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An approach for real time management of global manufacturing enterprises based on Digital Data Stream

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Abstract

Advances in sensor technology, IOTs, communication technologies, computing, data management and analytics is changing the way modern global manufacturing enterprises are managed. With appropriate design and architecture of these technologies it is possible to use digital data streams to manage these enterprises in real time. This paper focuses on issues related to the design of these systems. Specifically, we focus on developing approaches for the design of autonomous services that receive data from local devices (e.g. sensors) in real time, do some processing in real time, communicate with other services, and respond to stimuli received from other services in real time. This allows localization of appropriate decision making. These services pass on relevant information to other related services in a web like architecture.

Keywords: Real-time Management; Manufacturing; Global; Data Stream; Enterprises

1. Introduction

With the explosion of micro to nano-scale embedded devices and sensors in all aspects of manufacturing, the development of control software that takes advantage of the real time data generated by these devices to support real

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time decision making in a global manufacturing enterprise becomes extremely complex and critical. While the time scales for control decisions are shrinking, the scale and complexity of the systems are increasing. The large volume of data, real time processing requirements, and complexity of the overall operation requires that the software systems are designed and executed in a highly distributed manner. The processing of the data and routine decision making needs to be fragmented at the micro level yet still needs to be coordinated to enable a human decision maker to monitor the operations and take actions.

Based on the latest developments in service-oriented architecture, complex event processing, and smart cyber-agent technologies, we develop an approach called *'Service oriented, Event driven, Smart cyber-agent (SES)'* for the composition of systems for real time management of global manufacturing enterprises (GMEs) from existing agents and services. Specifically, we focus on the problem of identifying the appropriate level of granularity for smart cyber-agents, the delegation of appropriate decision-making authority and responsibility to these agents, and definition of services along with standard interfaces provided by the smart agents. This paper is part of a multi-year effort which is expected to result in a working prototype of the system and development of capabilities to address issues related to advanced manufacturing based on the latest developments in information and communication technologies.

The National research council's Committee on Visionary Manufacturing Challenges 2020 identified the problem of, "Instantaneously" transforming information gathered from a vast array of diverse sources into useful knowledge for making effective decisions as its grand challenge # 3 [NRC, 1989]. Despite several efforts to develop specific architectures for real time control of certain types of manufacturing systems [Heragu et al., 2002; Meyyappan, 2007; Sikora and Shaw, 1997], a generalized scalable mechanism is not available [Pereira and Carro, 2007]. Increasingly modern manufacturing systems are acquiring the characteristics of cyber-physical systems [Gill, 2006]. These are characterized by cyber capability in every physical component, networking on multiple and extreme scales, and complexity at multiple temporal and spatial scales.

Service-oriented architecture (SOA) is an architectural style where existing or new functionalities are grouped into atomic services [Arsanjani, 2007]. These services communicate with each other by passing data from one service to another, or by coordinating an activity between one or more services. SOA is a promising approach for designing real time manufacturing shop floor control systems. Agent based frameworks are increasingly being used to break up the complex decision processes. A smart cyber agent has an internal behavior model, a functional component consisting of procedures/heuristics/strategies, and a protocol for interacting with other agents [Sikora and Shaw, 1997]. Complex Event Processing (CEP) is an event processing concept that deals with the task of processing multiple events from an event cloud with the goal of identifying the meaningful events within the event cloud. CEP employs techniques such as detection of complex patterns of many events, event correlation and abstraction, event hierarchies, and relationships between events such as causality, membership, and timing, and event-driven processes.

SOA, smart agents, and CEP together offer a real opportunity for addressing the grand challenge and are increasingly being seen as ideas that potentially could revolutionize real time management of global manufacturing enterprises. This paper focuses on issues related to the design of these systems. Specifically, we focus on developing approaches for the design of autonomous services that receive data from local devices (e.g. sensors) in real time, do some processing in real time, communicate with other services, and respond to stimuli received from other services in real time. This allows localization of appropriate decision making. These services pass on relevant information to other related services in a web like architecture.

2. Cyber-physical system architecture:

As illustrated in Fig. 1, the proposed real-time SES manufacturing control system is the glue that links higher level ERP systems to shop-floor automation systems within a global manufacturing enterprise. The SES system provides a combination of automated and semi-automated decision-making capabilities that helps upper-level management and shop floor hardware cope with events ranging from new order arrivals and new management requests at the macro level, to machine breakdowns and process completions at the micro level.

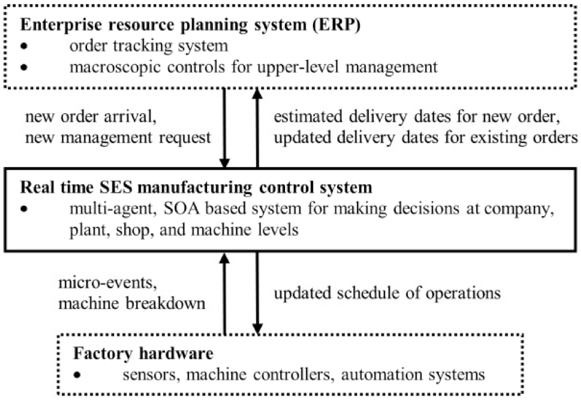

Fig. 1. Real time integration of ERP with shop floor.

The proposed SES is based on a service-oriented architecture consisting of multiple autonomous smart cyber agents capable of making decisions attached to a physical entity within the GME (Fig. 2). Smart Cyber Agents are designed to make or support decisions, and provide services using web service standards, when a stimulus (i.e. service request) is received from a neighbouring agent that is above, below, or at the same level within the overall GME. These decisions are made based only on the knowledge contained within the agent, without complete knowledge of the state of the entire GME. This allows each agent to operate independently there by reducing the system complexity, increasing the agility and ease of maintenance. The service orientation of the SES system leads to a highly agile architecture based on widely used global standards that does not depend on specific component/device's proprietary interfaces that would require manual integration and reconfiguration when responding to rapid changes in the environment.

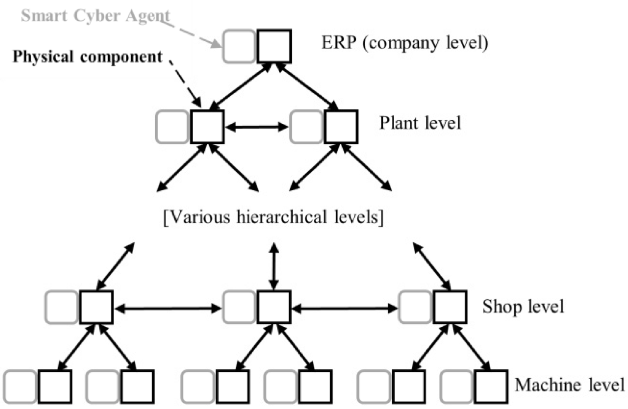

Fig. 2. The proposed SES system.

3. Agent decision process:

The Smart cyber agents are activated by external stimulus or by internal triggers (based on reaching certain conditions such as reorder points, scheduled preventive maintenance). Fig. 3 shows two of the three possible ways in which a smart cyber agent may be activated. When an agent receives a stimulus from above (e.g. when a new customer order arrives), the agent first determines which tasks it can handle directly and then delegates the remaining tasks to lower-level agents or other agents at the same level. When stimulated from below (e.g. when a machine completes a process and needs to be assigned a new task), the agent respond based on its internal knowledge or by manipulating one or more agents in the level below it. If the response cannot be generated in this manner, the smart cyber agent reports to (and thereby stimulates) agent above it and/or other agents at a similar hierarchical level. Agents may also receive stimuli from other agents occupying the same hierarchical level (not shown).

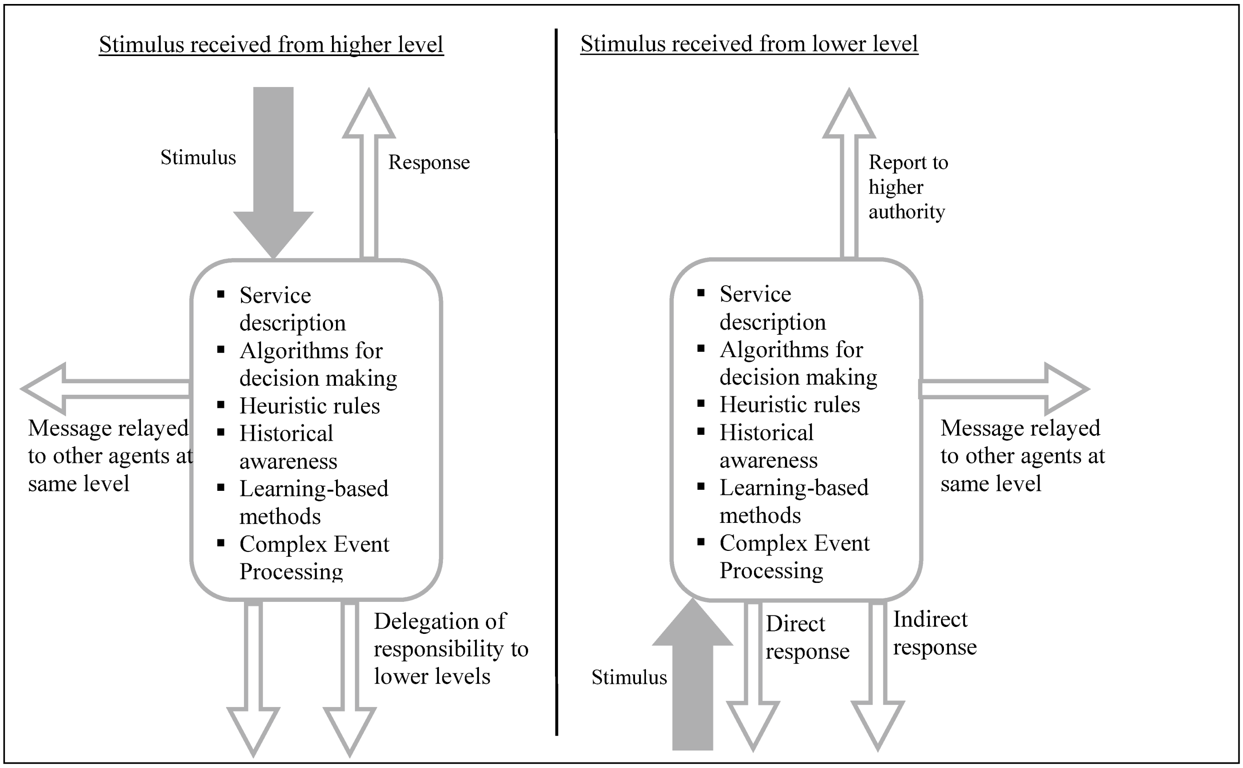

Fig. 3. Ways in which Smart cyber-agent might be activated.

Each agent has the essential knowledge and the real-time data needed to perform its activities. The agent's knowledge base consists of (1) a *list of neighbours*, i.e. all other agents to which the current agent has a direct contact; (2) *service description* specified using WSDL which specify what services are provided by its neighbours and how to invoke them; (3) a *set of algorithms* that the agent can call upon as needed to provide the service and make decisions; (4) a *learning module* that allows the agent to constantly improve its decision making over time; and (5) complex event processing capabilities. The service description includes thresholds and priorities attached to requests made by agents to other agents, and the responses to those requests. For example, an agent at the plant level might send a message to an agent at the shop floor level saying, "30 jobs of type 267, deadline March 20." In response, the latter agent might say "request not urgent enough to be accommodated given my current situation (i.e. my threshold not exceeded)." The set of algorithms help an agent decide (A) which of the tasks associated with an incoming request it can handle directly, (B) how to handle such tasks directly, and (C) what portions of an incoming request to delegate (or pass along) to neighbouring agents. These algorithms are heuristic methods designed for almost instantaneous response times in the microseconds. Finally, the learning module maintains a list of selected messages received in the past and the agent's responses. This list gives the agent the capability to "learn" from past successes or failures.

The data consists of the current state of the system as seen from the agent's perspective. The data tracked by each agent comes from two sources: (A) physical processes in the real world, and (B) messages received from neighbouring agents. Data of the former type are both microscopic and macroscopic. For example, sensors, factory hardware, and machine controllers capture the microscopic (i.e. operational) data, while customer, websites call centres, and outlet stores capture the macroscopic data related to customer orders. Agents at the lowest level in the manufacturing control system see the pure microscopic data, while agents at the highest level in the manufacturing control system see the pure macroscopic data. All other agent data comes from the messages received from neighbouring agents. The agents can store such data for use in the decision-making algorithms. For example, the data tracked by an agent at the shop

floor level includes the current set of jobs under its supervision and the current expected completion times of those jobs, but not a detailed Gantt chart showing how those jobs are assigned to the various machines under the agent's supervision. The state might also include current threshold values which govern how the agent responds to future stimuli from its neighbours.
We are currently in the process of implementing this architecture in a prototype application system.

4. Managerial Implications:

The real time management of Global Manufacturing enterprises based on the SES approach proposed here has significant implications for the IT and managers as they design and built systems based on the SES approach. The ability to collect real time information through RFIDs, sensor networks, Internet of Things and real time social media like Twitter provide significant capabilities to managers that if properly used can improve decision making and operation of the enterprises. However, challenges related to design, development and use of such systems needs to be addressed.

A. ***Think of scenarios where real time information can provide significant business value:*** The real time information will not provide equal values in all situations. Managers need to identify scenarios where real time information will allow them to take immediate action that will either allow them to avoid loss of productivity or delays or take advantage of an opportunity. For example, real time information on impending weather disturbances which may disrupt the supply of components or materials may allow managers to alter production plan and schedule to avoid loses or they may be able to find alternate sources. Managers need to select the areas for first implementation that will provide largest business value.

B. Appropriate delegation of decision-making authority: The efficient use of real time information requires delegation of routine decision making authority to the appropriate manufacturing cell, production line or plant and automating most of these routine decisions. The predictable decision situations need to be identified and heuristic rules and fast real-time algorithms needs to be develop to allow smart cyber agents to make large percentage of routine decisions. This will allow humans to focus on making decisions in non-routine unpredictable situations.

C. Managers need to be trained to make decisions in unpredictable situations based on real time information: In a recent meeting with senior management of a global automation company, the issue of training managers to make decisions based on real time information was discussed. There was general agreement that there is a paradigm shift in making decisions based on real time information. This requires systems to play supportive role in helping mangers to explore and evaluate alternatives and make timely decisions. The simulation models of the situations need to be developed to help train managers for these new situations. However, we must realize that these models will train the managers for the situations that can be imagined. The ability to handle completely new and unpredictable situations requires intuitive and logical thinking.

D. Do consider Human as part of real time system: The real time systems needs to be designed to take real time information not only from sensors, RFIDs, internet of things but also from humans who should be able to provide information through text messages, Tweets, or other means. All this information needs to become multiple streams in a complex event processing system.

5. Conclusion:

Appropriate use of real time information holds significant potential to improve the efficiency of global manufacturing enterprises. The architecture proposed in this paper is based on industry standard technologies and is agile and flexible. The smart cyber agent technology holds the potential of automating majority of routine decision making thus allowing the managers to focus on unpredictable events that may occur. The design of system requires delegation of decision making at appropriate level.

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