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Integrating a New Machine into an Existing Manufacturing System by using Holonic Approach

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***Abstract*—This paper focuses on simplifying and easing the integration of a new machine into an existing conventional hierarchical manufacturing system. Based on a distributed manufacturing paradigm (Holonic Component Based Architecture – HCBA), it proposes the functions and interfaces the new machine and the existing manufacturing system should possess, so that ready and simple configuration of additional machines into an existing manufacturing system (plug and play) can be achieved. The configuration process is intended to include not only mechanical and electrical interfaces, but also decision system interfaces (such as planning, scheduling and shop floor control) too.**

Text

I. Introduction

Manufacturing practices in the future will have to cope with customers demanding low cost products whose needs are likely to change quickly. Hence, the manufacturing operations will have to be organized differently and be more effective in responding. Traditional centralized manufacturing planning, scheduling and control mechanisms have been found incapable of supporting changing production methods or highly dynamic variations in product requirements [1]. Because of this, much research effort [1],[2] is being devoted to develop manufacturing systems which are able react to changes rapidly and cost-effectively. One of the key properties of the manufacturing system which can react to changes rapidly and cost effectively is reconfigurability [2]. The term reconfigurability can be defined as the ability of a manufacturing system to be simply altered in a timely and cost effective manner [3].

The reconfiguration of a manufacturing system can be categorized into three types; addition of new components, removal of existing components, or modifying existing components. Note that manufacturing components can be physical components, such as machines, or logical components such as control software.

This paper focuses on simplifying the process of integrating (adding) new machines into an existing conventional manufacturing system. The paper begins by reviewing the existing integration approaches and distributed manufacturing paradigms in section 2. Section 3 presents the proposed method and an example is given in section 4. Finally, section 5 summarizes the paper

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II. Background

This section gives a brief review of the previous work relating to the integration of new machines into an existing manufacturing system. It begins by giving examples of the solutions used in computer domain. Existing approaches used to solve the integration problem in conventional manufacturing systems are described next. Then agent based solutions are discussed. Finally the gaps for the existing methods are identified.

A. *Integration in computer domain*

The problem of reconfiguration does not exist only in manufacturing domain. Another domain in which the need for reconfiguration is frequent is the computer domain. Since this paper focuses only on the addition of new machines into an existing manufacturing system, only solutions for this type of reconfiguration in the computer domain will be discussed in this section.

Some examples of the integration problems in computer domain are; to add a new peripheral to a PC, and to add a new computer into a computer network. In the first case, each computer peripheral is usually different and the way each peripheral can be controlled is normally dissimilar. Computers and their operating systems (OS) cannot be expected to know how to control every device, both now and in the future. To solve this problem, OS essentially dictate how every computer peripherals should be controlled [4]. The “device driver” is used to translate the generalized command from OS into a specific command used to control a particular device [4]. In summary OS only need to communicate with the device driver. The device driver can be considered as a wrapper that wraps around the actual device. It acts as an interface between OS and the physical device as shown in fig. 1a.

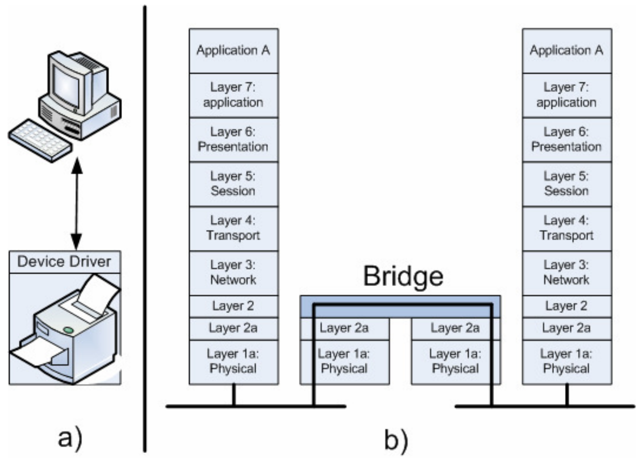

Fig. 1. a) The use of a device driver for a computer peripheral
b) The use of a network bridge in computer network

An example of the solution for the second type of the integration problem, adding a new computer into a computer netowork, is discussed next. On some occasions a computer, which have a different communication interface from that in a computer network, is required to be added into the network. In this case a network bridge can be used to connect the new computer into the computer network [5]. By using a network bridge, two different networks with different interfaces at the data link layer (layer 2) of the OSI model, such as Wireless LAN and Ethernet network, can be connected. In summary, a network bridge can be considered as an intermediate component which acts as an interface between two computer networks.

B. Integration in conventional manufacturing systems

There already are insudstrial standards that can be used to ease the integration process. Some of them are OLE for Process Control (OPC) [6] and ISA S88 [7]. OPC specifies a common way for applications (clients) to access data from any data source (server) like a device or a database. OPC enables the exchange of data between multi-vendor devices and control applications. An OPC server can communicate data continuously with PLCs on the shop floor, HMI stations and software applications on desktop PCs as shown in fig. 2.

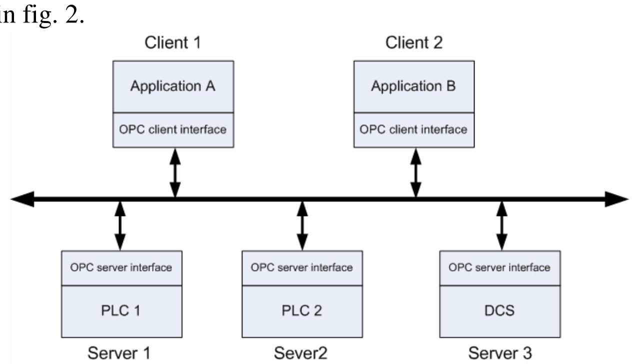

Fig. 2. OPC servers and clients [6]

On the other hand ISA S88 provides guidelines for designing manufacturing systems. Although it was initially intended for batch control, it can also be used for discrete manufacturing systems [8]. The great strength of ISA S88 is that it separates the production recipe (production procedure) from equipment control. This dramatically reduces the time required to modify the control program [9]. Also, it is possible to reuse the production recipe, since it has a modular structure [9].

Although OPC defines general interfaces to simplify the process of establishing communication between machines in a manufacturing system, it does not specify any control method. ISA S88 provides design philosophy can be used to design manufacturing systems. However, ISA S88 fixed hierarchical architecture limits the reconfigurability and the responsiveness of the manufacturing systems.

C. Distributed manufacturing paradigm

In order to improve the responsiveness and reconfigurability of the manufacturing systems, new control architectures are proposed [10]. Many of these control architectures are based on the Holonic control structure [11]. Holonic systems consist of autonomous, intelligent, flexible, and distributed cooperative agents or holons [12]. Three types of basic holons, which are resource holons, product holons, and order holons, are proposed in PROSA reference architecture [13]. Staff holons are used to assist the basic holons in performing their work. Leitao later proposed ADACOR architecture [14]. The structure of the ADACOR based manufacturing systems can be changed dynamically between heterarchical structure, which is used to deal with disturbances, and hierarchical structure, which is used to generate a global optimal schedule. Chirn, who focused on improving reconfigurability of the manufacturing systems, proposed the HCBA architecture [15]. The HCBA architecture is based on software component technology. This concept is used as a guideline to minimize the coupling between resource holons. Because of this, a new HCBA machine can be easily plugged into an existing HCBA based manufacturing system [15].

Although holonic based approaches are promising, most of the previous works create holonic manufacturing systems from scratch or focus on the behavioural part of the systems (scheduling or disturbance management) [11]. It is not unusual that a new machine is required to be integrated into an existing manufacturing system. Thus to allow the use of the holonic control structure for integrating a new machine into an existing non-holonic manufacturing system, the holonic based approach that minimizes the modification required to be made to the existing system, instead of re-building the manufacturing system from scratch, should be defined.

III. THE PROPOSED METHOD

As mentioned in section 2, the holonic (or agent) based approaches should be extended, if they are to be used to integrate a new machine into an existing non-holonic manufacturing system. By using holonic based approach to perform the integration, it is expected that the benefits of the holonic control structure, such as improving reconfigurability [15], should be achieved. Before presenting the proposed method, a fundamental concept used in the proposed integration method will be discussed. From the functionality point of view, a resource holon can be considered as a miniaturized factory as shown in fig. 3 [16]. A conventional manufacturing control hierarchy is shown in fig. 3a. Each function (planning, scheduling, manufacturing order release, manufacturing control, and device operation) is performed in a different level in the factory (see fig. 3a). However, in a complete holonic manufacturing system, a resource holon will possess all these functions [16]. Thus it can be considered as a miniaturized factory. The only different is a factory can perform many production operations and produce complete products. However, the resource may be able to perform only a small number of production operations and produce part of a product.

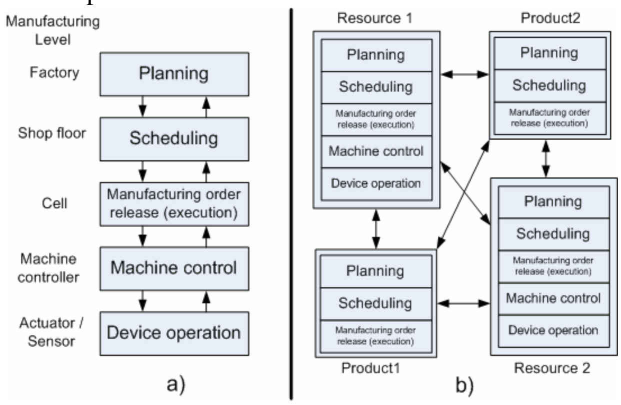

Fig. 3 a) Conventional centralized control approach [16]
b) Full holonic control solutions [16]

Since many holonic architectures have been proposed in the literature, candidate holonic architecture to be used in the proposed method was selected. In this project, the HCBA architecture [15] was selected for the following reasons. First of all, it has been implemented in real physical manufacturing system. Second, it specifically focused on improving the reconfigurability of the manufacturing systems when he developed this architecture [15]. Because of this, the integration process is simplified. However, it is expected that any holonic architecture or agent based solution should be able to be used. The existing manufacturing system must also be defined. In this project an existing manufacturing system is a discrete hierarchical manufacturing system based on ISA S88 standard [7]. However it is expected that the proposed method should be able to be applied to any type of conventional hierarchical manufacturing system.

Based on the wrapper concept and the distributed manufacturing paradigm, an approach for integrating a new machine into an existing conventional hierarchical manufacturing system is proposed. The proposed method comprises of three main steps; convert the existing manufacturing system into a holonic resource, convert the machine into a holonic resource, and system integration.

A. Step 1: Convert an existing manufacturing system into a HCBA resource

The first step is to convert an existing manufacturing system into a HCBA resource. To do this, first the existing manufacturing system must be analyzed. Then part of an existing system to be wrapped must be defined. Part of the existing manufacturing system to be wrapped can be found by identifying the associated centralized controller. This centralized controller will be used to control the new machine to be added, if the existing hierarchical architecture is used. Also, capabilities of the existing manufacturing system to be wrapped may need to be modified so that it can coordinate with the new machine to be added (see section 4 for an example). Also, it must be ensured that the redefined capabilities can be provided individually by the existing manufacturing system itself (see section 4 for an example). The capabilities should be matched with the language used to describe the production plans defined in the product holon. The next step is to compare the functions of the existing manufacturing system to be wrapped with those of the HCBA resource and identify the missing functions. Note that the wrapped existing manufacturing system will be considered as a single aggregated HCBA resource. After all the missing functions have been identified, intra resource interfaces and inter resource interfaces can be defined. Finally, a wrapper which provides the missing functions and interfaces is created and wrapped around the existing manufacturing sytem as shown in fig. 4.

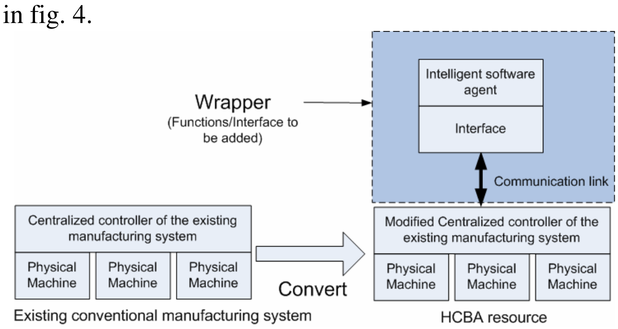

Fig. 4 Converting an existing cell into a single aggregated HCBA resource

B. Step 2: Convert new machine into a HCBA resource

The second step is to convert a machine into a HCBA resource. This can be done by, first of all, comparing the functions of the machine to those of the HCBA resource and identify the missing functions. After all the missing functions have been identified, intra resource interfaces and inter resource interfaces can be defined. The next step is to define the set of the capabilities will be provided by the machine. These capabilities should be able to be executed individually by this machine. The capabilities should also be able to be matched with the language used to describe the production plan defined in product holon. ISA S88 [7] can be used as a guideline for defining the set of the capabilities. Finally, a wrapper which provides the missing functions and interfaces is created and wrapped around the machine as shown in fig. 5.

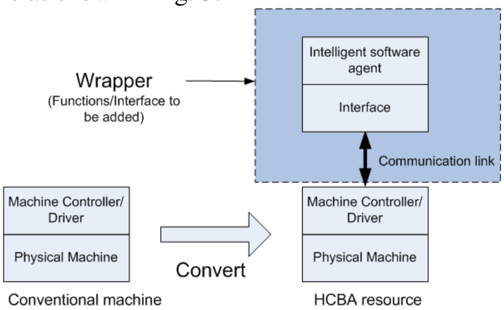

Fig. 5 Converting a machine into HCBA resource

C. *Step 3: System integration*

This step includes creating a product holon(s) (one for each type of product to be produced) and an interface to the higher level of the manufacturing hierarchy. The product holon is used to coordinate the production operations provided by resources. It has the necessary information required to produce a product which is equivalent to master recipe defined in ISA S88 [7]. The product holon is used to perform horizontal integration between resources. An interface for interfacing the new manufacturing system (the combination of a HCBA resource of the new machine, a HCBA resource of the existing manufacturing system and the product holon(s)) to the higher level of the manufacturing hierarchy is also created. This interface is used to receive order/command to produce products from higher level and send request to the associated product holon. The resulting integrated manufacturing system is shown in fig. 6.

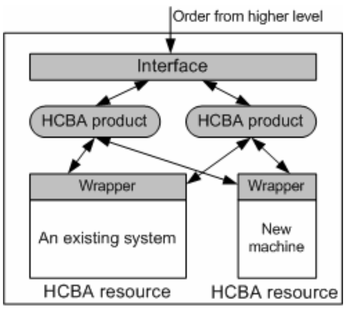

Fig. 6 The integrated manufacturing system

IV. CASE EXAMPLE

This section gives an example of how the proposed method can be implemented in real manufacturing system. The packing cell in the the Cambridge Distributed Information and Automation Laboratory [17] is used to demonstrate the proposed method (A picture of the Laboratory is shown in fig. 7 and Fig. 8 shows the layout of the Laboratory) It is assumed that there is no robot 4 (see fig. 8) in the initial configuration of the manufacturing system. The existing manufacturing system is used to pack gift boxes. Robot 4 (see fig. 8) is to be added to the existing system so that the boxes can be moved between docking station 5, shelf 1, and shelf 2 automatically. Note that robot1 is not used in this example.

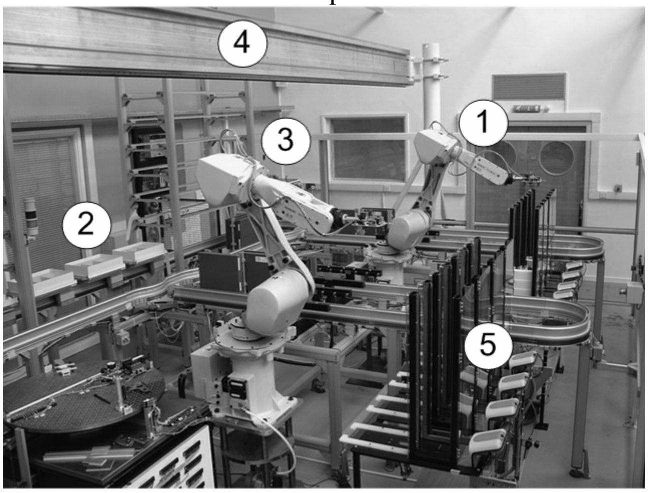

Fig. 7 Picture of Cambridge Automation Laboratory; showing robot3 (1) shuttles (2), robot1 (3), track for robot4 (4), and buffer (5)

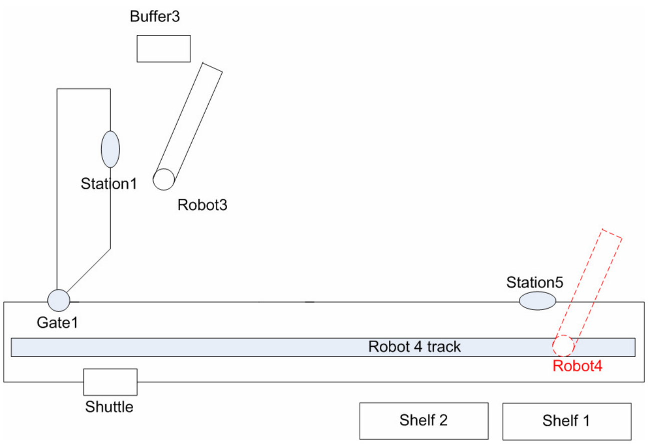

Fig. 8 Lay out of the experimental test bed

A. *Step 1: Convert an existing manufacturing system into a HCBA resource*

To convert an existing manufacturing system into a HCBA resource, first the existing manufacturing system must be analyzed. The structure of an existing system and its operation procedure is shown in fig. 9.

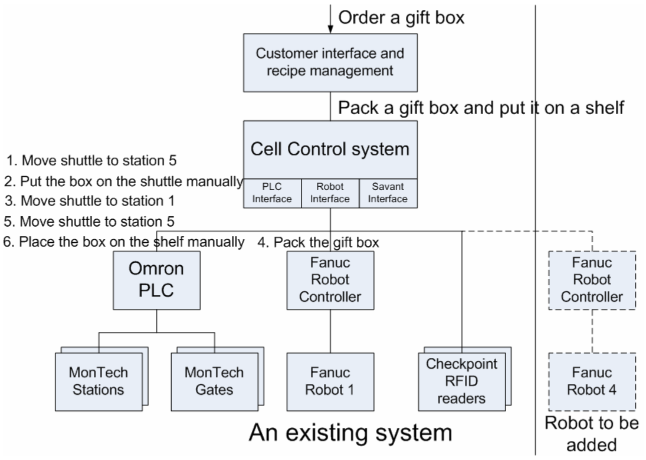

Fig 9. The structure of an existing system and its operations.

From fig. 9, cell control system will be used to directly control robot 4 if the existing structure is used. Thus, the wrapper will wrap around the cell control system. The operations of the existing system can be described as follows. First customer interface component receives an order from a customer. It then passes the order to cell control system. The cell control system performs scheduling and sends commands to its subordinates. It first sends a command to the Omron PLC to move a shuttle to docking station 5 (see fig. 8) where a box will be placed on the shuttle manually. The cell controller then sends a command to the Omron PLC to move the shuttle to docking station 1 where goods will be packed by robot 1. Finally, the Omron PLC receives a command from cell controller to move the shuttle to docking station 5 where an operator picks the box and places it on the shelf. In order to be able to integrate robot 4 into the system, the sequence of the production operation will have to be modified as shown in fig. 10.

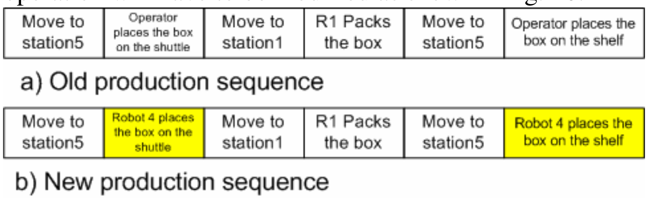

Fig. 10. a) Old production sequence
b) New production sequence

From fig. 10, the new capabilities of robot 4 must be defined. Also, the old process plan must be able to be split, so that the production operations of robot 4 (fig. 10) can be integrated into the production plan. It is suggested in ISA S88 [7] that the process plan (or production recipe) should be defined based on the product independent capabilities can be provided by each individual machine. By following this guideline a new production recipe can be created by rearranging the existing capabilities and adding new capabilities. In this project, the existing manufacturing system is based on ISA S88, thus an existing master recipe must be modified as shown in figure 10. Note that a master recipe will be maintained by a product holon.

The next step is to compare the functions of the existing system to be wrapped with those of the HCBA resource. The existing system already possesses the following functions; device control, machine control, execution and internal scheduling (scheduling within the cell). The communication links between controllers and the PC is also already existed. Thus, an interface between cell control system and intelligent software must be defined. The intelligent software, which is used to negotiate with product to create plan and schedule for the converted existing manufacturing system, is also created. This intelligent software wraps around the existing manufacturing system as shown in fig. 11.

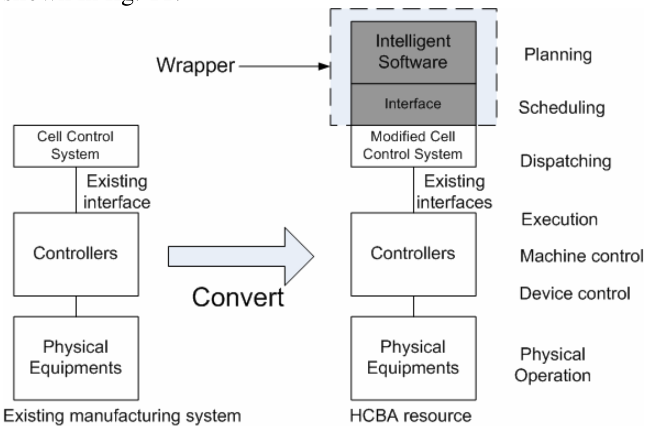

Fig. 11. Converting an existing packing cell into a HCBA resource

B. *Step 2: Convert a machine into a HCBA resource*

The second step of the integration process is to convert robot 4 into a HCBA resource. This can be done by comparing the functions of the robot to those of a HCBA resource and identify the missing functions. In this case the robot (and its controller) possesses the following functions; device control, machine control and execution. However, it does not have the ability to perform dispatching, scheduling and planning. Note that in HCBA, planning and scheduling will be done cooperatively by product holon and resource holon. Also, there is no communication link between the robot controller and the PC which is used to host intelligent software. Thus in this case an interface between robot controller and the intelligent software must be defined. The intelligent software must also be created. Before the interface between the robot controller and the PC can be created, the capabilities of the robot must be defined. In this case robot 4 has the capability to pick the box from shelf 1, shelf 2 or docking station 5 and place the box on shelf 1, shelf 2 or docking station 5. Having defined the capabilities, the interface between the robot controller and the PC can then be defined. This interface includes Ethernet link and robot interface as shown in figure 12. Finally, the intelligent software is crearted and wrapped around the robot. The intelligent software is used to negotiate with product holon and create resource’s schedule.

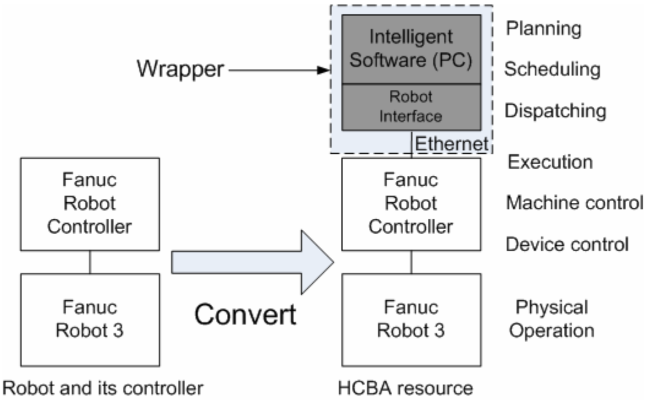

Fig. 12. Converting robot 3 into a HCBA resource

C. Step 3: System integration

The final step is to create a product holon(s) which is used to maintain the production recipe. The interface to customer interface and recipe management component is also created in this step. The structure of the result integrated packing cell is identical to that shown in fig. 6.

V. Summary

An approach of integrating a new machine into an existing system based on holonic manufacturing concept is presented. By using this integration method the benefits of holonic manufacturing systems can be achieved without having to transform every single machine into a holon. Moreover, if a holonic machine can be purchased directly from a machine vendor, this integration approach can be used to integrate the new machine into an existing manufacturing system. Also, if the existing manufacturing system is already converted into a HCBA resource, a new HCBA resource can be easily plugged into the system. The only things may need to be modified are the capabilities of the resources and the production recipes.

This is an ongoing project and the next step is to physically implement the proposed method in Cambridge Automation Laboratory. The proposed method will be compared with ISA S88 which is used as a representation of a conventional manufacturing system.

References

[1] P. Leitao, J. Barata, L. Camarinha-Matos, and R. Boissier, "Trends in agile and co-operative manufacturing," *Cost Oriented Automation - (Low Cost Automation 2001)*, pp. 149-158, 2002.

[2] Y. Koren, U. Heisel, F. Jovane, T. Moriwaki, G. Pritschow, G. Ulsoy, and H. Van Brussel, "Reconfigurable manufacturing systems," *CIRP Annals - Manufacturing Technology*, vol. 48, no. 2, pp. 527-540, 1999.

[3] E. Garcia-Herreros, J. Christensen, J. M. Prado, and S. Tamura, "IMS - Holonic Manufacturing Systems: System Components of Autonomous Modules and their Distributed Control," HMS Consortium,HMS -- Strategies, Vol.1, 1994.

[4] W. Oney, *Programming the Microsoft Windows Driver Model*. Washington: Microsoft Press, 1999.

[5] A. S. Tanenbaum, *Computer networks*, 4 ed. New Jersey: Prentice Hall, 2003.

[6] OPC Task force, "OPC overview,"1998.

[7] ANSI/ISA-S88.01, *Batch Control Part1:Models and Terminology* Instrument Society of America, 2000.

[8] E. G. Hernandez, E. A. Bricaire, J. A. Nava, and A. Sanchez, "A design strategy of discrete event controllers for automated manufacturing systems," in *2nd International Conference on Electrical and Electronics Engineering, ICEEE and XI Conference on Electrical Engineering, CIE 2005,* 2005 ed Mexico City, Mexico: Institute of Electrical and Electronics Engineers Computer Society, Piscataway, NJ 08855-1331, United States, 2005, pp. 361-364.

[9] Jim Parshall and Larry Lamb, *Applying S88 Batch Control from a User's Perspective* The instrumentation, Systems, and Automation Society, 2000.

[10] Monostori L, Va'ncza J, and Kumara S, "Agent based systems for manufacturing,", 55 ed 2006, pp. 697-720.

[11] R. F. Babiceanu and F. F. Chen, "Development and applications of holonic manufacturing systems: A survey," *Journal of Intelligent Manufacturing*, vol. 17, no. 1, pp. 111-131, 2006.

[12] P. Valckenaers, F. Bonneville, H. Van Brussel, and J. Wyns, "Results of the Holonic Control System Benchmark at KULeuven," in *4th Rensselaer International Conference on Computer Integrated Manufacturing and Automation Technology* Rensselaer, NY: 1994, pp. 128-133.

[13] H. Van Brussel, Wyns J., Valckenaers P, .Bongaerts L., and Peeters P, "Reference Architecture for Holonic Manufacturing Systems," *Computers in Industry*, vol. 37, no. 3, pp. 255-274, 1998.

[14] P. Leitao, "An Agile and Adaptive Holonic Architecture for Manufacturing Control." University of Porto: Faculty of Engineering, 2004.

[15] J.-L. Chirn, "Developing a Reconfigurable Manuacturing Control System -- A Holonic Component Based Approach." University of Cambridge, 2001.

[16] D. McFarlane and S. Bussmann, "Developments in holonic production planning and control.," *Production Planning and Control*, vol. **11**, no. **6**, pp. 522-536, 2000.

[17] R. Evertsz, M. Fletcher, R. Jones, J. Jarvis, J. Brusey, and S. Dance, "Implementing industrial multi-agent systems using JACK," in *Lecture Notes in Artificial Intelligence (Subseries of Lecture Notes in Computer Science),* 3067 ed Melbourne, Australia: Springer Verlag, Heidelberg, D-69121, Germany, 2004, pp. 18-48.