AN AGENT-BASED DISTURBANCE HANDLING ARCHITECTURE IN MANUFACTURING CONTROL

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Abstract: In industrial environments, disturbance handling is a major issue in reconfigurable manufacturing control systems, supporting the fast, effective and efficient response to the occurrence of unexpected disturbances. Those disturbances usually degrade the performance of the system, causing the loss of productivity and business opportunities, which are crucial roles to achieve competitiveness. This paper proposes an agent-based disturbance handling architecture that distributes the disturbance handling functions by several autonomous control units and considers the main types of shop floor disturbances that have impact at planning and scheduling level. The proposed architecture also integrates a prediction component, transforming the traditional “fail and recover” practices into “predict and prevent” practices.

1. INTRODUCTION

Manufacturing systems are notorious for their complexity and unpredictability, exhibiting complicated stochastic and chaotic dynamics, often non-linear. The occurrence of unexpected disturbances leads to deviations from the initial and optimized production plans, and usually degrades the performance of the system. Possible consequences from the occurrence of unexpected disturbances are the loss of productivity and business opportunities, which are crucial roles to achieve competitiveness. This complex and non-linear environment is amplified with the current environmental pressures and market demands, which asks for highly customized products with high quality at lower costs and with short deliver time.

This creates the need to develop collaborative, agile and re-configurable manufacturing control systems, with disturbance handling systems playing a critical role to support the proper adaptation and response to the environmental volatility. Multi-agent systems paradigm seems suitable to develop this new class of intelligent and re-configurable manufacturing control systems [1-2], mainly because they present decentralization of control over distributed structures and inherent capabilities to adapt to emergence without external intervention, improving their capability to respond promptly and correctly to change. Several manufacturing control systems using multi-agent system approach and addressing the above referred requirements were reported in the literature, e.g. [2; 3]. Of particular relevance for the future developments of the work being presented here is the work on Evolvable Assembly Systems (EPS) [4], which has its genesis on a PhD Thesis [5]. The main idea behind EPS is that a manufacturing system is a composition of modular entities that can be plugged and unplugged according to the requirements. An EPS is created according to a set of available modules that can be plugged in order to create a complex entity (the system), in the same way it is possible to create LEGO® constructions based on a finite set of reusable components.

The work on EPS is a good framework for the new generations of control systems in the sense that it supports re-configurability and agility quite naturally. However, in terms of disturbance handling, even this new generation of control systems is purely reactive, only applying corrective procedures when the disturbance occurs. In fact, traditionally, a disturbance handling mechanism comprises mainly the detection of the disturbance, the elaboration of a diagnosis to perform a correct and effective identification of the disturbance, and the recovery, taking corrective actions to minimize the effects of the disturbance. Preventive maintenance are often used in manufacturing systems domain (see e.g. [6-7]), but these types of mechanisms only considers one type of disturbance at shop floor level, the machine failure. A more generic disturbance handling system is then required, considering other kind of shop floor disturbances, such as delays and rush orders, that can also cause significant impact at planning and scheduling level [9].

The implementation of predictive procedures is also required, to forecast future disturbance occurrences based in the historical data, allowing planning in advance their occurrence, contributing to increase the system predictability. The development of intelligent and predictive disturbance handling systems, as part of the manufacturing control system, are yet an open subject and even in the predictive maintenance a generic and scalable prognostic methodology is missing since the developed approaches are application or equipment specific [8].

Motivated by these facts, this paper introduces an agent-based approach to disturbance handling in manufacturing control systems that:

- Instead of a centralized approach, it is based in multi-agent systems principles.
- Considers intelligent mechanisms embedded in autonomous and distributed agents, to support the fast and effective execution of detection, diagnosis and recover tasks.
- Rather than the traditional detection-recover mechanisms to face the occurrence of unexpected shop floor disturbances, it considers a prediction component.

The main point here is that disturbance handling and/or fault maintenance can only be correctly achieved if some activities are carried out locally at each individual module, which is only effective if modules are intelligent and pluggable. Saying it in another way, the basic principle in order to create an advanced control architecture able to efficiently deal with disturbances and maintenance starts with the definition of a system in which its basic building blocks are intelligent in order to supply the necessary information about themselves as well as providing some self-healing capabilities. Therefore the work being presented here relies on these premised of EPS: intelligent modules that can be plugged or unplugged on fly without reprogramming.

The paper is organized as follows: first, Section 2 describes the agent-based disturbance handling architecture for manufacturing control. Section 3 discusses the intelligent mechanisms embedded in autonomous agents for the recovery from the machine breakdowns, and Section 4 discusses the mechanisms to predict and to plan in advance the future disturbance occurrences. Finally, section 5 rounds up the paper with conclusions.

2. AGENT-BASED DISTURBANCE HANDLING ARCHITECTURE

Multi-agent systems suggests the definition of distributed control based on autonomous agents that account for the realization of efficient, flexible and robust overall plant control, and consequently the disturbance handling component.

Exploiting this distributed nature, the proposed disturbance handling architecture is built upon a set of autonomous and cooperative agents, representing manufacturing components and organized in a distributed structure. Such approach allows the development of complex constructions using simple autonomous agents, as functional blocks like LEGO® components, increasing also the facility of making new items by recombining standard objects, as it was defined for the EPS. In different contexts, scientists use the same concept to make complex objects, such as molecules, from simple objects [10].

It is important to clarify now that the work being presented here is mainly focused on individual agents and not yet on the global interactions between the agents. In fact the ultimate goal is to be concentrated at the interaction's level, since this corresponds to the system. Please be reminded that a system is a composition of intelligent devices (agents), and therefore only when the interactions among the agents are handled, it is possible to talk about handling disturbances and maintenance at system level. The important point to understand now is that it is not possible to consider the system level without first defining an architecture to handle disturbances and maintenance aspects at the individual agents. In fact, the architecture of the basic individual agents will influence the way the system will be handled at global level, and consequently the individual architecture is biased by what is planned to be achieved at the global level. The individual architecture being proposed here is defined taking into consideration that the handling at the system level (interactions) will be based on an architecture that will be inspired by the theories of complexity theory, chaos, and distributed intelligence or swarm. Aspects such as emergence and self-organization will be fundamental at system level.

2.1 Architecture's Components

In the proposed community of agents, each individual agent has its own objectives, skills and knowledge and behaves according to a small number of simple local rules or laws, which constitutes their behavioral repertoire. Additionally, an agent does not perform all tasks, but rather specializes in a set of tasks according to the manufacturing component it represents. Three different types of agents are identified, as illustrated in Fig. 1: task, resource and maintenance agents.

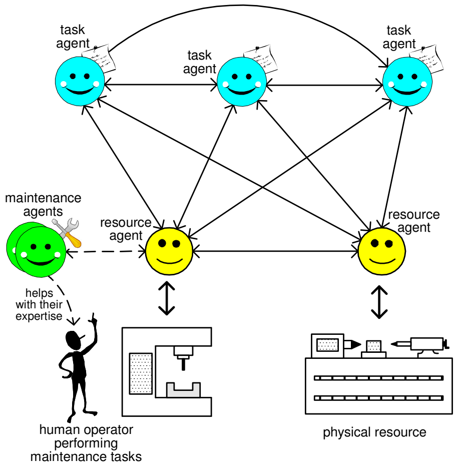

Fig. 1 – Agent-based Disturbance Handling Architecture

Task agents represent the production orders launched to the shop floor to execute products and contain the dynamic information about the production order. Resource agents represent the physical shop floor resources, such as operators, robots and numerical control machines, managing their behaviors according to the resource goals and skills [2].

The architecture considers also intelligent maintenance agents to assist human operators during the execution of recover and maintenance operations, providing useful information to the operators that will physically execute them. These intelligent mechanisms, embedded in maintenance agents, allow faster recover processes and consequently the improvement of the system productivity, and are based in artificial intelligence techniques, such as expert systems and virtual reality tools. Maintenance agents can be seen as a specialization of the resource agents, but due to the important role they play in the disturbance handling architecture, a special attention is devoted to explain their behavior.

2.2 Agent's Behaviors

In the proposed architecture the disturbance handling is achieved in a distributed manner. In fact, each autonomous and cooperative agent, both those which have tasks to be executed and those that represent the manufacturing resources, has embedded a local disturbance handling system, being able to detect and recover autonomously from disturbance, and also to predict the occurrence of the next disturbance, contributing to increase the system performance.

For this purpose, an architecture for the disturbance handling system embedded in individual control units is then required, specifying mechanisms to integrate the detection, diagnosis, recover and prediction components, as well the way they interact. The architecture of the disturbance handling mechanism embedded in each agent is illustrated in Fig. 2.

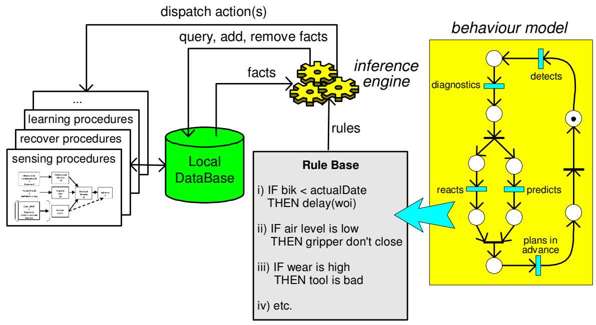

Fig. 2 – Local Disturbance Handling Architecture

According to the behavior model for the disturbance handling, represented in Fig. 2 using a Petri net, the monitoring function is permanently acquiring information and performing a comparison with the existing plans. If a deviation of the expected behavior is detected, either a disturbance at shop floor or a forecasted event that didn't occur, a diagnosis procedure is triggered. The intelligent mechanisms, embedded in each agent, elaborate a diagnostic in an automatic way, pointing out the possible actions to be executed to recover from the disturbance.

At this stage, the disturbance handling behavior evolves to execute two different actions in parallel: i) implementing procedures to react to the occurrence of the disturbance, by applying distinct recover mechanisms according to the type of disturbance, e.g. delays, machine failure or rush orders [9], and ii) predicting the occurrence of future disturbances by applying a proper forecasting algorithm according to the type of disturbance occurred. After the execution of these two actions, the system elaborates an adjustment in the plan, considering in advance the occurrence of the future disturbances, taking as input the forecasted values.

The described individual disturbance handling behavior model is translated into a set of few and simple rules, customized to each type of agent. The introduction of learning capabilities in each individual agent will provide the ability to improve dynamically its performance, performing better its disturbance handling function in the future, namely reacting better to disturbances, or even to decide to classify some disturbance occurrence patterns as normal behavior in future production plans.

2.3 Emerging from Agents Interactions

The overall behavior of the system emerges from the large number of agents, and their coupled interactions with each other and the environment.

Being the interactions between the agents non-linear, the overall behavior is greater than the sum of the behavior of the individual agents. These models allow the generation of incredibly complex systems and replace an emphasis on control, preprogramming and centralization with designs featuring autonomy, emergence and distributing functioning [11].

The achievement of this overall disturbance handling system requires a strong effort in designing cooperation mechanisms to support the combination of the local disturbance handling behaviors.

In the next sections, two disturbance handling architecture functions will be described, namely the recover from machine failures and the prediction of future disturbance occurrences. Here, only the mechanisms embedded in individual agents will be discussed as it was already mentioned.

3. INTELLIGENT BEHAVIOR TO SUPPORT MACHINE RECOVERY

The mechanisms embedded in each autonomous agent to support the recovery from a disturbance are mainly dependent of the type of the shop floor disturbance. In this section, the focus is the mechanisms that support the machine breakdown.

The occurrence of machine breakdowns implies disturbances at two distinct levels: at the machine level, by trying to recover physically it, and at the control level by trying to find alternative solutions aiming to minimize the impact of the disturbance. The actors and the actions performed in these two levels are different and distinguish. If at control level the solution is achieved by the interaction between task and resource agents, at the machine level, the maintenance agents assume a critical role.

When a machine breakdown is detected, the resource agent requests a recovering operation, i.e. a corrective maintenance operation, to one of the available maintenance agents in the system. The resource agent provides the results achieved by the diagnostic procedure to the maintenance agent, namely the possible cause(s) of the problem and the possible list of actions that should be executed to recover physically the machine, contributing to the fast recovery of the machine.

The physical execution of recover and maintenance operations, important in a disturbance handling system, are normally complex and requires high-level of skills and expertise by the human operators to execute those operations in short time, with the necessary quality. The use of new information technologies, such as expert systems and decision support systems, will facilitate the execution of the recover and maintenance operations by providing, e.g. information about how to proceed during the operation execution.

The maintenance agents will support human operators during the physical execution of recover and maintenance operations, playing the role of an expert advisor helping the human operator. They combine the provided diagnostic report with their previous experience in analogous situations and pre-designed actions for each failure type, to determine an action plan to be carry out during the recover and maintenance operations, as illustrated in Fig. 3.

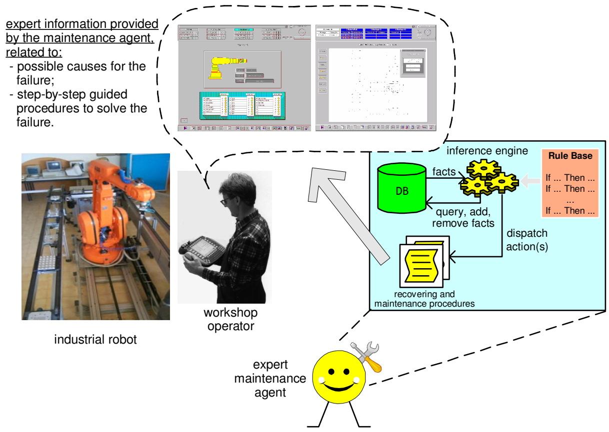

Fig. 3 – Intelligent Agents Supporting Human Operators during the Recovering Tasks

Human operators, using for example head mounted displays (HMD) or PDAs, can see, among others, the steps to be followed during the operation, the estimated time to perform the task and the list of materials needed. The use of virtual reality tools will provide an easy interface between the intelligent mechanisms embedded in the maintenance agents and the human operators.

Since the physical resource will be probability out-of-service for a long period of time, the resource agent searches for the operations that are planned to be executed during the expected downtime, and then cancel the actual allocation of these operations, notifying the task agents. For this purpose, the resource agent estimates the recovery time that defines the temporal window where operations planned to be executed by the resource must be returned to the task agent. During the machine downtime, the resource agent only accepts the allocation of new operations if they can be performed outside the estimated recovery time interval.

In presence of a machine breakdown, the task agent can take two different actions: i) if the part is destroyed, the task agent re-allocates from the beginning all operations belonging to the production order, and ii) if the machine became unavailable, the task agent re-schedules the returned operations, which can lead to delays in the posterior operations, requiring an adjustment of the temporal window to execute each operation. Thus, in both previous cases, a re-scheduling is performed using a distributed resource allocation schema, e.g. using a Contract Net -based protocol with direct interaction between resource and task agents [12], which can consider the information obtained during previous resource allocation processes.

4. PREDICTION OF FUTURE DISTURBANCES

The improvement of disturbance handling systems by planning the production in advance requires the existence of a predictive mechanism, which forecasts the occurrence of future disturbances by understanding the gathered data to find hidden patterns, as illustrated in Fig. 4. With the increase of predictability, the disturbances left to be real disturbances and became normal situations, since it is possible to plan their occurrence instead of simple reacting to their occurrence.

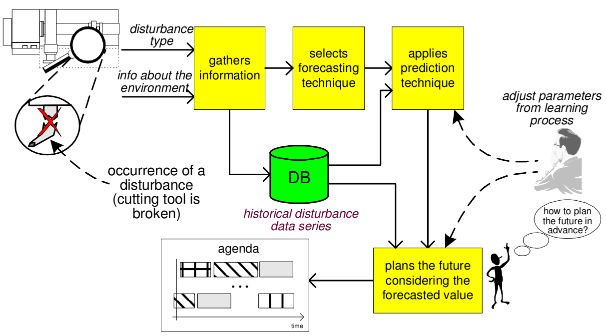

Fig. 4 – Prediction Mechanism to Support the Planning of the Future

4.1 Predicting from Disturbance Patterns

Forecasting is not a simple and easy task, being a challenge issue in manufacturing control, mainly due to its importance to support the planning process and to the complexity it presents. The forecasting process is based in the following main assumptions: i) any behavior of the time series observed in the past will repeat itself in the future, ii) there is a totally random fluctuation that could not be reasonably eliminated but the entire series is not completely random, and iii) if only a sub-set of the time series is considered, the forecasted value is not the correct one.

In manufacturing systems the forecasting of future disturbances is normally done by calculating the Mean Time Between Failures (MTBF) parameter, that provides the indication of the mean time a machine is operational between two consecutive failures. This method estimates the time to failure in a series of observations, considering only one type of disturbance at shop floor level: the machine failure. However, other kind of shop floor disturbances, such as delays and rush orders, can cause significant impact at planning and scheduling level and should be considered. For this purpose more appropriate forecasting techniques should be used, probably one for each type of disturbance, since each one may present different models and patterns.

Moving average and exponential smoothing are two similar statistical methods that address the previous observation. In spite of being fast in computation, the statistical mathematical treatment associated to the previous methods may lead to unsatisfactory results, since the objective is to find patterns in the historic events and not only an average [9]. This requires the use of more complex treatments that do not simple memorize the incoming information but understand and interpret the information supplied by the environment [12]. For this purpose, the recognition of patterns from the historical disturbance data can be performed, for example, using neural networks and clustering analysis.

A pertinent question is then related to the selection of the technique(s) that better fits the characteristics of each shop floor disturbance. Unfortunately, this selection is not an easy job, being the choice of the method dependent of several factors, such as the type of shop floor disturbance and the capability of the prediction method to forecast the next value in a reasonable time. If the prediction method has a small error but takes too much time to predict a value, some events can occur between predictions, degrading the efficiency of the mechanism. Thus, the selection of a technique should be a compromise that takes in consideration simultaneously the response to achieve a forecast value and the frequency of occurrence of the disturbance [9].

4.2 Planning in Advance the Disturbance Occurrences

Using the predicted value, the system plans in advance the occurrence of the next disturbance, minimizing its impact when it really occurs. In fact, if the system will consider that some time after the last occurrence, a similar disturbance will happen, the system can be prepared when the disturbance appears. The set of actions to be implemented is naturally dependent of the type of disturbance, since each one presents different features.

In case of machine failures, the system may plan preventive maintenance operations, avoiding the future occurrence of the predicted disturbance. Thus, the corrective maintenance, which implies to stop the machine and in certain situations to stop the whole production system, is transformed in preventive maintenance operations, performed according to the production convenience.

For another types of disturbance, such as the rush order, the agent-based control system can consider short periods of empty capacity in the schedule, i.e. virtual production orders, planned according to the forecasted occurrence of the disturbance. The empty capacity interval is estimated taking in consideration the average value of the previous recovery time for the same disturbance type.

During the execution of the production plan, elaborated in advance and considering the forecasted values, two different scenarios can occur: i) the predicted disturbance occurs and small modifications are required in the schedule, since the disturbance was already predicted, or ii) the forecasted disturbance does not occur, being this situation treated as the occurrence of a new disturbance.

A bad prediction leads normally to a new disturbance occurrence: since the occurrence of the disturbance was planned and it didn't occur, a deviation from the initial plan appears. Since the prediction can fail, it is necessary to introduce mechanisms to evaluate the prediction decision, adjusting, if necessary, the parameters of the prediction mechanism. For example, if the maintenance team verifies that the machine is in good state during the preventive maintenance operation, the prediction value for the occurrence of a machine failure should be increased. The introduction of learning mechanisms, allowing the agent to learn from its own experience, is crucial to achieve a dynamic improvement of the system behavior facing the possible volatility and hidden patterns of the disturbance occurrence.

A pertinent question is related to those disturbances that occur slightly after the predicted time: they may be treated as normal disturbances requiring the trigger of the entire disturbance handling process.

5. CONCLUSIONS

The dynamic, volatile and often chaotic environment associated to industrial manufacturing systems render the disturbance handling systems a key role in the development of re-configurable manufacturing control systems. In these circumstances, several related topics to disturbance handling should be addressed: the disturbance may be detected as soon as possible, the reaction should be as fast as possible and, if possible, the system should anticipate the occurrence of those disturbances. This requires the introduction of some emergent concepts and technologies, such as multi-agent systems, virtual reality and predictive methods.

The paper introduces an agent-based disturbance handling architecture for manufacturing control, which based in the distribution nature that multi-agent systems suggest, distributes the disturbance handling functions, i.e. detection, diagnosis and recover, by several agents. It also considers the main types of shop floor disturbances that have impact at planning and scheduling level. An example of intelligent mechanisms provided by the architecture is the introduction of intelligent agents to support human operators during the physical execution of recover and maintenance operations, playing the role of expert advisors helping the human operator. The proposed architecture also integrates a prediction component that tries to predict the occurrence of the next disturbance, allowing planning in advance its occurrence, minimizing its impact when it really occurs.

As future work, mechanisms covering all disturbance handling functions will be designed to be embedded in individual agents. The emergence of the overall system from the interactions among individual agents will need special attention.

REFERENCES

[1] Marik, V. and McFarlane, D., “Industrial Adoption of Agent-Based Technologies”, IEEE Intelligent Systems, vol. 20, n.1, pp. 27-35, 2005.
[2] Leitão, P., and Restivo, F., “ADACOR: A Holonic Architecture for Agile and Adaptive Manufacturing Control”, Computers in Industry, vol. 57, nº 2, pp. 121-130, 2006.
[3] Babiceanu, R. and Chen, F., “Development and Applications of Holonic Manufacturing Systems: a Survey”, Journal of Intelligent Manufacturing, nº 17, pp. 111-131, 2006.
[4] Onori, M., Barata, J. and Frei, R., "Evolvable Assembly Systems Basic Principles", Information Technology for Balanced Manufacturing Systems, vol. 220, W. Shen, Ed, Springer, pp. 317-328, 2006.
[5] Barata, J., “Coalition Based Approach for Shop Floor Agility”, Amadora - Lisboa: Edições Orion, 2005.
[6] Yuniarto, M. and Labib, A., “Fuzzy Adaptive Preventive Maintenance in a Manufacturing Control Systems: A Step Towards Self-maintenance”, International Journal of Production Research, vol. 44, nº 1, pp. 159-180, 2006.
[7] Iung, B. and Morel, G., “Issues and Trends Towards Intelligent Maintenance Integrated within the Enterprise”, 2nd IFAC Conference on Management and Control of Production and Logistics, 2000.
[8] Lee, J., Qiu, H., Ni, J. and Djurdjanovic, D., “Infotronics Technologies and Predictive Tools for Next-Generation Maintenance Systems”, Proceedings of 11th IFAC Symposium on Information Control Problems in Manufacturing, Brazil, 2004.
[9] Leitão, P. and Barbosa, J., “Disturbance Detection, Recover and Prediction in Holonic Manufacturing Control”, Proceedings of the IEEE Workshop on Distributed Intelligent Systems, pp. 133-138, 2006.
[10] Holland, J., “Emergence: From Chaos to Order”, Oxford University Press, 2000.
[11] Bonabeau, E., Dorigo, M., and Theraulaz, G., “Swarm Intelligence: From Natural to Artificial Systems”, Oxford University Press, 1999.
[12] Leitão, P., “An Agile and Adaptive Holonic Architecture for Manufacturing Control”, PhD Thesis, University of Porto, 2004.