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Cloud-based ubiquitous object sharing platform for heterogeneous logistics system integration

Ming Li[a], Peng Lin[a], Gangyan Xu[b,c], George Q. Huang[a,*]

[a] HKU-ZIRI Laboratory for Physical Internet, Department of Industrial and Manufacturing Systems Engineering, The University of Hong Kong, Hong Kong, China
[b] School of Architecture, Harbin Institute of Technology, Shenzhen, China
[c] School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore

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ABSTRACT

The intelligence of infrastructure gradually becomes the straw for logistics enterprises to make data-based or date-driven optimization. The integration of heterogeneous logistics systems with existing enterprise information systems is one of the most critical steps to achieve the intelligent infrastructure. Unfortunately, the integration is always a time-consuming process with heavy investment, which suppresses the longings of enterprises, especially for small and medium enterprises (SMEs). Aiming at simplifying the system integration, this paper proposed a cloud-based ubiquitous object sharing platform (CUOSP) to share the integration across SMEs based on the concept of sharing economy. CUOSP acts as a middleware system to make heterogeneous logistics systems universal plug-and-play (UPnP) for enterprise information systems. A kernel-based agent (KBA) is designed as the sharing entity of physical systems. It maintains the features of physical systems and is scalable for different application scenarios. A series of cloud gateway services are emerged not only to provide the basic running and sharing environment, but also to remedy KBA's weaknesses in computing capacity. A prototype system is developed and implemented based on the framework of CUOSP and a laboratory case according to the consolidation scenario in E-commerce logistics is demonstrated. Comparison experiments are also conducted to explore the real-time and multitasking capacity of KBAs with different kernel characteristics and different computing resources.

1. Introduction

Along with the rapid development of IoT technologies and industrial wearables, logistics has entered the golden period towards "smart logistics" [1]. These technologies enable the collection of front-line information and facilitate the construction of intelligent infrastructure [2]. However, the rapid development also exacerbated the gap between large enterprises (e.g. JD.com, Cainiao logistics) and small and medium enterprises (SMEs). Benefiting from the economics of scale, large companies are able to afford highly intelligent facilities and advanced information systems, which in turn facilitate intelligent decision-making and serve as an engine to continuously stimulate their development. On the contrary, labour-intensive operations prevail in SMEs with different levels of automatization and informatization [3]. Even though the people-oriented smart logistics is the calling of the times, it seems that these companies may struggle to bathe in the intelligent spring wind.

This phenomenon is derived from three major reasons. Firstly, the informalization level of SMEs is generally low that they lack basic intelligent infrastructure such as control systems and management systems. Secondly, the benefits of intelligence may not be shown immediately and obviously so that SMEs are unwilling to largely invest on it. Thirdly, the infrastructure of technologies such as IoT and wearable computing is diverse. It usually requires integration and deployment seamlessly with their existing infrastructures, enterprise information systems or their conventionalized operation business logics which are tedious, troublesome and time-consuming. Conclusively, the intelligence of infrastructure is a priority for all the developments of intelligent processes in logistics. How to make infrastructure intelligent in SMEs with enough flexibility at a lower cost is the key.

Heterogeneity of logistics systems is the major problem that impedes the system integration to build intelligent infrastructure. It is similar with the molecular heterogeneity in chemistry where an intelligent infrastructure requires the fusion of heterogeneous systems.

* Corresponding author at: HKU-ZIRI Lab for Physical Internet, Department of Industrial and Manufacturing Systems Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, China.
E-mail address: gqhuang@hku.hk (G.Q. Huang).

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Additionally, one system entity may consist of multiple atoms such as industrial wearables, AGVs, sensors and software modules. The heterogeneity is derived from three aspects. Firstly, the requirements for systems are varied, determined by many factors such as data capturing requirements, operating procedures, types of logistics, costs, and working preference. The second aspect is the difference between systems' granularities. In practice, the granularity for systems performing similar functions depends on SMEs' definitions. For example, only one AGV with single controller or a cluster of AGVs with a central controller both could be regarded as an automatic conveyor system. The third aspect comes from the heterogeneity of systems themselves. Models of systems, communication methods, driving environments, communication protocols and control methods are all different and the communication among these systems must follow the methods defined by the systems' vendors.

Research on heterogeneous systems integration is concentrated on the field of computer science. Heterogeneous storage system integration is one of the primary research directions to solve the problem of heterogeneity of file or database systems [4]. Currently, the computing consistent integration is a popular topic under heterogeneous computing architectures such as GPUs environments [5], mobile environments [6] and cloud environments [7]. The essence of solving heterogeneous problem mostly uses the philosophy of intermediate transition that wraps heterogeneous objects into homogeneous objects [8]. Similar essence is also adopted to solve heterogeneous devices integration for industrial devices, equipment sensors and wearables in manufacturing. For example, Fang et al. used agent-based abstraction method for heterogeneous interfaces to shield the heterogeneity of RFID readers in manufacturing [9]. However, the proposed systems from these research frameworks are also new heterogeneous systems comparing with other systems across SMEs. Making the situation even worse, the integration of drivers for newly added system cannot be absolutely omitted, and this kind of time- and resource-consuming works are usually costly under these frameworks. Therefore, how to simply and flexibly integrate heterogeneous logistics systems to support the development of intelligent infrastructure in SMEs still plagued the industry. The following three research questions should be addressed:

- How to build a cloud-based central sharing platform to serve SMEs for heterogeneous logistics system integration?
- How to abstract the heterogeneous systems into ubiquitous sharable objects?
- How to offer the ubiquitous sharable objects flexible computing resources?

To address the above questions, this paper proposes a cloud-based ubiquitous object sharing platform (CUOSP) as a total solution for SMEs to simplify logistics system integration. It acts as an enterprise service cloud to solve the problem of heterogeneity across SMEs. Object-oriented methodology (OOM) is applied to sketch the general framework for CUOSP. Agent-oriented programming is adopted as the major implementation approach to build core smart objects in the object-oriented framework. A ubiquitous sharable object model is built as cloud mapping for physical logistics systems using an innovative kernel-based agent-oriented approach. To fulfil the flexible computing requirements of ubiquitous sharable objects, service-oriented architecture is adopted to construct the objects of computing services. Finally, a smart coordinator is designed based on microservices architecture as major applications on CUOSP to simply organize ubiquitous sharable objects based on business logic and interoperate with enterprise information systems

The rest of this paper is organized as follows: Section 2 reviews the literature of heterogeneous system integration, and industrial agent-based system. Section 3 specifies OOM for this study. Section 4 elaborates the system design with innovative technologies. A system implementation as well as a simple demonstrative case is shown in Section 5 to specifically describe and discuss the implementation of CUOSP. Finally, conclusions and future works are given in Section 6.

2. Literature review

2.1. Heterogeneous system integration

The integration problem of heterogeneous systems has been puzzling many fields over two decades. The computer industry is the hardest-hit areas where more attentions have been received. The study on this problem is concentrated in two major directions including hardware and software. From the aspect of hardware, the heterogeneous system architecture is regarded as one of the easiest methods to pack different functional chips such as GPU and CPU into a uniform unit [10]. However, it seems that heterogeneous system architecture brings more challenges from architecture design to sharing mechanisms for common resources. Various architecture models for optimization in different application scenarios are proposed and verified through simulations [11,12]. Additionally, virtualization technology and synchronization mechanisms are the major methodologies to solve the sharing problem, especially for coherence in the shared memory access [13,14].

The research on the heterogeneity of software system is relatively diverse. Database systems are the most typical heterogeneous systems. The studies on integration problem of heterogeneous database systems are divided into three research directions. The first direction focuses on the data schema which aims at designing series of consistent data schemas to avoid the storage heterogeneity in different databases. The second direction is the access consistency which tries to shield the heterogeneity of programming interfaces among different databases. Reflection technology, dynamic mapping and dynamic reconfigurable technology are primary methodologies to solve this problem. Commercial development frameworks such as Hibernate, MyBatis and iBatis are typical applications for these methodologies. Another direction is the middleware system that performs the central transformation among different heterogeneous information systems including databases. Some prototype middleware systems such as data source interoperability tool are proposed and developed to exchange data among different enterprise information systems. However, these methodologies only provide the preliminary feasibility to solve a party of heterogeneity for various physical systems.

Distributed control system is an effective system to achieve real-time process control for small-scale heterogeneous systems such as the CNC machines, valves, switches and more via PLC or other control buses [15]. Only popular systems are supported in distributed control system because the integration development for newly added systems are complicated, especially for the sequential control on the controller due to the real-time control requirements. The worst yet is the exorbitant price for a distributed control system which cannot be afforded by most SMEs. However, the control for heterogeneous systems is usually inessential for SMEs, as they care more about the real-time information collection from the heterogeneous systems. Unfortunately, the research on this part of heterogeneous system consistency is still blank but urgently needed.

2.2. Industrial agent-based system

In the past decades, agent technology has been widely developed and adopted in intelligent manufacturing systems to encapsulate manufacturing activities or software systems and represent physical manufacturing resources [16]. A flexible agent-based framework for manufacturing decisions was proposed by Papakostas et al. where mobile agent-based systems were developed for real-time monitoring and information exchange [17]. Lu and Yih presented an agent-based production control framework where agents of production entities including line, cell or machine can work collaboratively [18]. Jia et al.