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Data-source interoperability service for heterogeneous information integration in ubiquitous enterprises ☆

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ABSTRACT

In a ubiquitous environment, various enterprise information systems (EISs) are used for supporting daily operations. Besides, with the support with Auto-ID technology, enterprises are able to collect real-time operation data but these data are continuously pushed to different EISs. Data without processing are meaningless and not able to support managerial decision-makings. The wide use of EISs and Auto-ID devices within an enterprise increases the difficulties in data interoperability among difficult data sources. Since data sources from applications and devices are characterized by multiple types of heterogeneities, such as communication protocols, blinding methods, and developing environments, the difficulty in managing heterogeneous data sources is highly raised. Information integration in ubiquitous enterprises is critical because it has a significant influence on the efficiency and effectiveness of decisions. This article presents an innovative Data-Source Interoperability Service (DSIS) that serves as a middleware for providing a querying and information integration service for heterogeneous data sources. The DSIS applies software agent technology that is capable of accomplishing tasks in an autonomous way without human intervention. Operations provided by DSIS Agent are converted into standard web services. The agent-based services are managed by DSIS Universal Description, Discovery and Integration registry (DSIS-UDDI) which facilitates collaboration among agents. Additionally, the DSIS platform also provides set of visual tools for users to manage and (re)configure different data sources within enterprises.

1. Introduction

Ubiquitous enterprise refers to a firm that is equipped with distributed and simultaneous information processing capacity by using various advanced technologies, such as Internet of Things (IoT), ubiquitous computing, Agent and Cloud techniques [1]. Within a ubiquitous enterprise, large number of complex information will be transferred, shared, and exchanged in real-time basis. For example, radio frequency identification (RFID) technology is able to create a ubiquitous environment in where machines, operators, materials, and jobs tagged with sensors are converted into smart objects which can sense, interact, and behave with each other anytime and anywhere in the enterprises [2,3]. Information integration in ubiquitous enterprises thus is critical since decentralized and autonomous decision-making manners heavily rely on accurate and real-time data.

Construction industry, as a typical prosperous area of implementing ubiquitous technology, consists of great myriad firms from wide ranges, such as prefabrication manufacturing companies, logistics parties, and on-site construction fields. A construction project may involve in large number of stakeholders who make collaborative decisions so as to ensure the quality, security, and smoothness of the structure [4]. Therefore, enterprise information systems (EISs) are widely used for supporting the collaborative decision-makings. EISs play an imperative role in integrating and coordinating their decision-making processes and activities. Since different systems are specialized in different functions, several EISs may be implemented within a firm [5]. That increases the difficulties in data interoperability among difficult EISs when some critical decisions needed to be carried out, especially along with the Auto-ID technology performing real-time data capture and collection.

Information integration is the essence of data interoperability since it has a significant influence on the efficiency and effectiveness of decisions [6]. However, there are several challenges when carrying out information integration in construction ubiquitous

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enterprises. Firstly, many different EISs have their own databases which are heterogeneous in terms of structures, types, and data formats. Such heterogeneities make the data are prone to be asynchronous, inconsistent, and inaccurate among different EISs. Secondly, various ubiquitous devices, such as RFID sensors, are deployed in these enterprises, thus, large number of data are continuously pushed to different EISs [7]. How to manage such huge amount of real-time data between distributed devices and various EISs will be a critical factor for ensuring the efficiency of an enterprise. Thirdly, since every EIS or ubiquitous device is independent and has their own operation logic, it requires highly collaborative capacity to accomplish tasks through information transmissions, data sharing, and database operations. Unfortunately, current data exchange scheme is not able to meet the requirements, especially when large quantity of data are transferring among various EISs and different devices.

In order to address the above challenges, many researchers and practitioners have contributed to different application areas, such as medication management [8], multidisciplinary design optimization [9], and supply chain management (SCM) [10–12]. Reports from construction industry equipped with ubiquitous enterprises are scarce. Though advanced EISs like Building Information Modelling (BIM), and Enterprise Resource Planning (ERP) have been used for supporting different decision-makings, isolated information islands are formed since traditional communication or data sharing approaches are used for information integration. For instance, printed paper sheets, phone calls, e-mails and fax documents are widely used in construction stakeholders, which cause the lagged information. Decisions based on such information are prone to be unreasonable, unworkable, and uncurbable.

Enhancement of the information integration within different ubiquitous enterprises in construction industry is essential. To this end, this paper introduces a data-source interoperability service (DSIS) for heterogeneous information integration in ubiquitous enterprises. To demonstrate the DSIS, several research questions and associated technical contributions are presented:

- How we can establish a model or a mechanism to integrate data from different sources? This paper designs and develops a query mechanism and a data information model (DIM) to query and integrate information from heterogeneous data sources through a standard data structure serving as common medium for system collaboration.
- How we can build up a platform to enable different end-users to use the provided services for facilitating their operations? This paper adopts service-oriented architecture (SOA) in implementing the architecture and develops a DSIS platform to provide a set of visual tools for assisting ubiquitous enterprises to manage heterogeneous data sources easily.
- How we can design various services or tools to ease the system implementation? This paper uses web service technology to make full use of the agent features so that these services could be easily registered, discovered, and invoked by different end-users.

The rest of this paper is organized as follows. Section 2 reviews some related work, such as digital enterprise technology integration, software agent technology, SOA and web services, as well as existing commercial solution. Section 3 presents the key principles in DSIS in terms of overall architecture, heterogeneous data source query mechanism, and token-based DIM. Section 4 illustrates the design and implementation of DSIS. Section 5 reports on a case study from construction industry in Hong Kong. Our contributions and future work are highlighted in Section 6 to conclude this paper.

2. Literature review

2.1. Digital enterprise technology integration

Enterprises in the 21st century are facing an environment where markets are frequently shifting, new technologies are continuously emerging, and competition is globally increasing. The market becomes more dynamic complex [13]. Therefore, the business environment especially for manufacturing industry is more time-sensitive. To improve the competitiveness, enterprises try to use advanced technologies to rationalize the value creation processes [14]. Digital Enterprise Technology (DET) is defined as "the collection of systems and methods for digital modelling of the global product development and realization process, in the context of lifecycle management" [15]. This technology can cope with the aforementioned complexities and uncertainties, as well as increase efficient of utilizing and sharing information with different business functions [16]. Additionally, as the increasing use of heterogeneous software and hardware, system integration becomes an important prerequisite to achieve efficient and effective collaboration [17]. The objective of enterprise information integration is to provide a uniform access to various data sources [18].

Data integration is a pervasive challenge, thus Sujansky summarized four significant representational heterogeneity differences for aggregating data, which are structural differences, naming differences, semantic differences and content differences [19]. Another challenge is the interoperability between different systems. Systems are difficult to access accurate data, information, and knowledge because they lack of standards for managing data [20]. A lot of methods has been proposed for data integration so as to integrate and merge EISs systematically [21–24].

2.2. Software agent technology

Researchers have attempted to apply agent technology to manufacturing enterprise integration, manufacturing process planning and scheduling, shop floor control and holonic manufacturing [25,26]. Software agent technology is an important branch of artificial intelligence for more than two decades. It has been widely accepted and adopted in different areas, such as enterprise integration, enterprise collaboration, supply chain, manufacturing, and product design due to its autonomy, interoperability, flexibility, re-configurability, and scalability [27–30]. Software agents are commonly applied and implemented in distributed intelligent manufacturing systems by encapsulating manufacturing activities or wrap legacy software systems so as to facilitate the integration of heterogeneous software and hardware systems [31]. Agent-based approaches have played an important role in achieving outstanding performance with agility in various kinds of applications, such as resources management, planning and scheduling, and information processing [32–34]. Many researchers have probed into solutions for enterprise integration and concluded that the agent technology provides a nature way to realize enterprise integration. Pan has proposed an intelligent agent framework to integrate enterprise so that human and intelligent agent can interact to facilitate the information flow and decision making [35]. Qi has used mobile agent to integrate data in distributed sensor network [36]. In most proposed methods and solutions, agents are used to encapsulate existing resources, information systems using various middleware approaches [37].

Various organizations have contributed in providing standards for agent-based system. The well adopted standard is Foundation for Intelligent Physical Agents (FIPA). Founded in 1996, it is an international standardization organization promoting the development and specification of agent technologies. It provides an

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