Extending ANEMONA with NDT phases

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Abstract

A reliable maintenance system is critical to maintain an acceptable level of profit and competition. One of those techniques that are gaining a lot of interest in the manufacturing field is Non-Destructive Testing (NDT). In this work we propose an approach to integrate NDT into the development process of intelligent manufacturing systems. We propose an extension of ANEMONA, a multi-agent based method for engineering intelligent manufacturing systems, in order to integrate and take into account NDT for maintenance during the development process. With the proposed approach the intelligent manufacturing system is developed specifying all its constituent entities in terms of intelligent behavior and cooperation interactions, together with the activation planning of NDT maintenance activities for all the resource agents of the system that requires it.

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1. Introduction

The management of maintenance activities extremely affects the useful life of the equipment, product quality, direct costs of maintenance and consequently production costs. Thus, a reliable maintenance system is critical to maintain an acceptable level of profit and competition. The set of maintenance activities can vary from, for example, human visual inspection to automated operations in which sophisticated machines and or processes are involved. One of those techniques that are gaining a lot of interest in the manufacturing field is Non-Destructive Testing (NDT). NDT is the branch of engineering concerned with all methods of detecting and evaluating flaws in materials. Flaws can affect the serviceability of the material or structure, so NDT is important in guaranteeing safe operation as well as quality control and assessing plant life. The flaws may be cracks or inclusions in welds and castings, or variations in structural properties that can lead to loss of strength or failure in service.

Non-destructive Testing is one part of the function of Quality Control and is complementary to other long established methods. By definition non-destructive testing is the testing of materials, for surface or internal flaws or metallurgical condition, without interfering in any way with the integrity of the material or its suitability for service.

Whilst being a high technology concept, evolution of the equipment has made it robust enough for application in any industrial environment at any stage of manufacture - from steel making to site inspection of components already in service. A certain degree of skill is required to apply the techniques properly in order to obtain the maximum amount of information concerning the product, with consequent feedback back to the production facility.

An important aspect in maintenance operation for manufacturing systems is timing. Related to timing is how to integrate maintenance operation in the whole manufacturing system. We believe that such integration must be dealt with during the analysis and design of the system instead of delaying it to the operation stage.

Integration of maintenance into manufacturing organization can be partitioned into "hard integration" and "soft integration" variables. The "hard" issues deal with
integration supported by technology and computers. "Soft" integration, on the other hand, deals with human and work organizational integration issues. The two integration variables are closely related to the prevention variable, and are considered important enablers for effective realization of preventive policies [1]. Integration must facilitate the bi-directional flow of data and information into the decision-making and planning process at all levels. This reaches from business systems right down to sensor level.

Hard maintenance integration issues deal with CMMS (Computerized Maintenance Management System) of the maintenance, repair and operating supplies store and scheduling of maintenance work, condition monitoring technologies, built-in test equipment, databases with reliability data on electronic and mechanical components, and decision support. On the other hand, soft integration issues of maintenance deal with the structure and the actors in the organization. New technology allows plants to have fewer humans directly participating in the physical manufacturing processes.

In this work we propose an approach to integrate NDT into the development process of intelligent manufacturing systems. We propose an extension of ANEMONA [2], a multi-agent based method for engineering intelligent manufacturing systems, in order to integrate and take into account NDT for maintenance during the development process.

2. Intelligent Manufacturing Systems and ANEMONA

The manufacturer's success is no more measured by their ability to cost-effectively produce a single product, success now seems to be measured in terms of flexibility, agility and versatility [3]. In order to survive, manufacturing systems need to adapt themselves at an ever-increasing pace to incorporate new technology, new products, new organizational structures, etc.

The above trends have motivated researchers in academia and industry to create and exploit new production paradigms on the basis of autonomy and co-operation because both concepts are necessary to create flexible behavior and thus to adapt to the changing production conditions. Such technologies provide a natural way to overcome such problems, and to design and implement distributed intelligent manufacturing environments [3]. In the past twenty years, researchers have been applying techniques from Artificial Intelligence to many problems in manufacturing systems. For a large literature review of these applications see [3]. Distributed intelligent manufacturing systems, are based on multiagent system (MAS) technology [4]. MAS studies the coordination of intelligent behavior among a group of (possibly preexisting) agents. An agent is an autonomous and flexible computational system, which is able to act in the environment [4]. Today MAS is a very active area of research and is beginning to see commercial and industrial applications.

ANEMONA [2] is a MAS methodology for Intelligent Manufacturing Systems analysis and design. It integrates features from Intelligent Manufacturing Systems, MAS and Enterprise Modeling techniques [5,6].

In ANEMONA, the manufacturing system is specified, by dividing it into more specific characteristics that form different views of the system. The overall idea is to construct the Intelligent Manufacturing System specifying its components and the relationship among them. Every component is called agent/holon, and can represent a: product, resource, work order, and a staff entity with expert high-level knowledge such as scheduling, management, planning, etc. In this way the entire manufacturing system can be seen as a community of different type of agents that interact in order to get some product or catalog of products produced.

ANEMONA has five views, or models [7,8]. The agent model is concerned with the functionality of each agent: responsibilities and capabilities. The organization model describes how system components (agents, roles, resources, and applications) are grouped together. The interaction model addresses the exchange of information or requests between agents. This is a key model because in it the different cooperation domains required to model the dynamic operation of a manufacturing system is specified. The environment model defines the non-autonomous entities with which the agents interact. The task/goal model describes relationships among goals and tasks, goal structures, and task structures.

![Fig. 1 ANEMONA development process](image)

In Fig. 1 we can see the development stages of ANEMONA. The first stage, System Requirement Analysis and the second stage Holon Identification and Specification define the analysis phase. The aim of the analysis phase is to provide high-level HMS specifications from the problem Requirements, which are specified with the help of the problem domain experts and which can be updated at any stage of the development. The analysis adopts a top-down recursive approach. One advantage of a recursive analysis is that its results, i.e. the Analysis Models, provide a set of elementary elements and assembling rules. The next stage in the development process is the Holon Design stage, which is a bottom-up process to produce the System Architecture from the Analysis Models of the previous stage. The aim of the Holon Implementation stage is to produce an Executable Code for the SetUp and Configuration stage. Finally maintenance functions are executed in the Operation and Maintenance stage.
In order to take into account NDT for maintenance activities in the whole development process of ANEMONA we have to integrate them when the system is being designed. In the following section we present an extension of ANEMONA in order to integrate NDT during the Holon Design phase of the method.

3. ANEMONA 2.0: including NDT for maintenance during design

In order to include NDT activities during the design stage of an Intelligent Manufacturing System the Holon Design phase is extended. Fig. 2 depicts the design phase augmented with the new activities and work products required to include NDT for maintenance. The new elements are marked with an oval.

In the design phase the initial system architecture, i.e. Analysis Models, must be completed with details of the target implementation platform. This phase is divided into two steps.

The first design step, Refine Holon Specification, is dedicated to completing analysis models without taking platform-modeling issues into account. The design teams must focus on the agents identified in the analysis phase in order to complete their definitions. In order to couple with NDT for maintenance every resource agent that represents a machine and/or tool in the system, together with those agents that represent materials that are used in the manufacturing process, must be analyzed in order to specify and design NDT activities for them (in the following paragraph these NDT specific ANEMONA 2.0 features are detailed). The second design step is Build System Architecture. ANEMONA defines design guidelines to implement the Intelligent Manufacturing system as proposed by Christensen in [9]. For high-level control (intra-holon information processing and inter-holon cooperation), ANEMONA provides design guidelines for JADE [10]. For low-level control (physical operations), our methodology provides design guidelines for function blocks (IEC 61499 series of standards) [11]. In order to complete the System Architecture with NDT Specifications ANEMONA 2.0 provides specific guidelines for NDT for Maintenance.

In order to extend the Refine the Holons Specification step (see Fig. 2) with NDT specific design we have augmented the original ANEMONA work definition with a new activity called Specify NDT Activation Functions. In this step every resource agent that represents a machine, tool or material is completed with new tasks that should be executed during maintenance of the manufacturing system. The work product of this new activity is a complete Agent Model in which the new NDT activities for maintenance are specified as functions associated with the agent. In order to specify these functions, the designer needs to take into account pre-conditions that activate the NDT activity, timing requirements, and/or number of processed products, etc. Apart from these activating features, the designer must also take into account what type of machine; tool or material is represented by the agent in order to specify which type of NDT should be applied. The NDT activities must be planned as maintenance operations during the life cycle of the resource agents. How to provide a complete specification of the NDT Activation Functions is detailed in the NDT for Maintenance Guidelines.

During the step Build the System Architecture (see Fig. 2) the designer must complete a series of templates that completely specify the system architecture. ANEMONA 2.0 adds a new last activity to its last design step in order to complete the NDT Specification template (Fig. 3) in which all the details of the NDT activities should be specified.

In order to complete the NDT Specification template ANEMONA 2.0 provides the NDT Maintenance Guidelines (Table 1). These guidelines try to help the designer to identify and complete the specification of the NDT Activation Tasks.
Table 1. ANEMONA 2.0 NDT for Maintenance Guidelines.

<table>
<thead>
<tr>
<th>ID</th>
<th>Guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A NDT Activation Task is a function associated with a resource agent that represents a machine, tool or material that requires NDT for maintenance. NDT is the testing of materials, for surface or internal flaws or metallurgical condition, without interfering in any way with the integrity of the material or its suitability for service. In order to design those activities for maintenance during the manufacturing system execution, every resource agent may have an associated NDT.</td>
</tr>
<tr>
<td>2</td>
<td>For every resource agent that represents a machine, tool or material analyze what type of maintenance activity is required. In case the resource requires a testing without interfering in any way with its integrity and or suitability select it and follow guideline 3, in other case select another resource agent and repeat guideline 2.</td>
</tr>
<tr>
<td>3</td>
<td>Create a NDT Activation Task for the agent selected in guideline 2. In order to complete the specification of the new task instantiate a new NDT Specification template (Fig. 3).</td>
</tr>
<tr>
<td>4</td>
<td>Complete section 1 of the NDT Specification template with the Agent ID. In section 2 state the platform ID in which the agent was assigned to. In section 3 define a template code with the format NDT-XXX. The last three characters should be a unique identifier made up of alphanumeric characters.</td>
</tr>
<tr>
<td>5</td>
<td>Complete section 4 of the NDT Specification template with the type of maintenance testing technique that must be applied in the NDT task. Possible techniques are (but not limited to): Radiography – X and Gamma, Magnetic Particle Inspection, Dye/Liquid Penetrant Testing, Ultrasonic Flaw Detection, Eddy Current and Electro-Magnetic Methods, Leak Testing, Infrared and Thermal testing, Acoustic Emission testing, Visual testing (for a complete and updated list see [12]).</td>
</tr>
<tr>
<td>6</td>
<td>Does the NDT Activation Task have some pre-conditions for its activation? If yes, detail them in section 5 of the NDT Specification template. In other case, complete with nil.</td>
</tr>
<tr>
<td>7</td>
<td>Is the NDT Activation Task a periodic activity that should be executed every “n” time units? If yes, state it in section 6 of the NDT Specification template. In other case, complete with nil.</td>
</tr>
<tr>
<td>8</td>
<td>Is there an internal and/or external event that activates the NDT task? If yes, state it in section 7 of the NDT Specification template. If there is more than one event write a list of events. In other case, complete with nil.</td>
</tr>
<tr>
<td>9</td>
<td>Complete section 9 of the NDT Specification template with the maintenance planning for the NDT execution. For every pair &lt;operation, time&gt; add a line in the planning table.</td>
</tr>
<tr>
<td>10</td>
<td>When a given NDT Specification template is completed, start the whole process from guideline 2 for the next resource agent. When the entire resource agents of the intelligent manufacturing system where analyzed the last design step of ANEMONA 2.0 is finished.</td>
</tr>
</tbody>
</table>

4. Conclusions

In this paper we have proposed ANEMONA 2.0, which includes NDT for maintenance during design. In this way the system designer takes into account types of maintenance activities during the System Architecture design. At the end an intelligent manufacturing system is developed specifying all its constituent entities in terms of intelligent behaviour and cooperation interactions, together with the activation planning of NDT maintenance activities for all the resource agents of the system that requires it. The work presented in this paper is an initial proposal that requires validation and tuning. For refining ANEMONA 2.0 a set of test cases is planned to prove the effectiveness and completeness of the guidelines and the appropriateness and completeness of the NDT Specification template.

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