as a service and use hardware resources as a virtualized platform across the host connected by the Internet [20].

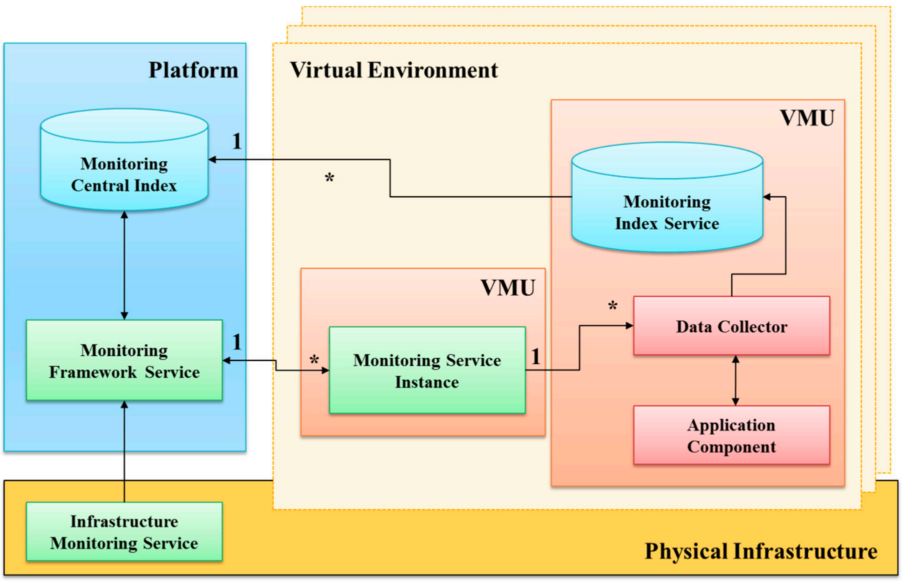
A simple architecture for a cloud computing system has been depicted in Figure 2 [21,22]. System virtualization serves as the unit for the realization of an infrastructure within an independent operating environment. Cloud platforms have been addressed as computing clouds, as they use large-scale data as data clouds in this environment [21,22]. Monitoring systems that use computing resources have been are search topic of interest for many years. Gregory *et al*. [23] proposed a monitoring mechanism for computing resources in the cloud computing environment, as shown in Figure 3.

Figure 2. A cloud computing system.



DS: Domain Service; PR: Public Relations; SRM: Site Recovery Manager; IPS: Intrusion-prevention system; VM: virtual Machine; VMM: Virtual Machine Manager.

Figure 3. Monitoring infrastructure architecture for the cloud computing environment.



VMU: Visual Memory Unit.

They deployed monitoring system using the cloud computing layers:

(a) PaaS: used for aggregation, evaluation of the monitoring application and infrastructure data.
(b) IaaS: used for monitoring the hardware resources, including data storage and memory.
(c) SaaS: used for monitoring software applications, logic, programs, and so on.

However, their research does not go as far as suggesting a monitoring service tailored to the manufacturing system. In this environment, hardware and software for cloud computing-based manufacturing systems also need a process for handling huge data quantities in factory environments.

2.3. Green Computing

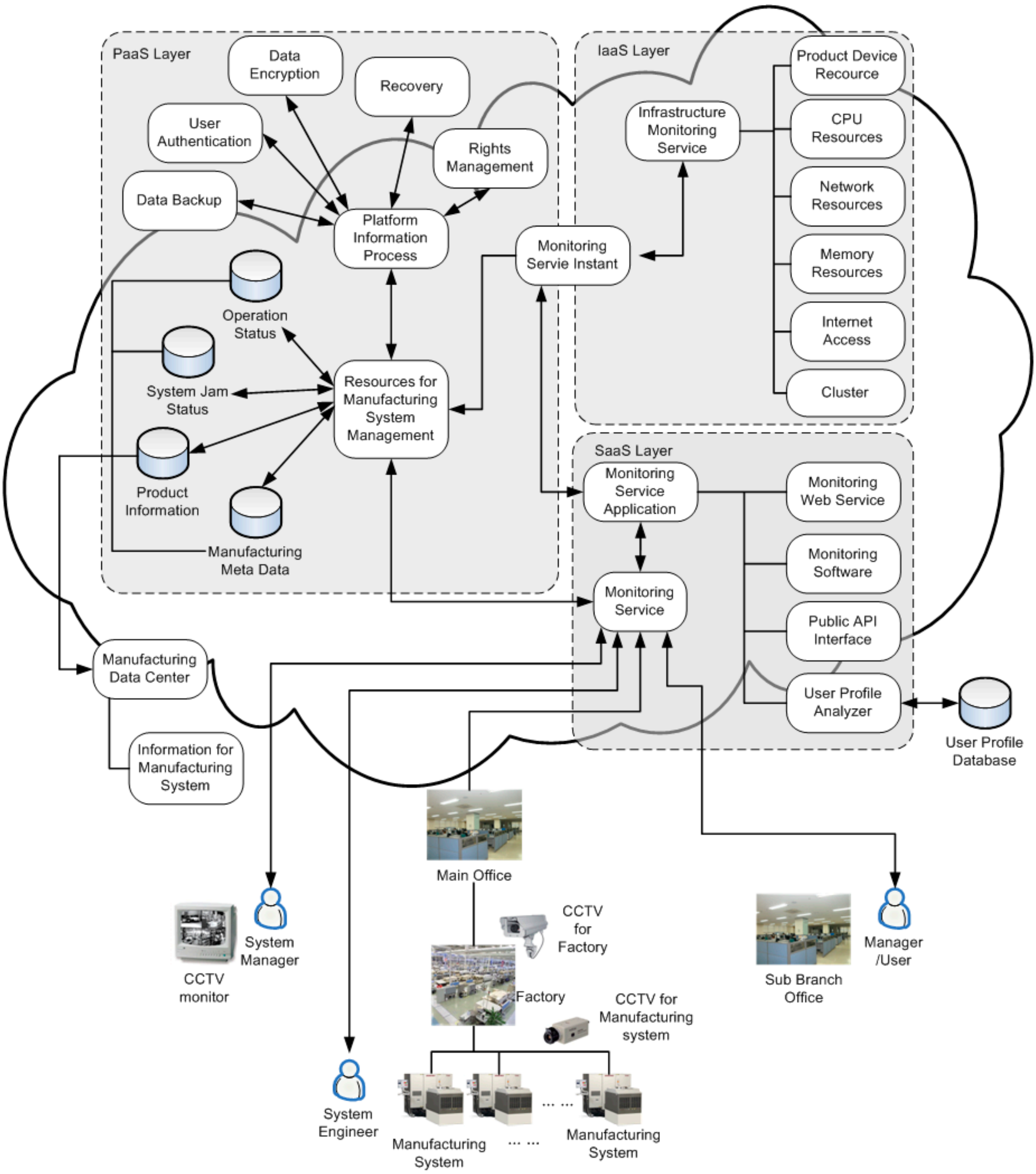
Since the middle of 2000s, the energy consumption of Internet-based applications has become a concern due to the rise of greenhouse gas (GHG) emissions; hence, architectures and protocols for power saving have started to be considered. As of 2009, ICTs account for 4% of global electricity consumption, and this is expected to double in the next few years [24].

Green cloud computing is a new computing paradigm that uses a virtualized server infrastructure to provide virtual operating system instances dynamically and that can yield greener computing by reducing power consumption. Virtual resource management provides new methods to increase computing accuracy and decrease the power consumption of computing in virtualized systems. In addition, green communication and networks have become a critical component that all of the next-generation communication and network designers have to consider in order to reduce energy costs [25]. For example, in [26], they use small environmental monitoring sensors to lower electricity costs and improve energy efficiency. The deployed sensors can measure the temperature of the computer room while the servers are running. Scheduling algorithms can efficiently arrange work for servers to lower the room temperature according to the information delivered from the deployed sensors. Their system design, including hardware and software, provides a good experiment for building a green data center [10,13,14].

3. G-Cloud Based Monitoring System Featuring a User Profile

This research aims to make a cloud monitoring system structure for manufacturing systems using a user profile. Figure 4 shows the proposed architecture for the monitoring system with CCTV (Closed-Circuit TeleVision) cameras in a cloud computing environment. It has three layers; Paas, IaaS and SaaS. PaaS supports the platform resources and IaaS provides infrastructure resources to the monitoring system. SaaS processes the system software for users. In PaaS, the main processes are the platform information process, manufacturing system management and a monitoring service. The platform information process consists of five factors: data backup, user authentication, data encryption, recovery, and rights management. All of them deal with processes to manage data and authentication. Manufacturing system management has four databases: operation status, system jam status, product information and manufacturing metadata. This data is related to system status and operations, such as the system operation time ratio, MTTR (mean time to repair), MTTF (mean time to failure), system jam ratio, production ratio, and so on. Such data is essential in managing and monitoring the manufacturing system. In particular, operation status, system jam status and product information are directly related to manufacturing system performance and productivity.

Figure 4. Cloud monitoring architecture using CCTV cameras for a manufacturing system in a factory.

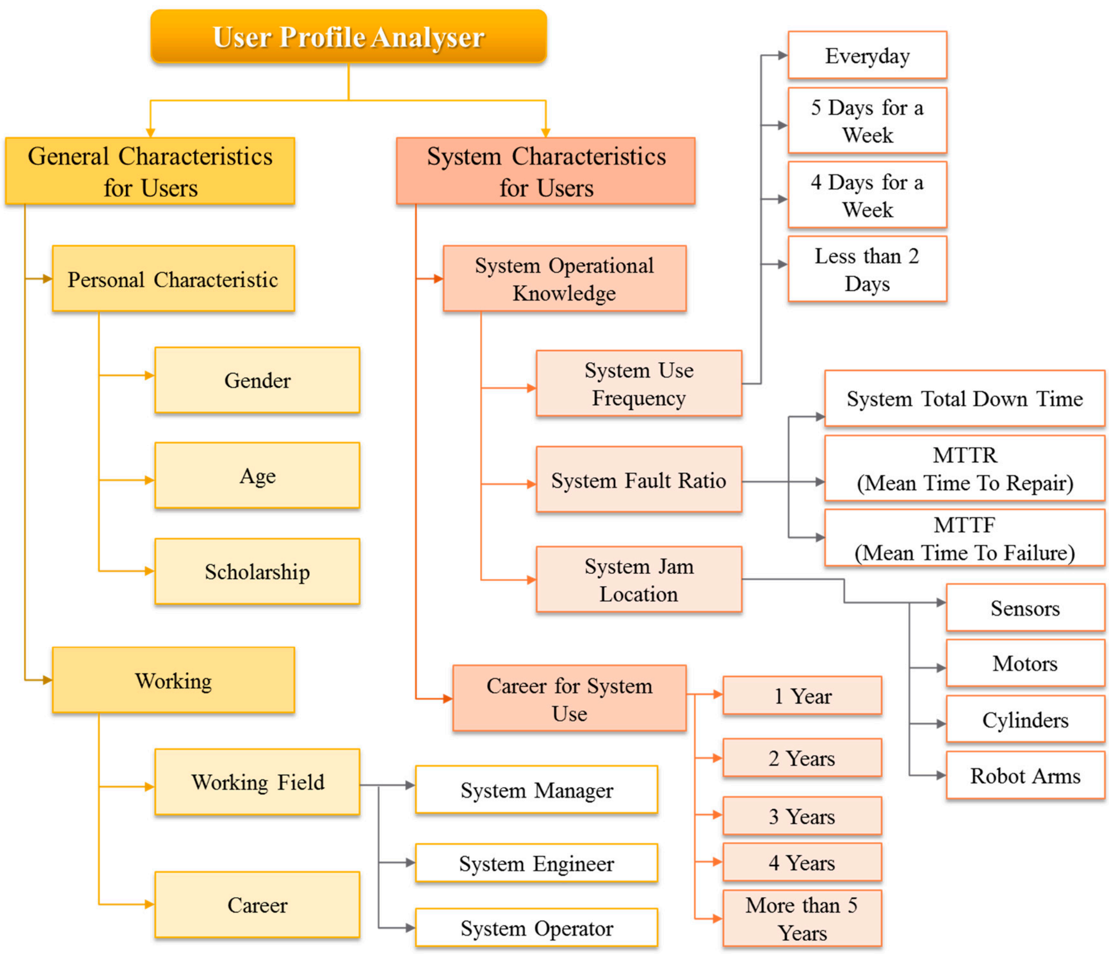


The IaaS layer has an infrastructure monitoring service as a main process. The service consists of six factors: product device resource, CPU resources, network resources, memory resources, Internet access, and cluster.

All of these are related information processes for hardware or device resources. In the SaaS layer, the monitoring service application, which is the main process in this layer, consists of three factors: monitoring web service, monitoring software and public API interface. In this model, the system manager who is working in the main office, the system engineer who is working in the factory and the manager or user who is working in the sub-branch office are all able to request and access the monitoring service for the cloud computing environment. Before this work, all of the manufacturing system's data that were obtained from the system and CCTV cameras during the system's operation were sent to the databases in the PaaS layer of the cloud computing environment. Then, the monitoring service sent the data to the manufacturing system management process to store them in their respective databases. When the user requests the service for cloud computing, the monitoring service process requests the manufacturing system management and monitoring service immediately. Finally, the monitoring service application sends the data and service via the monitoring service to the users.

In order to consider the user profile for a manufacturing system's monitoring and management, the user profile analyzer, which is in the SaaS layer of Figure 4, was used, as shown in Figure 5. It consists of two characteristics: general characteristics of the users and system characteristics of users. The general characteristics are personal factors, such as gender, age, scholarship, working department and career. The system characteristics for users are about skills, with real career and years of the system operation, such as system use frequency, system fault ratio and system jam location.

Figure 5. Auser profile analyzer for a green and cloud computing (G-cloud) monitoring system.



4. Experimental Results

In order to evaluate the effectiveness of the proposed framework, we conducted research on which subjects were end-users (system operators), system engineers or managers in the factory. Among the 124 participants, 30% were system engineers, 30% were system managers and 40% were end-users (system operators). All participants took part in both the pre-test and post-test phases. The pre-test conditions involved processes that are consistent with existing methods, with only the monitoring system and the post-test involving the methods proposed, which included the user profile analysis and the green and cloud computing(G-cloud)monitoring system. The questionnaire for the test has a one factor system satisfaction. Table 1 shows values and descriptions for each item on the questionnaire.

Table 1. Satisfactory values and corresponding descriptions for individual items on the questionnaire.

Value	Contents
0	Highly Unsatisfactory
25	Unsatisfactory
50	Neutral
75	Satisfactory
100	Highly satisfactory

According to the test results, Figure 6 shows the pre-test and post-test histogram for system satisfaction. We can see that the frequencies for each item fall into a normal distribution curve.

Figure 6. Pre-testand post-test histogram for system satisfaction.

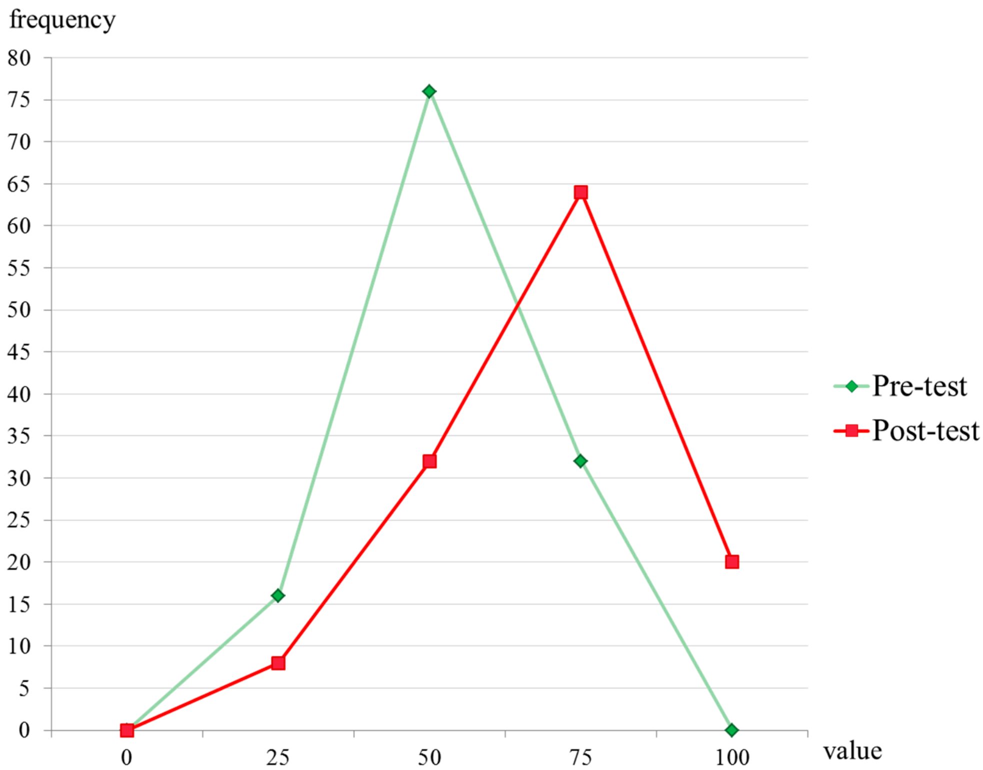


Table 2 shows the results of paired sample statistics, and Table 3 shows the results of paired sample *t*-tests between the pre-test and post-test.

Table 2. Paired sample statistics for system satisfaction.

	Mean	N	SD	SE Mean
Pre-Test	53.2258	124	15.27783	1.37199
Post-Test	69.3548	124	19.86712	1.78412

Table 3. Paired sample *t*-test for system satisfaction.

	Paired Differences							
	Mean	**SD**	**SE Mean**	**95% Confidence Interval of the Difference**		***t***	**df**	**Significance (2-tailed)**
				Lower	**Upper**			
Pre-Post	−16.12903	25.93644	2.32916	−20.73946	−11.51860	−6.925	123	0.000

As shown, the mean score of the post-test increased about 16 points, as shown in Table 2. Table 3 shows that the difference in mean scores is significant under a significance level of 0.05 and $p = 0.000 < 0.05$. Additionally, the 95% confidence interval indicates −20.73946~−11.51860, and the value does not include zero.

Consequently, the proposed system is useful and efficient, and the monitoring system in factory automation can provide high satisfaction to users, as shown by the performance evaluations.

5. Conclusions

This research focuses on a monitoring system for a manufacturing system in a factory. The main purpose of this research is to make a framework to provide a process to enable users to observe the manufacturing system's status using user profiles and to share the operational data of the system at any time or place. For this purpose, all of the data of the manufacturing system stored in each of the databases provides information via this monitoring service in the cloud computing environment. The service process and databases were connected to each other by three layers: PaaS, IaaS and SaaS. To consider user characteristics, we used the user profile analyzer in SaaS layer, and it consisted of two factors; general characteristics for users and system characteristics for them. For the general characteristics, we considered personal characteristics, such as gender, age and scholarship (academic level), and working (operational experience for the system), such as work field and career. The system characteristics are very important factors to monitor and manage the system. This is because the amount of system experience a user has determines how well and how quickly they can recognize the system status from monitoring data and, thus, manage the system efficiently. Therefore, we considered two main factors; system operational knowledge and career for system use. The system operational knowledge has information of the system status, such as system use frequency, system fault ratio and system jam location. The career for system use is about the real career for system operation, and it refers to how many years of manufacturing system operation experience a user has. Through this consideration with user experience of the manufacturing system, we think this architecture can be used in the cloud manufacturing system with green computing, and the system manager, engineer and user are all able to access, check and manage manufacturing data via the Internet.

To collect our experiment results, we recruited 124 participants as a test population, including system engineers (30%), system managers (30%) and end-users (system operators) (40%). They took both a pre-test and a post-test to measure usability. The pre-test was conducted in accordance with existing measures and the post-test in accordance with the measures proposed in this paper. In conclusion, we can see that all frequencies are of a normal distribution, and the proposed method can improve system satisfaction.

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Author Contributions

All of the authors contributed equally to this work. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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