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AN ANALYSIS UPON INTELLIGENT HOLONIC MANUFACTURING CONTROL DEVICE COMMUNICATION SYSTEM: LAYOUT AND IMPLEMENTATION

An Analysis upon Intelligent Holonic Manufacturing Control Device Communication System: Layout and Implementation

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Abstract – A holonic manufacturing system (HMS) represents a new breed of intelligent shop-floor management technology for the production of artifacts that satisfy unique customer requirements. Flexibility is an essential characteristic of the HMS in order to manufacture high-variety low-volume artifacts. Autonomous 'smart' entities called holons interact, via cooperation protocols, within a HMS to support the runtime reconfiguration demanded by such an agile shop-floor. This paper presents a framework to model and reconfigure, in real-time, the holons' abstract behavioral specifications through the application of Internet-based mobile agents. A tool is also described to convert these specifications into a corresponding implementation model (based on the IEC 61499 function block architecture) that holons can execute across an open network of controller devices. In particular, an argument is developed that holonic manufacturing systems provide greater agility than their current industrially adopted counterparts.

Manufacturing systems must adapt to new challenges impacting the economy. New structures, behaviours and requirements arise in response to those challenges. These elements are systematised and different problem approaches are analysed. Multiagent concepts generally and holonic concept specially are studied. Based on its requirements and characteristics several frameworks are compared. This paper focuses on implementation issues at the interface between holonic control devices (HCDs) and agent-based systems. In particular, we look at a jimction block-based approach to communication that is applicable to existing IEC 61131-3 systems and emerging IEC 61499 systems.

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INTRODUCTION

Many manufacturing paradigms promise to meet these challenges. Two of these paradigms, namely, distributed intelligent manufacturing systems and holonic manufacturing systems, have recently been receiving a lot of attention in academia and industry.

Techniques from artificial intelligence have already been used in intelligent manufacturing for more than twenty years. However, recent developments in multiagent systems in the domain of distributed artificial intelligence have brought about new and interesting possibilities. Distributed intelligent manufaturing systems, or agent-based manufacturing systems, are based on multi-agent system (MAS) technology. MAS studies the coordination of intelligent behavior among a group of (possibly pre-existing) agents. An agent is an autonomous and flexible computational system, which is able to act in an environment. Today, MAS is a very active area of research and is beginning to see commercial and industrial applications.

The application of holonic concepts to manufacturing was initially motivated by the inability of existing manufacturing systems (i) to deal with the evolution of products within an existing production facility and (ii) to maintain satisfactory performance levels outside normal operating conditions. Suda introduced the concept of holonic manufacturing in the early 1990s to address the challenge for manufacturing in the 21st century.

Teams of industry experts, scientists, and engineers from the world's leading industrial nationsworked together from 1992 to 1994 to build and test a framework for international collaboration in intelligent manufacturing systems (IMS). The experiences of teams coming together from Australia, Canada, Europe, Japan and the USA to work for one year on collaborative "test case" projects formed part of a two-year feasibility study that began in February 1992. This feasibility study proved that this kind of international collaboration could achieve significant results in a relatively short time.

A holonic manufacturing system is based on the concept of “holonic systems”, developed by Arthur Koestler. Holons in a holonic manufacturing systems assist the operator in controlling the system: holons autonomously select appropriate parameter settings, find their own strategies and build their own structure. Koestler also points out that holons are autonomous self-reliant units, which have a degree of independence and handle contingencies without asking higher authorities for instructions. Simultaneously, holons are subject to control from (multiple) higher authorities. The first property ensures that holons are stable forms, which survive disturbances. The latter property signifies that they are intermediate forms, which provide the proper functionality for the greater whole. Finally, Koestler defines a holarchy as a hierarchy of self-regulating holons that function (a) as autonomouswholes in supraordination to their parts, (b) as dependent parts in subordination to controls on higher levels, (c) in coordination with their local environment.

Work in the HMS program has translated these concepts to the manufacturing world, viewing the manufacturing system as one consisting of autonomous modules (holons) with distributed control. The goal is to attain the benefits that holonic organization provides to living organisms and societies, in manufacturing, i.e., stability in the face of disturbances, adaptability and flexibility in the face of change, and efficient use of available resources. The HMS concept combines the best features of hierarchical and heterarchical organization. It preserves the stability of hierarchy while providing the dynamic flexibility of heterarchy.

The holonic manufacturing paradigm was developed in the framework of the Intelligent Manufacturing Systems (IMS) programme. In a feasibility study, conducted in 1994, six test cases were considered, one of which was ‘Holonic Manufacturing Systems: system components of autonomous modules and their distributed control,' or HMS. The HMS project aimed at a better understanding of the requirements for future-generation manufacturing systems and at ways to build systems satisfying these requirements. A holonic manufacturing architecture shall enable easy (self-)configuration, easy extension and modification of the system, and allow more flexibility and a larger decision space for higher control levels.

This study describes the holonic reference architecture for manufacturing systems developed in GOA/HMS. A reference architecture is defined as a set of coherent engineering and design principles used in a specific domain. It aims at structuring the design of a specific system architecture by defining a unified terminology, the structure of the system, responsibilities of system components, by providing standard (template) components, by giving examples, etc..

Holonic Manufacturing Systems (HMS) represent a topical research field that aims at finding a solution to some challenges for the present manufacturing environment. Concisely, it is harder and harder to have an optimal control architecture for a manufacturing process whose inputs can have great variations (e.g. the production refers to small series and the custom commands require important changes for the manufacturing design and control), to comply with the time constraints and to operate with the smallest costs. A holonic approach can be the answer that results by applying in a synergetic way certain methods and tools from Artificial Intelligence (AI), Control Engineering, Software Engineering and Mechatronics.

Thus, the term holon was for the first time used by Koestler in order to better formalize the relationship between a part and the whole. Starting with Koestler’s idea that a new model is needed to describe the hybrid rapport between wholes, sub-wholes and parts in real-life systems, a new methodology has been developed regarding the manufacturing systems, under the name of holonic approach. Its attractiveness results from the way it provides means for combining both the hierarchical and heterarchical schemes, and the possibility to consider important features for the present manufacturing systems: autonomy, flexibility, adaptability. The problem still existing for the HMS is the lack of systematic methods for the designing and implementation phases, as well as the little practical experience. Thus, these aspects are the main points for this contribution.

HISTORICAL BACKGROUND

Holonic systems originate from the works of the philosopher A. Koestler, who in 1967 proposed the term holon to describe his observations of the behaviour of biological and social systems. The word holon itself originates from the Greek word ”holos”meaning ”whole” and the suffix ”on” meaning ”part of” i.e. a neutron or proton. He found that all biological and social systems evolve, grow, and adapt to complex and changing environments by forming stable intermediate holons. More specifically, holons exhibit a dual behaviour which he called the Janus Eject. On the one hand, each holon has an autonomous quality. Its development and functionality is sufficient to exist alone. On the other hand, each holon also has a cooperative quality that allows it to depend upon a social framework of holons.

In such a way, they interact together to meet overall goals of the collective. It was these ideas which Suda felt would be particularly beneficial in a manufacturing system. Soon afterwards, the Holonic Manufacturing Systems Project with its associated research consortium was formed as one of the six Intelligent Manufacturing Systems (IMS) feasibility studies. Since then, numerous conceptions (of 8 varying degrees of similarity) were proposed to bring holonic principles to a manufacturing context. In order to instantiate more concretely such a holon, one generally accepted conceptual architecture is introduced in Figure 1.

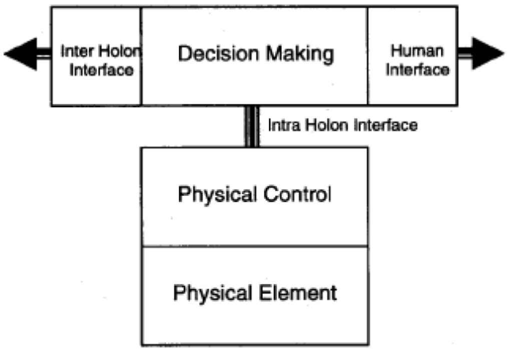

Figure 1: A Generic Architecture of a Holon.

Over 30 years ago, Arthur Koestler proposed the word “holon”. It is a combination of the Greek holos = whole, with the suffix -on which, as in proton or neutron, suggests a particle or part. Two observations impelled Koestler to propose the concept of holon. (a) Complex systems will evolve from simple systems much more rapidly if there are stable intermediate forms than if there are not; the resulting complex systems in the former case will be hierarchic. (b) Although it is easy to identify sub-wholes or parts, ‘wholes' and ‘parts' in an absolute sense do not exist anywhere. This made Koestler propose the word holon to describe the hybrid nature of sub-wholes/parts in real-life systems; holons simultaneously are self-contained wholes to their subordinated parts, and dependent parts when seen from the inverse direction.

The HMS consortium translated the concepts that Koestler developed for social organisations and living organisms into a set of appropriate concepts for manufacturing industries. The goal is to attain in manufacturing the benefits that holonic organisation provides to living organisms and societies, i.e., stability in the face of disturbances, adaptability and flexibility in the face of change, and efficient use of available resources. The HMS concept combines the best features of hierarchical and heterarchical organisation. It preserves the stability of a hierarchy while providing the dynamic flexibility of a heterarchy.

A STRUCTURE FOR HOLONS AND RECONFIGURATION

A holonic manufacturing system (HMS), as proposed by Koestler (1967) and consequently developed by the international HMS project, is an example of the next generation of manufacturing businesses where 'smart' entities called holons collaborate to manufacture an ever-increasing variety of products from the business' product family. The term holon comes from the Greek word holos (signifying whole) with a suffix on (a particle, as in proton). Holons provide all the facilities needed to control, transport, transform and store artifacts within a factory. Holons can also process information such as being a server or expert system. Each holon is a dynamic system with input, processor, output and a controller. Our approach to managing a HMS is as a consequence of experimenting with an industrial test bed where lumber (i.e. a natural material with irregular internal deformities) is cut in a flexible manner to construct value-added wood products for assembly into furniture. We envisage that the introduction of "holonic" ideas into such manufacturing enterprises will lead to significant increases in the following: (i) robustness to disturbances; (ii) adaptability to rapid change; and (iii) efficient use of available resources. Structurally, a holon has (i) a physical processing part that is associated with an item of shop-floor machinery to process artifacts, and (ii) an information processing part to handle knowledge management and execute software algorithms pertaining to the holon's control system specification (i.e. its behavioral model). Holons' behavior is characterized by a combination of their:

- Autonomy (i.e. the ability to create a plan and execute to process both physical artifacts and information, while overcoming disturbances in the factory environment).
- Cooperation (i.e. the capacity to generate plans, execute them and overcome disturbances through interaction with other holons and human users).

Continual automatic reconfiguration of the HMS to manufacture products that have different specifications from the existing machine set-ups is a complicated operation. In other words, the holons in the HMS must be able to repetitively change their own control system to handle shop-floor configurations geared towards batch sizes of unity. Moreover, this transition must be achieved without temporarily taking the system down and re-initializing it. This scenario demands the ability to change the autonomous and cooperative behavior of the holons on the fly and compensate for any anomalies generated during this transition period.

We believe that the solution lies in the creation of a flexible framework, the development of modern AI techniques and a sophisticated tool for modifying how holons execute their tasks and interaction patterns. Namely the holons' control system specification (or behavior model) must be reconfigured dynamically at runtime. Furthermore, these runtime modifications must be performed while the holons are performing actions that have real-time constraints attached to them, e.g. a hydraulic platform must move in the next 50 microseconds or else an assembly worker may get injured. For our purposes, reconfiguration of the software in each holons' control system relates to two issues:

- Changes with respect to what software components are in the control system and how are they related, i.e. modifying a logical model of configuration. For example, the structure of the holonic control system for our lumber cutting task must be changed from one configuration to another, due to the replacement of a PID control algorithm with a fuzzy logic control algorithm for better efficiency.

- Changes to where the software components reside in the network of controller devices that are executing the distributed system, i.e. modifying a physical model of configuration. For example, migrating the control system's output algorithm from devices 1 to 3 (both within the scope of a single cutting holon) to improve load balancing.

Such reconfiguration is founded upon changes to the holons' behavioral models (namely the control system specifications run by holons), with respect to their autonomous and cooperative actions. This incurs several advantages over more traditional techniques, including those advocated in innovative factory management proposals, like concurrent engineering or supply chain management. The input data used to initiate runtime reconfiguration is not a prescriptive description of how every type of product can be manufactured using every particular holon, and thus is not prone to failure if a holon is disrupted. The behaviors are dynamically determined from beliefs, desires and intentions of the software agent managing the information processing part of the holon, and hence the system performance does not significantly degrade over time as behaviors age. Furthermore, using pre-defined behavior patterns downloaded from a central repository may result in missing important opportunities to use shop-floor resources efficiently. Holonic behavior can also be used to enhance the performance of other approaches to reconfiguring the manufacturing process such as just-in-time processing with minimal batch sizes (through Operational Research or Kan ban. These existing techniques are often based on matching, in real-time, the current and desired system behaviors against theoretical models generated prior to system startup. However, if there is no a priori model then the manufacturing system would not recognize how to reconfigure itself; the incorporation of the holonic paradigm is intended to overcome this difficulty.

HMS COMMUNICATION MECHANISM

In order to design a communication mechanism for an HMS certain architectural constraints have to be considered. The holonic system has to support the recursive organization and a service based interaction protocol, as presented above. Considering the holon as a composite entity, spatially and functionally distributed, a solution for the implementation is to use a communication middleware to transparently ensure the support for addressing applications running on different computers, publishing services and managing events in the distributed system. CORBA contains a set of standards for implementing object request brokers (ORB), the core of distributed middlewares, and adjacent services. By making use of the CORBA specific services, the holon entity can be built around an ORB which handles the communication between the software agent and the structural component; in this way the previous scheme is materialized according to Fig. 2. The structural component can be either a physical execution device commanded through a driver application for certain resource holons, or a holarchy formed from other holons for the upper level holons in the semi-heterarchic organization. The communication protocol for the information flow

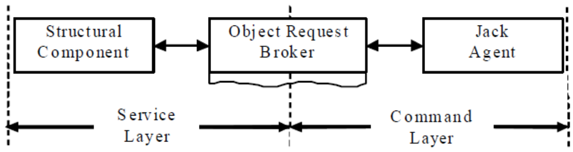

Fig. 2 – A holon builfing scheme.

between the holon components has to be transparent related to the communication layers, so the agent will only have to know the parameters required by the structural component's communication interface. The agent, as being the holon decisional part, is responsible for finding plans in order to satisfy the requests received from other holons. using the ORB component to discover available services which can implement the actions corresponding to specific plans. The ORB component facilitates the seivice oriented approach in the distributed environment. A service is a mechanism used by a server entity, usually a software application, to export a certain functionality which can be requested by one or more client entities, also software applications, by making use of platform independent interfaces granting communication protocol transparency. A service is implemented as a method exported by an object instantiated by a server application, and in order to be referred by client applications the object has to be addressable. The ORB application maintains a list of all available objects and makes them public through a set of global services. as follows :

1. The naming service is a component of the ORB application which transparently associates a reference to each object published by any of the connected applications, disregarding of software application location or network protocol used to communicate with the ORB. A client application can retrieve the object reference

and directly call the service implemented with the specific object.

2. The event service is another component of the ORB. managing the events generated by the inter-connected software applications in the distributed system, One entity can register as producer for an event channel, publishing events for eventual consumer applications. The consumers register with specific channels and they are transparently notified in real time upon event generation by the event service. The transparency is given by the way a producer application doesn't have to maintain itself a list of consumers and implement peer-to-peer notifications.

3. The trading object service is complementary to the naming service and implements the support for dynamically establishing producer-consumer relations in distributed systems, The producers (agents or driver applications in the proposed architecture) publish service offers using the trading service. and the consumer applications can query the trading service in order to find available services to fulfill required actions; this facility is to be combined with the multi-agent specific coordination mechanism, as already explained.

The organization of the inter-holon communication mechanism is important for the efficiency of the HMS. In usual scenarios an order holon encapsulating a global goal in the manufacturing system can have as structural component a holarchy formed from one or several product holons. which contain the operational context to manufacture the product types referred in the goal, and each of them uses a set of resource holons. This holarchy will be the result of the coordination mechanism. A typical approach is to define the relations between the agents corresponding to different holons and also the specific communication channels either a priori, at design time, or in real time if the agents know each other's capabilities and dynamically establish group relations by a negotiation process.

CONCLUSION

The more active fields are those related to developing holonic control systems. From these developments we can conclude that currently multi-agent system technology is the toolmost utilized for developingHMS. Nevertheless, there is very little work on methods for HMS development.

We have presented a general framework for reconfiguring an intelligent holonic manufacturing system in order to manufacture new products, cope with differing production specifications, and overcome the problems associated with machine failures and introduction of high priority orders. This framework, its application of Internet-based mobile agents and its associated tool (DIRECT) are based on techniques that automatically select the appropriate function block application to manage how the manufacturing tasks are to be executed, when, where and what coordination (e.g. synchronization and concurrency) are demanded. This has the potential to eliminate inconsistencies from the holons' behavior as well as keeping it up-to-date. Furthermore, appropriate graphical user interfaces are supported in order to facilitate human-in-the-loop decision making with respect to how the HMS is reconfigured at runtime.

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