Web-Centric Diagnosis and Prediction System for Global Manufacturing

Mihaela Ulieru
Electrical & Computer Engg.
The University of Calgary
Alberta, Canada
ulieru@enel.ucalgary.ca
http://isg.enme.ucalgary.ca/

Abstract.

A FIPA-enabled diagnosis and prediction system is proposed for dealing with disturbances in the flow of information and production at al levels of the holonic collaborative enterprise. Built on the power of integrated soft computing technologies the system acts as a proactive agent to continuously update its fuzzy diagnostic model by accessing remote databases found on the sites of the collaborative partners. The web-Centric implementation enables advertisement of the system's services for interested parties inside and outside its area of collaboration. The system provides continuous feed-back to the production planning and operation scheduling at the intra-enterprise level by updating the maintenance schedule according to the fault predictions it perform while evaluating the evolution in time of the machine status. System's capabilities are illustrated on a simple scenario.

1. Introduction: Holonic Enterprise as an Information Ecosystem

In today's economy success depends on the power to collaborate in the global market. To support inter-enterprise collaboration we have developed a new paradigm for global manufacturing: Holonic Enterprise [1]. We are currently working within FIPA (the Foundation of Intelligent Physical Agents) to the development of a standard multi-resolution collaborative architecture that enables production coordination through management of agents at the inter-enterprise, intra-enterprise and resource levels (see: http://www.fipa.org – PD&MF Work Group Link). Based on the latest research results in holonic manufacturing (http://hms.ifw.uni-hannover.de/) and multi-agent systems the developed abstract architecture enables the coordination of global production by maintaining consistency within the flow of information from the order-tracking/supply-chain/e-commerce inter-enterprise collaborative level into each individual organization where the particular work undertaken for the collaboration is to be planned and distributed for production on the available resources. Integrity of the production goals is maintained throughout all levels by replicating the holonic paradigm, Fig. 1 [3] (http://isg.enme.ucalgary.ca). Inter-levels communication is secured by thoroughly defined ontologies. At the inter-enterprise level the focus is on finding partners for collaboration on the topic of interest (e.g. development of a certain new product). Here virtual organizations emerge [2] from the search for the most synergetic suppliers and partners in the collaboration. The architecture enables at this level [3] on-line order tracking and order status reporting as well as order failure notification with possibility of on-line re-configuration of the collaborative cluster for re-solving the problem by including other partners. Once the particular role has been identified for each of the collaborative partners, this information is sent to the immediate lower level and work is coordinated internally within each enterprise via strategic planning and dynamic scheduling of production on the internal departmental resources (sections, shop floor production, etc). The main functions of the architecture at this level are: multi-criteria optimization of production (to ensure maximum efficiency in resource utilization while delivering on-time and with minimum production cost); functional reconfiguration-(re)selecting functional units, (re)assigning their locations, and (re)defining their interconnections (e.g., rerouting around a broken machine, changing the functions of a multi-functional machine). In [4] we have presented the development of a dynamic virtual clustering methodology, Fig. 2, that enables on-line reconfiguration of production in case of unexpected machine breakdown in distributed manufacturing. The methodology is based on fuzzy entropy minimization in the information distributed across the manufacturing system and secures optimal production with available resources at any time. With this ensured the focus is transferred to the machine control level for the effective command of physical machines. At this level the architecture aims to enable agile manufacturing through the deployment of self-reconfiguring, intelligent, distributed automation elements. The main issues addressed here are: development of ontologies for manufacturing process-task-operation-function block mapping (e.g., PSL); use of IEC 61499 as an agent framework; uniform use of XML for transfer syntaxes (e.g., ACL, content

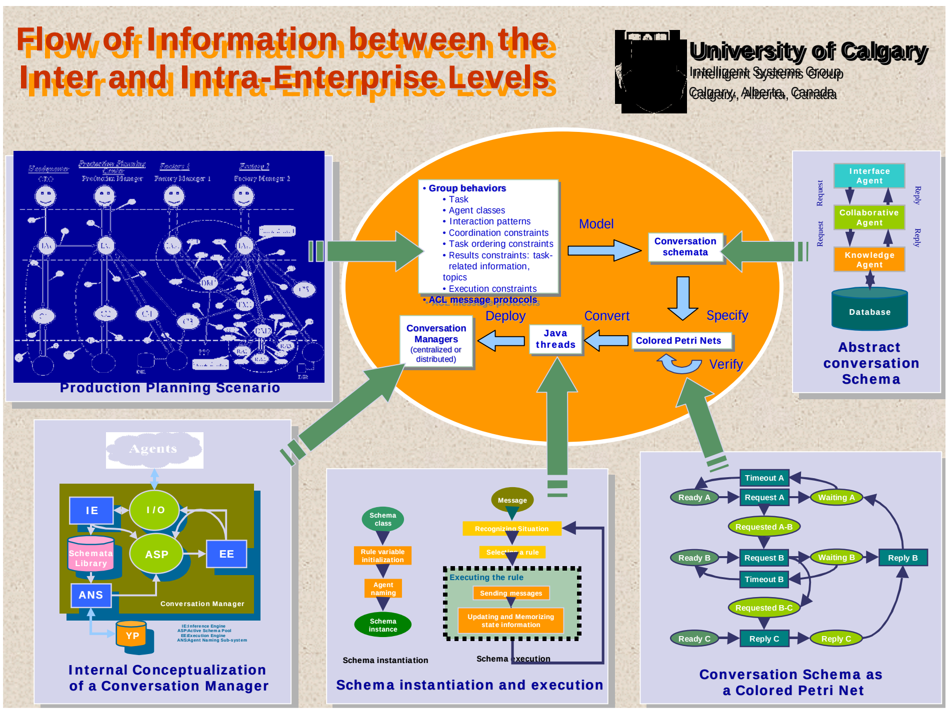


Fig. 1: Holonic Enterprise as Information Ecosystem

languages, ontologies). For details on the holonic control of intelligent machines please see http://www.holobloc.com/stds/fipa/hcd/

2. Requirements on Fault Diagnosis and Prediction for the Holonic Enterprise

To deal with unexpected disturbances in the flow of collaborative production across the three levels one needs to ensure mechanisms for fault detection and recovery as well as prevention by anticipating eventual problems that may occur. These mechanisms are enabled by the holonic properties of the collaborative architecture that allows information access and data collection throughout the heterarchy (Figs 1,2) at any time. Mobility and flexibility of the constituent intelligent software agents that manage the information transfer, backed by strong security management at each intra-enterprise gate permit continuous status update for system diagnosis purposes at all levels.

2.1. Inter-Enterprise Level

Requirements here are dictated by the desire to cope smoothly with the eventual disturbances that may affect the synergetic collaborative cluster of enterprises. The main need is for decision support when for example an order cannot be fulfilled in due time by the partners that committed to it, such that other collaborative partners can be found "on the spot" to take over that part. Repositories and yellow page agents based on the broker architectural pattern enable this through our architecture as these agents are endowed with strong decision-making capabilities based on the latest advances in distributed artificial intelligence [3].

2.2. Intra-Enterprise Level

Here the main requirement is for on-line production re-configuration. This may be demanded in by two cases:

- while a machine breaks down unexpectedly (in this case production has to be re-distributed on the available resources)

- while a high-priority order has been received and has to be planned on the available resources (in this case the whole production is dynamically re-scheduled on the available resources).

We have addressed production reconfiguration for machine breakdown in detail in [4], while dynamic scheduling is dealt with in [1]. Mediator-based architectural structure, Fig. 3, enables dynamic clustering of machines to be automatically generated according to the ever-changing needs for reconfiguration in the production holarchy. Meta-agents [5] embedding optimization strategies play the

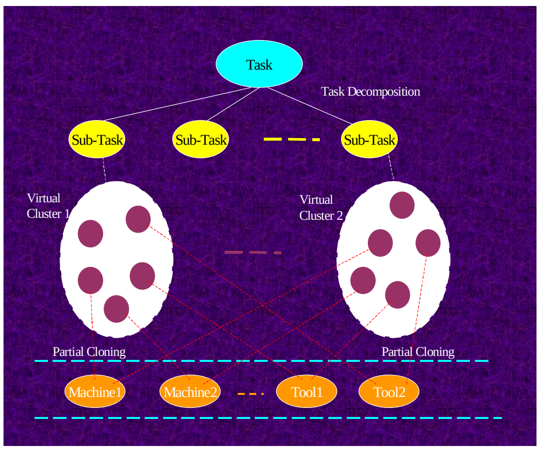


Fig. 2: Virtual clustering mechanism with machine cloning into software agents

role of mediators that decide on the clustering configuration. Once this mechanism has been secured the next step is to provide the right control signals to the appropriate machine.

This is done via holonic control at the machine level.

2.3. Machine Level

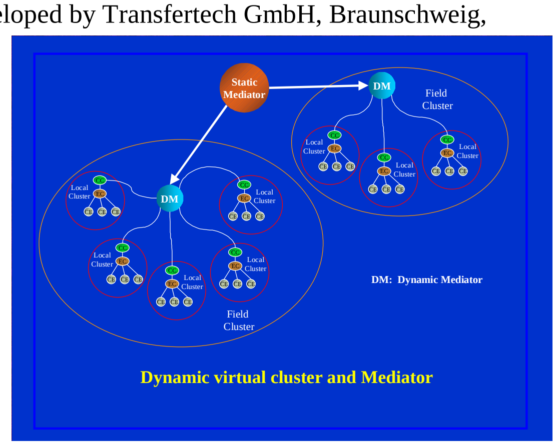
Requirements here are influenced by the physical functionality of each particular machine. Enough diagnostic knowledge [6] has to be available or made available by exploiting the web-centric high accessibility to data ensured by the distributed architecture. Breakdown prediction algorithms should ensure for maintainability actions in due time as much as possible. Early fault detection [7] should be ensured via signal processing and residual generation. Each machine shall possess its own diagnostic system – working as an agent at the logical level that clones the machine for interaction with the distributed software architecture, Fig. 5 [3]. The system shall be open to interact with the other 'diagnostic agents' monitoring the status of the other machines in the cluster to be able to provide as well as to collect knowledge useful in making on-line diagnostic decisions. In the sequel the implementation details of the machine diagnosis level are clarified.

3. Integrated Soft Computing Techniques for Fault Diagnosis and Prediction

Each diagnostic agent possesses a preliminary rule base on which fuzzy reasoning is enabled [6]. Using novel methodologies for extraction of fuzzy models from data [8] the rule base is continually updated from diagnostic repositories dynamically accessed and found via the web connections. New knowledge is constantly mined by each diagnostic agent using the holonic architecture's accessibility to information via the web. At the same time the existing knowledge base is continually tuned by a neural network that 'learns' from every new diagnostic experience as well as from each newly accessed data repository. Using evolutionary strategies the diagnostic agent can predict how the status of the machine that it represents will evolve, eventually towards a fault – and by this predictive maintenance plans can be made in due time for avoiding break-down. In what follows we present

Fig. 3: Mediator-based virtual clustering mechanism

the development of the intelligent diagnostic agents, by integrating three commercial software packages developed by Transfertech GmbH, Braunschweig,



Germany (http://www.transfertech.de), Fig. 4

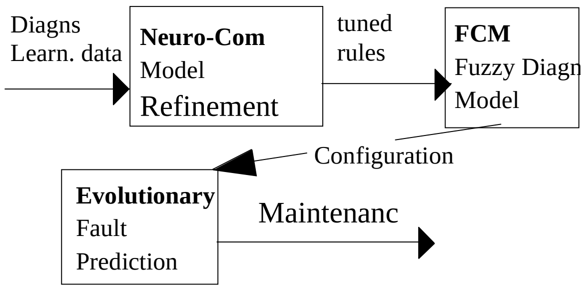


Fig. 4: Integrated soft computing techniques for diagnosis and prediction

(a) **Development of a preliminary fuzzy diagnostic model** using the Fuzzy Control Manager package. The model consists of fuzzy IF-THEN rules encapsulating several behavioral characteristics of the machine. The model is by far not complete as diagnostic knowledge is not readily available especially for newly developed technologies and the corresponding manufacturing machines.

(b) **Continuous Diagnostic Knowledge refinement**. The preliminary fuzzy diagnostic knowledge base is backed by a neural network (here implemented by the Neuro-Com Package) capable to learn new rules from diagnostic data repositories, once they become available and as well from every new diagnosis done on the respective machine [9]. For this purpose the fuzzy classification extension of Neuro-Com provided by Transfertech is used, in a similar way as exposed in [10]. The integration of Neuro-Com with Fuzzy Control Manager results in a **dynamic diagnostic system** that continuously updates its knowledge as its domain of data accessibility increases. Here the proactivity endowed by the agent paradigm is exploited to continuously search for new diagnostic information throughout the collaborative chain as well as for new collaborative partners that have such knowledge or data based on which such knowledge can be extracted by the neural system and fed into the fuzzy diagnostic model.

(c) **Fault prediction**. Based on the diagnostic result the evolution of the machine status can be determined by using evolution strategies [11], [12]. For this the output of the diagnostic system is fed into the Evolutionary Optimizer package provided by Transfertech. The probability of failure is obtained by automatic selection of the most probable fault to develop given the machine parameters preprocessed by the diagnostic system.

The diagnostic agent, based on the provided diagnosis as well on the available machine parameters, automatically configures the software.

4. How the Web-Centric Diagnostic System Works

To clearly grasp the high adaptability and availability of the proposed machine diagnostic solution within the context of the collaborative architecture we will present in what follows a simple scenario on which we will explain all the capacities of our approach.

Consider a cluster of enterprises that collaborate to manufacture a product (Fig. 1). The task has been split among the partners at the supply chain level and orders have been distributed within each enterprise among departments and sections with task allocation on each machine in the production chain at the shop-floor level, Fig. 2. At every moment the diagnostic system evaluates the chance for machine breakdown for each machine and updates the maintenance schedule accordingly. Production is rescheduled automatically [14] by the scheduling agents, Fig. 5 based on the information from the maintenance schedule, to avoid production interruptions. This adds a predictive component to the dynamic scheduling already implemented in our approach [1], [3] at the intra-enterprise level. The associated diagnostic agent continuously inquires about more data to complete its knowledge base. Every new collaborative partner that joins the global production cluster is demanded to provide access to its repository of production machines from which the diagnostic agents extract the necessary knowledge, and in turn provide knowledge available upon request from the agents working on the partner's site. At the same time the diagnostic agents advertise their services throughout the partnership domain such that other systems that joined the cluster can improve their predictive scheduling capabilities using the available knowledge.

5. Conclusions

The proposed diagnostic agent is suitable for a wide range of applications including the medical domain. We are currently working to the extension of an already proposed glaucoma diagnosis and prediction system [15] with web-centric capabilities that would enable direct accessibility by the eye surgeon from the operating room in case he needs advice while encountering a new situation. At the same time the

surgeon can introduce data into the system via speech input when diagnosing an unusual condition.
Current work undergoes for the integration of the diagnostic agents within the holonic control strategy implemented by the function blocks.

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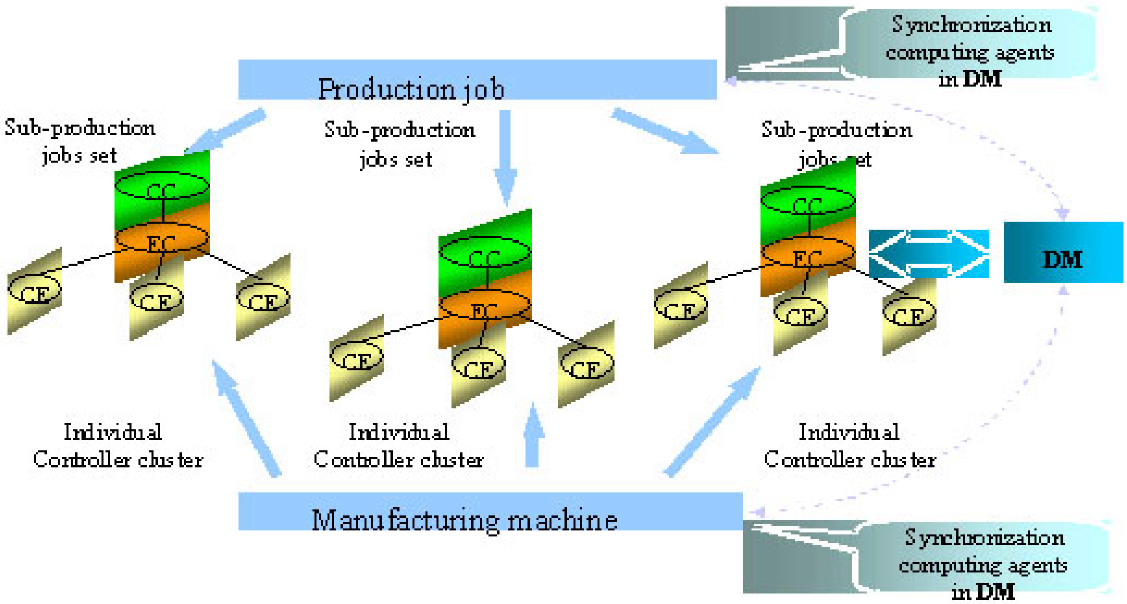

Fig. 5: Scheduling and dispatching of multiple jobs on individual machines via dynamic mediators