Automation in Construction 26 (2012) 21–31

Contents lists available at SciVerse ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Critical reliability assessments of distributed field-monitoring information systems

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ARTICLE INFO

Article history:
Accepted 18 April 2012
Available online 26 May 2012

Keywords:
Reliability assessment
Service-oriented architecture
Web services
Distributed computing
Field monitoring
System configuration

ABSTRACT

The volume of monitoring data is expected to increase exponentially in the near future. To cope with large volume of data, an information system was designed using concepts of distributed computing and service orientation. The system design consists of five discrete services, and it leads to a flexible, reliable, and scalable information system. One major challenge for this design is how to configure it properly. This work proposes the use of reliability assessment to answer such challenge. Three critical aspects for such information systems are assessed. They are reliabilities of data storage, data transmission, and server under load. Methods to estimate these reliabilities are presented and discussed. These discussions should help system administrators use quantified indices to configure information systems of distributed nature.

1. Introduction

Information systems are important for managing field monitoring data, including data-storage, backup, retrieval, and presentation. Effective management of monitoring data enables: 1) quick assessment of service conditions of built structures [1,2,15,16,26,28], 2) sculpturing better computer models [7,10], 3) building credible decision support systems [4,5], and 4) accumulation of knowledge through data-mining and regression [21,24]. Most of these utilizations of data require accumulation of monitoring data for an extended period and assimilation of monitoring data at large quantity. Large-scale data acquisitions are economically feasible using wireless sensor network (WSN) technology [18,23], which is based on distributed-computing. However, most monitoring information systems are based on the client–server architecture. Such architecture is unlikely to scale up to handle data sources of distributed-computing nature, such as WSN. Therefore, a new information system architecture was proposed to use service-orientation and distributed-computing [11] to solve scalability issue and to provide reliable data-storage. This new information system architecture orchestras the data service, the field service, and the coordination service to provide data-storage reliability at multiple levels; it also provides virtually infinite scalability on both data storage capacity and network bandwidth with zero down time during scaling operations. With this new architecture, one may deploy 200 data services on 200 computers and one coordination service on a dedicated computer to serve 5000 field services; one may also deploy 800 data services on 200 computers with four different ISPs (Internet Service Providers) for improved data redundancy and reliability. However, the reliability of this new system architecture is not well understood, and the flexibility in system deployment using this new architecture poses challenges to system administrators. For example, how do we configure such a system for handling 10,000 sensors?

In this work, we propose the use of reliability analyses combined with reliability targets to answer the aforementioned questions. Reliability analyses have many applications in civil and construction engineering: 1) estimating life-cycle costs of engineering projects [8,9], 2) analyzing safety of engineering projects with considerations of uncertain parameters [12,17], 3) estimating more representative parameters [14,27], and 4) achieving optimal engineering designs while concerning reliabilities [3,29]. However, reliability analyses seem never be used to evaluate information systems developed for civil/construction engineering purposes, probably because most information systems built to date are based on the client–server paradigm. The reliability for such system is straightforwardly determined by the server. This is however not true for information systems built on top of several discrete services, or service-oriented architected information systems. There are some work discussing making reliable web-services [6,13,19,20], but they mostly discuss data replications or reliability of web-services with long business processes. None of them seems to discuss how reliability evaluations can be used to help system administrators or implementers of information systems.

This work demonstrates 1) the use of elementary reliability analysis methods to devise simple evaluations of system reliability for such information system, 2) the use of reliability evaluation to improve system reliability at system design time, and 3) the use of reliability evaluation to help system administrators decide the configuration of information systems built on the service-oriented architecture. Furthermore, we propose a method of determining the load imposed by sensors to assess the failure probability of data servers due to overloading.

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doi:10.1016/j.autcon.2012.04.012

This paper is organized as the following. Section 2 describes an extended information system architecture based on our prior work [11]. The system is then analyzed for its data-storage reliability in Section 3. The method presented in this section can advise system administrators on how to configure the system with data reliability. Section 4 evaluates the reliability of data transmission with concerns on the hardware and networking. This section also demonstrates the use of reliability analyses to improve design and implementation of system operations. Section 5 further uses a modeling approach to estimate the failure probability of data transmission with concerns of limited computer capability. Such estimation can help system administrators determine system deployment configuration for such information systems. Finally, concluding summaries are drawn in Section 6.

2. A service-oriented monitoring information system architecture

This section describes our newly designed architecture for field monitoring information systems. This new design has five services. These five services are first introduced, and features for this new design are discussed. Possible deployment configurations of the system are then described and discussed.

2.1. Essential services for an automated field monitoring information system

Hsieh and Hung (2009) [11] proposed using service-oriented architecture to construct a monitoring information system with SOAP (simple object access protocol) web-services. Their design uses three services: the data service (DS), the field service (FS), and the coordination service (CS) to constitute the automated monitoring information system. FS collects monitoring data in the field and transmits the data to the associated DS; CS serves FS a list of its assigned DS configured by the system administrator; DS stores monitoring data sent by FS and serves desktop applications or web-based applications to present monitoring data. By allowing one FS simultaneously associating with many DS, data redundancies are introduced to improve the data reliability; by introducing CS to loosen the coupling between FS and DS, easy scaling is enabled in both data-storage capacity and network bandwidth. Project information was stored in CS in the original design.

In this work, two additional services: the project service (PS) and the alert service (AS) are introduced. The information system architecture proposed and evaluated in this work is illustrated in Fig. 1, and it consists of five services. Fundamental functions of CS, DS, and FS are identical to the prior work described in the last paragraph, but the project information is removed from CS and managed on PS in this new design. PS manages project information such as project owner, site location, and its associated CS, FS, and sensor settings. Introducing PS simplifies the work of CS and makes it focus on coordinating between FS and DS. AS is the other added service, which sends alert messages to designated personnel when pre-defined sensor thresholds are exceeded on FS. In other words, when FS collects a new sensory reading, it compares it with predefined values and uses AS to send messages (through emails, text messages, etc.) when necessary.

It is also seen in Fig. 1 that in addition to the five services (CS, DS, FS, AS, and PS) previously mentioned, there are applications that consume these services. The application can be either a desktop application or a web-based application, and it provides user interfaces for its users to administrate the information system and to view collected monitoring data. These functionalities may consume any of the five services that constitute the information system to implement required functions. The required functions of this application and functionalities that each service should provide, however, are beyond the scope of this work.

2.2. Features of the proposed information system architecture

There are many desirable features in the information system architecture proposed by Hsieh and Hung (2009). First, it has great flexibility. The system can be configured and deployed for small-scale projects, as well as for huge projects. This is discussed in the next section. Second, the architecture has unlimited scalability. The system can scale up its storage capacity by adding more DS. Adding DS incurs no interruption of the information system. The system can also scale up its networking bandwidth by deploying the system across multiple internet service providers. Third, the design allows data reliability by introducing redundant data storage. The redundancy can be setup at each individual DS. It can also be setup by saving data onto multiple DS. These two setups are further explored in Section 3. Finally, the architecture basing on web services has good accessibility. The data stored can be easily obtained by using provided web service interfaces.

The above-mentioned features are inherited from Hsieh and Hung (2009). We added two extra services, AS and PS, to the design of information system. They thus added some additional features. AS helps

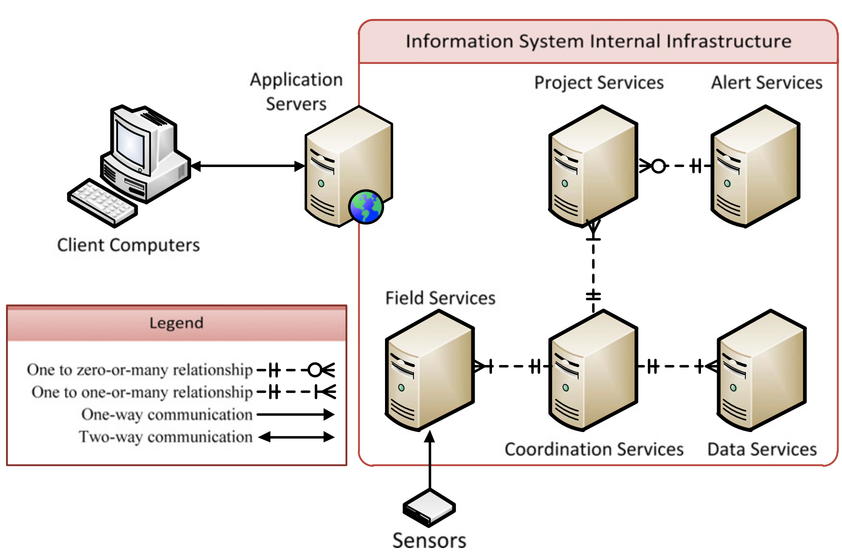

Fig. 1. An extended information system architecture based on Five Services.