Holonic Architecture for Shop-floor Control

A. Tharumarajah, S. Walsh

CSIRO Manufacturing Science and Technology, Australia

Email: a.tharumarajah@cmst.csiro.au

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Abstract Future manufacturing requirements envisage a highly distributed and flexible arrangement of manufacturing entities to permit easy (re) configuration and adaptability to changing operating and demand situations. In such a system, the manufacturing entities, like machines, parts, tools and transports will function similar to autonomous wholes co-operating with each other to achieve production goals. Based on the concepts of holonic systems, this paper proposes an architecture that enables the construction of such flexible systems in order to satisfy the future requirements. Application of the architecture is illustrated for a machining cell.

1 INTRODUCTION

A holonic system has the essential attributes of autonomy and co-operation of its entities, called holons [7]. These attributes of the entities endow the system the capabilities to become adaptive to changes in the operating environment whilst making it easier to re-arrange or re-configure the organisation. This concept has been successfully used to propose holonic manufacturing systems (HMS) [10]. It is envisaged that HMSs will be capable of rapid response to changes in customer demand and operational requirements, through constant adaptation of their function and organisation. A holonic shop floor would resemble a community of machine, transport, part and other types of holons that interact with each other to plan, schedule and execute their activities.

Architecture to realise a holonic shop floor would include communication among the manufacturing holons and control of their individual and joint activities. It has to also consider the problem solving organisation and the mechanisms of co-ordination for addressing typical

production optimisation problems that a shop floor faces. The architecture proposed here is comprehensive in addressing these issues. It builds on a few generic types of holons that provide a high degree of self-similarity, which in turn reduces the demands on integrating new components and benefits the quick and easy reconfiguration. Application of this architecture is illustrated for a machining cell.

The paper is organised as follows. Section two discusses the concepts of holonic systems. Section three proposes a definition of holon types suitable for manufacturing. Building on this definition, the next section describes a holonic architecture for a shop-floor environment. Section six illustrates the application of this architecture to a machining cell. This is followed by conclusion.

2 HOLONIC CONCEPT

The concept of holonic systems portray a system being made up of a set of autonomous entities or holons that can co-operate amongst themselves and self-steer their total behaviour. This self-steering quality is one of its abilities to self-organise to cope with changes in its environment either by adapting its behaviour and/or actively re-configuring the arrangement of its constituent parts. But, how does this quality come about in holonic or other similar systems? The answer lies in the connections, interactions, and feedback loops between the parts (i.e. holons) of the system. These parts act in a manner that is mutually accommodating to maintain self-consistency. That is, in one respect the entities act to preserve themselves, but to do so they have to be accommodating, otherwise their very existence as a viable unity may be threatened. These two typical properties are fundamental and are put forward by Koestler [7] as the attributes of autonomy and co-operation of holons.

Koestler defines the systems made up of holons and exhibiting characteristics of self-organisation as holarchies. A holarchy is not confined to a single level, rather it can be a multi-level structure. At each level, though, the members of the holarchy (the members can be holons or holarchies) would have the twin attributes of being autonomous and co-operative. This way, there is no strict hierarchy as is common in organisations, but there exists an invisible boundary that encapsulates and defines the environment in which a set of holons operate. In order to maintain these characteristics, a holarchy defines the basic rules of co-operation for its member holons and thereby limits their autonomy.

3 A BRIEF REVIEW OF LITERATURE

Both single- and multi-level holonic architectures have been proposed. The former is where there is no definition of a holarchy and only a set of specific types of holons and how they co-ordinate their actions are defined. For instance, the specific types may include functional holons such as scheduling, planning, execution and monitoring [1, 8, 5, 6]. In other cases, the holons represent manufacturing entities such as machines and parts, and have embedded functional capabilities to plan and schedule [3, 4]. Co-ordination among the holons can be an in-built function [10] or a separate holon by itself [3, 4, 9].

Constructing a multi-level structure by simply extending a single-level architecture can be difficult without appropriate definitions of holarchies to represent the representing diverse characteristics of a system. To this end, Fletcher and Deen [2] propose a HMS global architecture. In this architecture a Co-ordination Domain provides the mechanism for the holons to work together with other holons on joint tasks. It is task oriented rather than performance oriented. The difference is that the former is for short-term gains while the latter provides for stability and long-term performance optimisation as intended by the definition of a holarchy. Further, purely task-oriented definition often lacks the representational requirements of manufacturing to model capability-based organisational groupings (e.g. a machining cell) as holarchies. Also, it becomes difficult to specialise the implementation of task-oriented holarchy definitions.

The PROSA architecture [12] overcomes this limitation by proposing and building single- and multi-level holonic architectures on four basic types of holons suitable for manufacturing:

- Resource holon: represents a physical entity (like a machine) with procedural knowledge and functions to make allocation decisions and organise co-operation with other holons.
- Product holon: represents a product with the required processing knowledge to assure correct processing.
- Order holon: represents a customer or make-to-stock order, or generally a task that need to be executed.
- Staff holon: represents specialist knowledge for taking decisions, such as an advisory role.

To define multi-level structures, the basic types are used. For instance, holons of a type are clustered together to form one aggregated holon. Also, in other cases such as an Order holon, the architecture proposes exclusivity in ownership of needed resource holons by an order holon to prevent

deadlock situations. The PROSA architecture raises two questions. First is how restrictive a forced assignment of ownership will be on the flexibility of the system. For example, how will an Order holon deal with a situation requiring routing flexibility or to deal with job transfers when disturbances occur. . Secondly is how well it supports temporary membership of holons in a holarchy. Further, a clear definition of holarchy types are notably absent in the proposed architecture and is left to the specifics of implementation.

4 PROPOSED ARCHITECTURE

4.1 Basic entities

The architecture we propose extend the two basic types of entities in a holonic system, namely the holon and the holarchy. To further clarify the definitions of these two types, a holon is differentiated by its atomic nature, i.e. it provides an individual function and cannot be further divided. In contrast, a holarchy provides a societal function in that it functions so as to facilitate the smooth operation of its members.

In order to differentiate between these two types, the holons are aptly named a-Holons to highlight their atomic nature. A holarchy is named as a Co-operation Domain (CD). The definitions of both the a-Holons and CDs are explained below:

4.1.1 a-Holon

The basic features of an a-Holon are:

- It is a communication environment capable of sending and receiving messages to or from other a-Holons or CDs.
- It has information processing and physical processing capabilities where appropriate.
- It can engage in joint decision making activities by co-operating with other a-Holons, such as executing a Contract-net negotiation process.
- It can request and become a member of a CD and where appropriate relinquish its membership.
- An a-Holon, however, has to be a member of at least one CD, its home base.

4.1.2 Co-operation Domain

For practical applications, the invisible boundary of a holarchy can be difficult to construct. Also, while holarchies accommodate only stable associations there may be associations that are temporary. The concept of Co-operation Domain is introduced to deal with these difficulties. It can be

thought of as a mechanism for the holons to initiate a holarchy or an association and its membership and manage the interactions. It would define common rules of engagement and, in essence, provides a closure that encapsulates the interactions among its members and thus acts similar to a whole. The management of the interactions can be left to the a-Holons or to a co-ordinator role.

The basic features of a CD are as follows:

- A CD is a communication environment capable of sending and receiving messages from its members or from other outside CDs or holons.
- Initialises and retains an association or membership among a set of holons. The member holons may request entry or exit from the membership thereby allowing temporary membership.
- Permits multi-level structures to be constructed by allowing definition of CDs as members.
- Facilitates a smooth (and optimised) operation of the association: The facilitator role is specialised according to the implementation of a CD.

In addition, a CD has a shared memory space, similar to a memory table, for storing information that is transparent to all the member holons. This information is placed and deleted by the members only. It serves as a way of providing status information of members and tasks being executed. Where a holon has multiple memberships, it is assumed that it has sufficient information to access the particular shared memory appropriate for the purpose.

4.2 Constructing a holonic structure

A holonic structure is created by first defining individual holons and associating them to a base CD. The base CD acts similar to a home. When dynamic associations are created, a holon that is already a member as defined initially can become a member of the new CD. Multiple memberships can also be defined initially, but only one base CD can be defined for a holon.

By implication, a holon uses its CD's services for communicating with other holons as shown in figure 1. Initially, the architecture specifies the CD and the member holons. This information is recorded in a CD register for address look-up. In this implementation, the CD register is common to all CDs. To keep up-to-date on changes, the contents of a register are communicated to all CDs (if operating in different platforms) when membership details change.

Figure 1: Basic Communication Architecture

5 Demonstration application

The application of the proposed architecture is illustrated for a machining cell shown in figure 2. The cell has four machines capable of producing similar part types. The parts are brought in and taken out of the cell buffer by a gantry transport. Another gantry transport services transportation between the buffer and the machines.

The holonic model of the cell as shown in figure 3 is constructed using the following specialised holons:

- **Machine holon:** It is derived from an a-Holon type. Other than the basic functions of an a-Holon, a Machine holon has capabilities to process parts using the processing information supplied by a part processing database (PPDB as shown in figure 3), entertain calls for proposal from Order holons and schedule the jobs.
- **Order holon:** This too is derived from an a-Holon and assumes the definition of a customer order as defined in PROSA [12]. An Order holon has capabilities to call for proposals from the Machine holons and select a suitable machine for the job.
- **Cell Broker (CBR):** This represents the Co-operation Domain of the machines in the cell. The functions of the broker include managing communication among its members and with other CDs, and job transfer among machines when disruptions or delays are encountered. Also, it

provides rules that limit the bidding freedom of the machines, such as the number of awarded bids a machine can have. Job transfer among machines is made possible by machines periodically interrogating the shared memory managed by the CD. That is, once a machine decides that it cannot fulfil the award conditions, it gives up the job by putting it in the shared memory for others to consider.

- Production Manager (PM): This represents a CD for the Order holons. Its main function is to prioritise the order release into the shop. Other functions such as grouping orders for processing are also contemplated.

Figure 2: Layout of cell

The holonic structure of the cell is defined top-down by first defining the CBR and then creating and associating the Machine holons as members. As alluded to earlier, an a-Holon is at least associated with one CD. A similar approach is taken for the Orders holons by first defining the PM and associating the Order holons as the customer orders arrive.

Figure 3: Holonic architecture of cell

The operation of the holonic system is initiated by the behaviour embedded in the holons. For instance, when the Order holons are first

created they implement an unprovoked action of calling for bids to process the required jobs to execute the customer order. This, in turn, makes the Machine holons that receive the call for proposal message to respond by submitting bids that are subsequently evaluated and a job awarded to a select Machine holon.

Extensions of this architecture are in defining specialised holons for transports and input/output buffers to complete the holonic structure of the cell.

5. CONCLUSION

The holonic architecture proposed here have many advantages. Using the basic a-Holon and CD types both single and multi-level holonic structures can be constructed. It allows stable holarchies to be constructed while permitting the members of such a holarchy to maintain their individual autonomy properties. The CD is defined so as to allow local rules of operation to prevail in holarchies in order to optimise member performance including bidding for jobs and dealing with disturbances. The architecture lends itself to be built progressively and permits flexibility of organisation by allowing changes in CD membership. The communication structure proposed is general enough to be implemented across different platforms.

Currently, the holonic cell architecture illustrated in this paper is being used to develop a holonic manufacturing system of a multi-cell industrial FMS testbed.

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