Vladimír Mařík
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Holonic and Multi-Agent Systems for Manufacturing

Second International Conference on Industrial Applications of Holonic and Multi-Agent Systems, HoloMAS 2005
Copenhagen, Denmark, August 2005, Proceedings

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Proceedings

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Czech Technical University
Faculty of Electrical Engineering, Department of Cybernetics Technická 2
16627 Prague 6, Czech Republic
and Rockwell Automation Research Center
Prague Pekařská 10a/695, 15500 Prague 5, Czech Republic
E-mail: marik@labe.felk.cvut.cz

Robert W. Brennan
University of Calgary
Department of Mechanical and Manufacturing Engineering
2500 University Drive NW, Calgary, Alberta T2N 1N4, Canada
E-mail: rbrennan@ucalgary.ca

Michal Pěchouček
Czech Technical University
Faculty of Electrical Engineering, Department of Cybernetics
Technická 2, 16627 Prague 6, Czech Republic
E-mail: pechouc@labe.felk.cvut.cz

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Preface

The challenge faced in today's manufacturing and business environments is the question of how to satisfy increasingly stringent customer requirements while managing growing system complexity. For example, customers expect high-quality, customizable, low-cost products that can be delivered quickly. The systems that deliver these expectations are by nature distributed, concurrent, and stochastic, and, as a result, increasingly difficult to manage. Unfortunately, the traditional hierarchical, strictly centralized approach to control used in these domains is characteristically inflexible, fragile, and difficult to maintain.

These shortcomings have led to the development of a new class of manufacturing and supply-chain decision-making approaches in recent years. Solutions based on these approaches usually explore a set of highly distributed decision-making units that are capable of autonomous operations while cooperating interactively to resolve larger problems. The units, referred to as *agents* in classical computer science and software engineering, or *holons* if physically integrated with the manufacturing hardware, interact by exchanging information. These units are motivated by arriving at local solutions as well as collaborating and sharing resources and goals in solving the overall problem in question collectively.

Despite a focus on the manufacturing domain in the late 1990s, applications of the holonic and agent-based approach were not restricted to this area and currently span a wide range of applications such as highly distributed real-time control systems, discrete event simulation, RFID technology, business and supply-chain management, etc. The research communities working in these different fields approach the problem of intelligent industrial solutions from different viewpoints and have already started to cooperate efficiently. Thus, global visions of applying the agent-oriented design philosophy from the level of real-time highly distributed execution control to dynamic operational planning on the machine or workshop up to managerial tasks connected with running the businesses have appeared. We can see solutions requiring coalition formation and teamwork planning, strongly supported by the challenging visions of virtual manufacturing and virtual enterprises. There is evident convergence in terminology, standards and methods. Moreover, we can clearly document that this convergence is amplified and catalyzed by the requirements from the real industrial *environment.*

In recent years we can identify trends toward *feasibility validation* of agent-based solutions, usually exploring specialized agent-based simulation tools. *Agent-based simulations* together with the first considerations on how to leverage the significant progress in the *RFID technology* field for discrete manufacturing represent dominant trends in the current industry-oriented research of agent-based systems.

This strong multi-agent community, organized around groups such as FIPA (Foundation for Intelligent Physical Agents) or AgentLink (European Co-ordination Action for Agent-Based Computing), is aware of the fact that one of the most challenging areas for the application of the agent-based computing and decision-making systems is the *field of intelligent manufacturing*. Special activities focused at industrial applications of agent-based computing have been established recently. For example, the AgentLink Agent Technology Conference annually brings together commercial organizations interested in exploiting agent technologies to benefit their businesses. As well, an Industry Track was organized for the first time at AAMAS, the leading international conference in the field of multi-agent systems. This track brings together researchers and academics on one side and commercial developers and key technology decision makers on the other side.

We are convinced of the value and importance of the continuation of the HoloMAS events. In particular, HoloMAS was among the first pioneering melting pots for ideas connected with distributed decision-making and control and has already gained international reputation. The first four HoloMAS events held under the DEXA event umbrella (three workshops, particularly HoloMAS 2000 in Greenwich, HoloMAS 2001 in Munich and HoloMAS 2002 in Aix-en-Provence as well as the first HoloMAS 2003 conference held in Prague) helped to bring together the research communities focused on agent-based industrial solutions, to realize the joint principles of agent-oriented applications on different levels of manufacturing, factory and supply chain management and to integrate better their research activities and results. At HoloMAS 2005 we wanted to document the feasibility and viability of the initial ideas, to show the continuity of the industrial agent-oriented research and to make the progress in the field clearly visible.

We expected that the HoloMAS 2005 conference would create an excellent, highly motivating environment, and help to continue to integrate the community. It was expected to contribute to a clarification of the goals and to a more efficient coordination of the research in the subject fields. This conference also continued to serve as a window to current holonic and agent-based manufacturing research and, as such, offered information about the state of the art to specialists in neighboring, knowledge-processing research fields covered by the DEXA multi-conference event. We are very thankful to the DEXA Association for providing us with this excellent opportunity.

For this year's edition, 40 high-quality papers were submitted by the most important, core research bodies engaged in holonic and agent-based manufacturing worldwide. After a careful reviewing process the Program committee selected 23 papers to be presented and included in this volume. They contain the most representative results of the corresponding research and provide an excellent overview of what is the current state of the art.

We would like to thank also both the AgentLink III EU Coordinated Action and the I*PROMS EU Network of Excellence for their support and technical co-sponsorship.

Prague, Calgary
June 2005

Vladimír Mařík
Robert W. Brennan
Michal Pěchouček

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2nd International Conference on Industrial Applications of Holonic and Multi-agent Systems (HoloMAS 2005)

Applications of Holonic and Multi-agent Systems

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Experience with Holonic and Agent-Based Control Systems and Their Adoption by Industry

Kenwood H. Hall[1], Raymond J. Staron[1], and Pavel Vrba[2]

[1] Rockwell Automation, Inc., 1 Allen-Bradley Drive,
Mayfield Heights, OH, 44124 USA
{khhall, rjstaron}@ra.rockwell.com
[2] Rockwell Automation s.r.o., Research Center Prague, Pekarska 695/10a,
155 00 Prague 5, Czech Republic
pvrba@ra.rockwell.com

Abstract. Currently industrial automation systems are built using a hierarchical top-down approach, yielding tightly coupled and low flexibility systems. Holonic and intelligent agent-based industrial control systems have the potential to be much more highly robust and flexible systems with very loose coupling between subsystems. Despite this potential these systems are slow to be adopted by industry. This paper explores Rockwell Automation's current agent philosophy, application experience, the obstacles to widespread adoption of agent technology in industrial automation systems, and its recent activities to overcome some of the obstacles.

1 Agent Philosophy

Holonic manufacturing systems (HMS) represent a novel paradigm to address some critical problems faced by manufacturing businesses in the twenty-first century. Ever increasing customer requirements are calling for new manufacturing strategies satisfying the needs for (i) open and dynamic structures to allow the on-line integration of new subsystems or removal of existing subsystems from the system without the need to stop and reinitialize the working environment, (ii) agility to adapt quickly to continuous and unanticipated changes in the manufacturing environment, and (iii) fault tolerance to detect and recover from a failure by minimizing its impact on the whole system.

Distributed intelligent manufacturing can meet these requirements. The more traditional sequential and centralized solutions, used within the scope of such agile environments, do not work since they are slow to react, impose operational bottlenecks and are a critical point of failure. Holonics is a decentralized 'bottom up' approach and provides principles to ensure a higher degree of responsiveness and handling of system complexity. The fundamental building blocks of a HMS are called *holons*, fundamentally as presented in [1], to reflect the fact that these entities: (i) are both parts and wholes and (ii) behave simultaneously in an autonomous and cooperative fashion.

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The vision of a *holonic factory*, in which all the operations (including product ordering, planning, scheduling, manufacturing, and invoicing the customer) are based entirely on holonic principles, covers several levels of information processing for manufacturing. At least three separate levels can be distinguished:

- **real-time control**, tightly connected with the physical level of manufacturing equipment
- **production planning and scheduling** both on the workshop and factory level
- **supply chain management,** integrating the particular plant with its external entities (suppliers, customers, partners, sales network, etc.)

The particular research results in the holonic field are connected mainly with real-time control. In the other two subfields, the research centers on the philosophical or architectural level, but the particular implementations exclusively use the research results of multiagent systems (MAS). The HMS community has fully realized that the *function block* based real-time control (utilizing the IEC 61499 standard described, for instance, in [2]) is applicable to control tasks only, i.e., they are not the best way to implement the higher level reasoning of agents. Thus it is necessary to leverage the results achieved in the MAS field to widely exploit the visions of a holonic factory. Several general architectures for combining both the function block and MAS technologies have been designed. The most popular new holon model encapsulates one or more function block oriented devices into a wrapper containing a higher-level software component (see Figure 1).

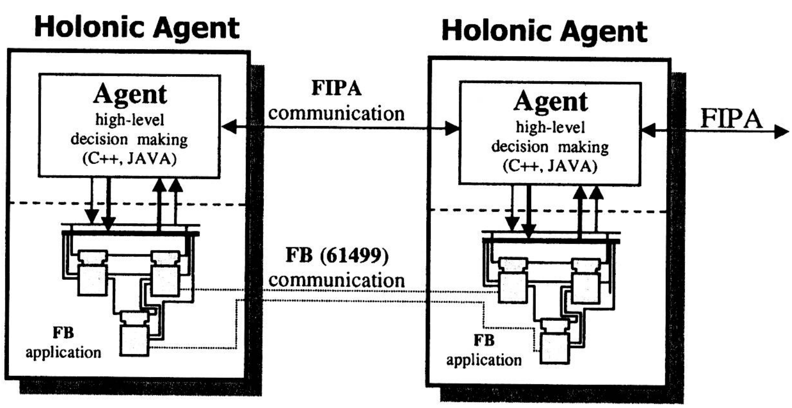

Fig. 1. Model of a PLC-based automation controller with holonic agents using 61499 function blocks for real-time control

Rockwell Automation (RA) has realized that the 61499 function blocks are not as ubiquitous as the IEC 1131 programmable controller languages described in [3], and therefore has implemented its multiagent system using standard relay ladder logic (one of the 1131 languages) instead of 61499 function blocks. The RA model for its *holonic agents* (or simply, *agents*) is still one containing a higher-level intelligent software component, as shown in Figure 2.

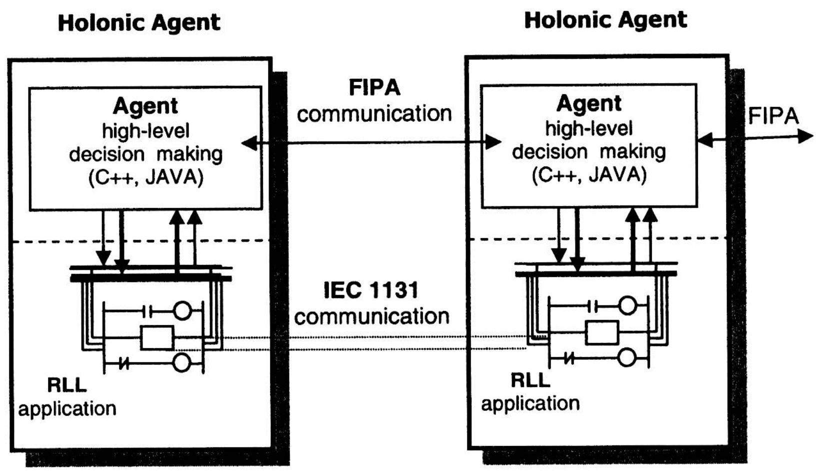

Fig. 2. Model of a PLC-based automation controller with holonic agents using IEC 1131 relay ladder logic for real-time control

In such an agent, equipped with both a lower level real-time component and a higher-level intelligent component, there are three communication channels:

- intra-agent communication between the real-time component and the intelligent component; RA has implemented its agents on its Logix brand of controllers, and the data tables are used for communication between the two components;
- inter-agent communication that is aimed at communication among the intelligent components of multiple agents; RA uses the FIPA standards with its own Job Description Language (JDL) as the content language;
- a direct communication channel among real-time components of the neighboring agents; RA uses the CIP standard for these high speed, deterministic communications.

These agents can therefore widely communicate among themselves, carry out complex negotiations, cooperate, develop manufacturing scenarios, etc., as well as control the manufacturing equipment.

Selling the use of agent-based control systems to customers has proven somewhat problematic. In those discussions RA points out several benefits that its implementation offers over conventional control systems [7]. Moreover, RA discusses with its customers what types of applications can expect to benefit from the use of an agent-based control system. In general, agents are beneficial in control applications where the number of possible configurations of the equipment is impractically large, i.e., too large to accommodate them in traditional programming. This large number can be a result of (i) the nature of the machine or process to be controlled; (ii) redundancy or flexibility built into the design of the solution; or (iii) the large number of combinations of failures that might occur. We offer some examples in the next section, and then in the following section, discuss some of our observations on existing obstacles to widespread adoption of agent-based control systems.

2 Application Experience

Rockwell Automation has investigated agent-based solutions for a number of applications and has implemented agent-based solutions for two specific industrial applications. The common requirement of these applications is the need for flexibility and reconfiguration. The justification for these projects has been either the increased utilization of manufacturing assets or a more robust system that can continue to operate during major disturbances.

2.1 Rod Steel Production

The first RA industrial agent project involved increasing the machine utilization of a steel rod bar mill. The mill makes steel rods by reheating steel and rolling the steel to size using multiple rolling stands and cooling the steel along a defined temperature profile using multiple cooling boxes as shown in Figure 3. The production process recipes for most of the steel rods require the use of neither all of the rolling stands nor all of the cooling boxes.

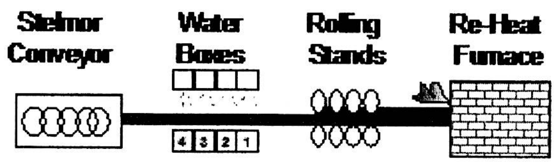

Fig. 3. Bar steel mill process diagram

Hence the system had built-in redundancy and flexibility since it could use any combination of cooling boxes and rolling stands from the subset of working units to produce a given steel rod recipe, as long as the required temperature profile was followed. The aggregate desired behavior of the system was to select and configure a subset of cooling boxes from the working units to satisfy the recipe requirements. This was implemented by enabling each cooling box or unit to assess its own health and bid on its part of the operation. The bids were used with a very accurate simulation of the steel cooling process to enable rebidding until a suitable subset of units and configurations was found as presented in [4].

The agent-based control system did not directly control the bar mill but instead recommended a configuration to the operator. Because of safety concerns and possible damage to equipment the risk was too high to enable direct control by this new technology. Although the agent system preformed very well in all the tests, to release the system for production would require testing all steel recipes with all possible subsets of cooling boxes.