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A re-configurable multi-agent system architecture for error recovery in production systems

Nicholas G. Odrey*, Gonzalo Mejía

Industrial and Systems Engineering Department, Lehigh University, Bethlehem, PA 18015, USA

Abstract

Multi-agent systems for manufacturing systems appear to provide adequate response to abrupt disturbances on the shop floor. To date, most of the work has been focused on planning and scheduling but very little work has been done on issues pertaining to monitoring, diagnostics and error recovery. Our approach addresses the issue of combining the discipline of hierarchical systems with the agility of multi-agent systems. Within the context of a hierarchy, the focus is on the workstation level and, in particular, the construction of a re-configurable system having production agents, error recovery agents, and a mediator agent structure connecting production and recovery agent hierarchies. In addition, the relationship to a multi-level, multi-layer hierarchy control is established. This latter hierarchy, based on Petri Net constructs, serves, in one sense, as a retrieval based resource for process planning and generation of recovery plans for production and recovery agents within the proposed multi-agent system. An objective of this effort is to provide a test-bed for comparison of hierarchical systems, heterarchical, and a hybrid combination which is the focus of the investigation presented here.
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1. Introduction

Today's manufacturing companies need to effectively adapt to sudden changes in customer demand, constant evolution of software and hardware, and unpredictable events such as failures and disruptions. Multi-agent based architectures for manufacturing systems appear to provide adequate responses to such requirements since their distributed nature provides flexibility and reactivity to changing situations [1]. Several intelligent-based architectures for manufacturing systems have been proposed in the literature: examples are Holonic Manufacturing [2,3], the NIST Real-Time Control System (RCS) [4], the MetaMorph Architecture [5], and the AARIA project [6].

While several performance tests [7,8] suggest that intelligent agent architectures for manufacturing systems outperform other control architectures in disruption-prone scenarios, the lack of standards on design methodologies, communication protocols, and task distribution among the agents imposes difficulties to their introduction to real-life applications. As a counterpoint to such intelligent-agent-based architectures, classical hierarchical architectures have been conceived with such standardization issues in mind. A major drawback of hierarchical architectures is that the structure can be overly rigid and consequently difficult to adapt to unanticipated disturbances [3].

A critical issue in the design of a control architecture for manufacturing systems is the definition and execution of the input and reporting (feedback) functions. In the context of hierarchical architectures for manufacturing systems, such control tasks are clearly differentiated among hierarchical levels (e.g. equipment, workstation and cell levels). The input function is exerted top–down while the reporting (feedback) operation is exerted bottom–up [9]. In addition, in the event of local errors, the controller of the workstation should devise and execute adaptive control actions to reinstate the normal course of the operations as soon as possible [10]. Such control actions at the workstation level include monitoring, diagnostics, error recovery and the corresponding adjustments to the execution plan.

To date, most of the research work on intelligent-agent-based architectures [2,5,6] has been focused

*Corresponding author. Tel.: +1-610-758-4036.
E-mail address: ngo0@leigh.edu (N.G. Odrey).

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towards planning and scheduling in dynamic environments [11,12,13]. The subjects of monitoring, diagnostics and error recovery tasks have received little attention from the perspective of intelligent-agent-based architectures. While in intelligent agent architectures "production" tasks (e.g. planning, scheduling and machine sequencing) have been assigned and distributed among several agents, the error recovery tasks have either been centralized in very few agents (e.g. [14]) or entirely assigned to each individual agent without the benefit of information sharing [13]. The potential disadvantages of current error recovery approaches are the lack of coordination among recovery tasks, programming redundancy, and the lack of specialization on recovery methods.

This paper presents enhancements agent over previous work by the author [10] on a hybrid hierarchical intelligent-agent-based system consisting of three structures of agents: (i) a "production" structure in which the agents are responsible for all production tasks, (ii) a "recovery structure" dedicated to in-depth reasoning for recovering unanticipated or difficult-to-handle errors, and (iii) a communication link between the "production" and the "recovery" structures provided by a structure of mediator agents. The mediator agents have the function of filtering and re-directing information between the production and recovery agents. In the approach proposed here, the production, mediator, and recovery agents are autonomous entities organized in hierarchical but re-configurable architecture. Overall, this approach is expected to combine the discipline of hierarchical systems with the inherent ability of quick reactions of an intelligent-agent-based system.

2. General principles of the proposed architecture

The approach proposed here is based on the previous work on hierarchical control [10,15,17] and multi-agent architectures [16]. The differences here are that (i) production agents are autonomous (i.e. the last decision on the execution of a task is made by the production agent itself), and (ii) the diagnostics and error recovery functions are delegated to specialized external agents. Autonomy allows the production agents to adapt and modify the commands issued by higher-level agents if conditions dictate. Specialized agents for diagnostics and error recovery functions release production agents from computationally demanding tasks not associated with their primary objective. The architecture is partitioned into three sections, namely production, mediator and recovery sections, as shown in Fig. 1.

Production agents comprise two sub-types of agents, namely planner agents and control agents. Planner agents are responsible for creating and optimizing execution plans for the tasks assigned by higher-level commands. Control agents are responsible for the execution of such assigned tasks. Control agents receive and process information from planner agents, environment sensors, mediator agents (recovery plans), and higher-level agents. Based on the processed information, the control agents make autonomous decisions that lead to the generation of a final execution plan which constitute the input function for lower-level control agents.

Recovery agents provide diagnostics and generation of recovery plans. The input for a recovery agent is a detailed report containing all the information pertaining

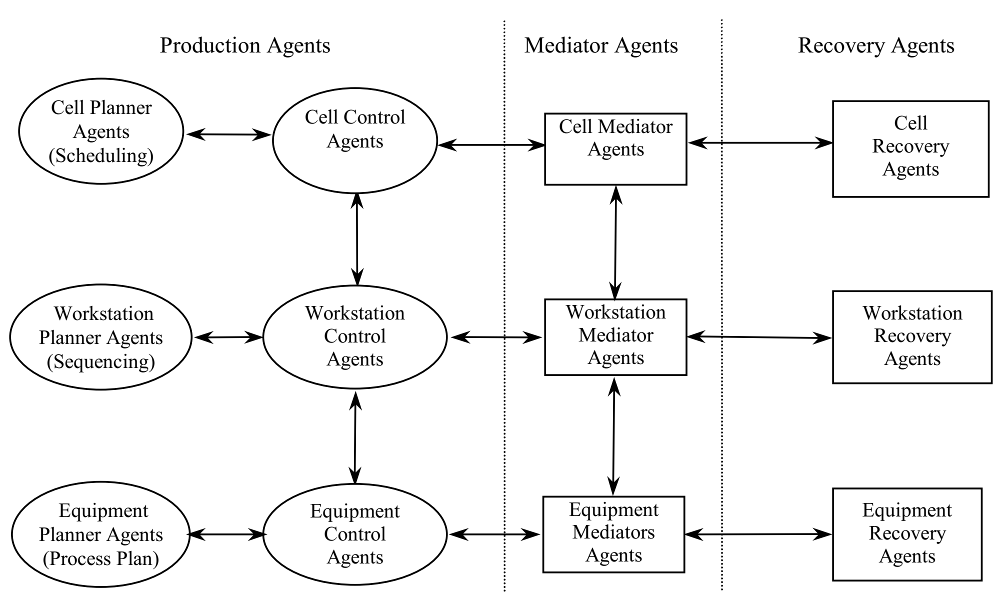

Fig. 1. Intelligent-agent-based hierarchical architecture having error recovery agents.

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