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I2MS2C – Intelligent Maintenance System Architecture Proposal

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Maintenance is crucial for the operation of today's complex production systems. Insufficient maintenance due to missing spare parts, service equipment or personnel can result in breakdowns that have major negative impacts. Minimizing downtimes of the maintained system and on the other hand keeping the supply chain cost within an acceptable range can only be achieved by forecasting system breakdowns. Due to the occasional character of the maintenance demand and the broad range of affected system components, the application of "classical" forecasting methods – e.g. for finished products – does not allow for precise demand predictions and causes low forecast qualities. The objective of the Integrating Intelligent Maintenance Systems and Spare Parts Supply Chains (I2MS2C) project is improving the effectiveness and efficiency of service management operations for complex technical systems by integrating Intelligent Maintenance Systems (IMS) with planning and coordination methods and processes within the spare parts supply chain. This paper proposes an architecture for the Intelligent Maintenance System of the I2MS2C project, based on service oriented architecture using a multi agent system.

1. Motivation and problem description

Maintenance is crucial for the operation of today's complex production systems. Insufficient maintenance due to missing spare parts, service equipment or personnel can result in increasing downtimes of systems and have major economic effects. Downtimes cause diminishing profits for system operators coming along with negative effects on their customers' satisfaction and service perception. Thus, the reasonable management of maintenance activities including spare parts provision has major relevance for the effective and efficient operation of complex technical systems.

In reactive maintenance the demands for maintenance services and spare parts occur upon system breakdowns. This occasional demand presents different forecast characteristics in comparison to the demand of final manufacturing products. In preventive maintenance systems, despite of the periodicity of services allowing a schedule for spare part provision, a fail occurrence can still occurs. Thus, it is highly important for system operators to be able to estimate the maintenance need of a system and its components. This is fundamental for an efficient planning of respective maintenance activities and spare parts replenishment in order to minimize downtimes of the maintained system.

Maintenance activities occurring only in reaction upon system failures imply high costs with respect to spare parts production and replenishment and on-site maintenance. Facing this research issue in the domain of intelligent maintenance systems has led to new methods for monitoring technical systems' maintenance condition, as presented by Zio (2012). Thus, suchlike technological status information and sensor positioning configuration (Chang et al., 2011) form the basis for more efficient maintenance services and spare parts replenishment, since the minimization of downtimes by exaggerated spare part inventories and maintenance service personnel incurs high running costs which may exceed the benefits of a high service level.

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The integrated management of maintenance services and spare parts supply chains has to simultaneously provide an adequate maintenance service level with spare parts availability and low costs for maintenance service and spare parts provision. The right balance is critical for the competitiveness of production system operators and/or respective maintenance service providers.

The described challenges can be further specified and set into relation to the peculiar characteristics of maintenance services and spare parts supply chains as follows. First, from a technical point of view, the challenge is to gain information about the maintenance status of a system, i.e. estimations of components' maintenance needs and alerts upon concrete failures. Second, fulfilling the requirements on effective and efficient maintenance services, i.e. a high service-level with low costs, induces contradictory needs on the management and planning of spare parts supply chains. On the one hand, spare parts have to be available at the right time in the right amount and location. On the other hand, the characteristics of spare parts in combination with low inventories impose special requirements on the actors being involved in spare parts provision.

The I2MS2C (Integrating Intelligent Maintenance Systems and Spare Parts Supply Chain) project is proposed to approach the challenge of simultaneously coping with the constraints and specificities of Intelligent Maintenance Systems and Spare Parts Supply Chain. It has the goal of improving the effectiveness and efficiency of service management operations for complex technical systems. This will be achieved by integrating information provided by embedded IMS systems with planning and coordination methods and processes in the spare parts supply chain. Maintenance operation also benefits from an improved planning of the service operation synchronizing service demands with spare parts availability and servicing capacities. Another feature in this project is the Mixed Reality Interface to support the maintenance team, visually identifying the part to be replaced and indicating the operational sequence to be carried out. On this context, tthe aim of this paper is to present the service oriented architecture proposal for the IMS of the I2MS2C, and the communication with the Maintenance and Spare Parts Supply Chain Coordination (MSPC).

2. Intelligent Maintenance System

Condition Based Maintenance (CBM) is a maintenance strategy that involves the monitoring the equipment health using sensors that measure physical variables (vibration, sound, energy consumption, torque) associated with equipment performance. This information is used to forecast the rest of utile life (RUL) of equipment and optimize the maintenance schedule. Systems with these characteristics are also known as Intelligent Maintenance Systems (Thurston, 2001).

The IMS system chosen in our approach has a core component, called Watchdog Agent (Djurdjanovic et al.,(2003)) that evaluates the working state of the equipment and forecast the time to fail and the part needed to replacement. The Watchdog Agent consists in a set of tools, to perform feature extraction, health assessment, and performance prognosis and condition diagnosis. The tools must be selected for the desired application, according with the type of faults that should be detected and the information that is monitored.

The case study for this project is an electric valve actuator model CS06, producer by Coester, a partner Brazilian company. This product has been focus of other IMS projects (e.g. Gonçalves, 2007, 2011). In Gonçalves (2011), a Self-Organized Map (SOM) is used to evaluate the health of the system and to diagnose witch part have is on degradation. To estimate the RUL, a research is in progress using the Autoregressive Moving Average algorithm (ARMA) as the performance prediction.

The figure 1 shows the test bench used to training and tests the system. In the high left corner, highlights on the vibration sensor, positioned in the bearing of the motor shaft. These and the torque from main shaft are used as information for the diagnostic algorithms.

The IMS systems run in a cRio9082 controller from National Instruments, using the Watchdog Agent Prognostics Toolkit for Labiew to implement the Wavelet Packet Energy and C++ block coding to implement the SOM and the ARMA algorithms.

Figure 1. Test bench with CS06 actuator

3. The FRISCO framework

The actors and respective decision domains of spare parts supply chains can be distinguished by their roles of producing, distributing and using a spare part. Supply chains design and capacity planning in general impose several research and practical challenges (e.g. Giarola et al., 2011). Specifically, the producers of spare parts have to account for production, lot-sizing and local inventory holding decisions. Furthermore, they can fulfill the distribution on their own or rely on logistics service providers. Respective decisions especially affect inventory holding at multiple sites and the determination of transports. The usage of a spare part in concrete maintenance activities has to be accounted for either by system operators or third party maintenance service providers.

Thus, the structure of spare parts supply chains with multiple involved actors induces the need for a coordination of their respective activities. Consequently, challenges on the integration of these two perspectives arise. This especially affects the provision of technical maintenance status information to the different planning and decision domains of spare parts supply chains, their inclusion into tailored planning methods and the coordination of the multiple involved actors. The general idea of FRISCO is to provide an environment that allows modeling and evaluating decentralized coordination mechanisms for arbitrary heterarchical supply chains (SCs) (Hellingrath, 2011b).

The ultimate goal of this research is to pave the way for suchlike coordination mechanisms from primarily being a research domain to practical applications in real SCs. Basically, the framework consists of two parts: a modeling and an evaluation environment for collaborative planning (CP) coordination mechanisms. Due to the suitability for heterarchical SCs and CP, FRISCO is based on Multi Agent System (MAS) concepts. In order to be able to efficiently cope with differently shaped CP mechanisms beyond the mere modeling, an approach in analogy to model driven development (MDD) was chosen. The goal is to provide an environment that allows modeling the complex structures and processes of CP concepts and furthermore to use these models in order to automatically create executable code for an evaluation of the CP approaches in different scenarios. Modeling MAS and the automated transformation of models to executable code has been researched intensely in the MAS context and several approaches have evolved (for an overview see e.g. (Nunes et al., 2009)). The DSML4MAS domain specific modeling language (Hahn et al., 2009) was chosen to describe the agents. This language provides the required concepts for a representation and implementation of CP approaches, especially with respect to the graphical definition of complex interaction protocols required by CP.

The abstract syntax of this modeling language is described by an agent-platform independent metamodel called PIM4Agents (Hahn et al., 2009). The concrete syntax of this modeling language has been specified and implemented by means of the Eclipse Modeling Framework (EMF), i.e. graphical modeling of complex MAS is supported by the DSML4MAS environment. Furthermore, translation rules have been defined transforming conceptual models to executable code which can be run on the FIPA compliant MAS platform JADE.

4. Architecture proposal and implementation

Some platforms and architectures has been proposed in the literature, such as PROTEUS (Bangemann, 2006), TELMA (Levrat, 2007). PROTEUS focus on the integration platform where the central service application (CSA) provides integration oriented services. Additionally the platform relies in intelligent core adapters (ICA) to provide standardized interface transformers for the peripheral applications and functional core applications (FCA) to implement supplementary functions needed by the global service requirements and not provided by the platform tools. TELMA is a platform that integrate a CBM strategy with the Enterprise context offering the following functionalities: Intelligent agents (on-line services) directly implemented at the shop-floor level into the PLCs or the remote I/O of the components (smart systems) for continuous, real time, remote and distributed monitoring and diagnosis of devices to establish the device health condition; Infotronic platform supporting the data vs. information vs. knowledge processing, storing and communication on each level (shop floor and business) but also between the two levels and Services (off-line) among users for aided decision-making in front of the degraded situation. These services materialize, for each expert, the assessment of the (current degraded) process performance, then the prognostic of the future situation (if the degradation is evolving). A complete review on the concept of e-maintenance, major achievements and current research is provided in Muller (2007). A conceptual framework for e-maintenance using Web Service over the TELMA platform is proposed by Iung (2009). Ribeiro (2009) proposed an architecture for supporting maintenance team management and offering contextualized operational support. All the functionalities hosted by the architecture are offered to the remaining system as network services. Any intelligent module, implementing the services' interface, can report diagnostic, prognostic and maintenance recommendations that enable the core of the platform to decide on the best course of action

The proposed architecture is based on the service orientated architecture as used by Iung (2009). To integrate the Maintenance Manager with the Supply Chain Coordinator, the FRISCO framework is adopted, so the services will be provided by a MSPCAgent (Maintenance and Supply Chain Coordinator Agent) and the IMS system also plays the role of an agent. The MSPCAgent, on its way, can coordinate multiple

It is assumed, for the first approach, that the maintenance service is provided by one inter-organizational MSPCAgent agent that coordinates the Spare Parts and Maintenance Planning Agents. So, the IMSAgents just have to find the MSPCAgent in the Service Diretory, without negotiate the availability of services. Figure 2 present this relation.

To access the MSPCAgent, the IMSAgent must identify yourself, to check if there services available. After this, the IMSAgent will report periodically the health of the monitored equipment. The periodicity of report is related to equipment's health and operation. If a degradation state is reach, a request for maintenance is sent. To implement the Identification and Maintenance Request service, the FIPA-ACL request protocol is used and to inform the system about Health Status of the device, a regular message exchange is performed.

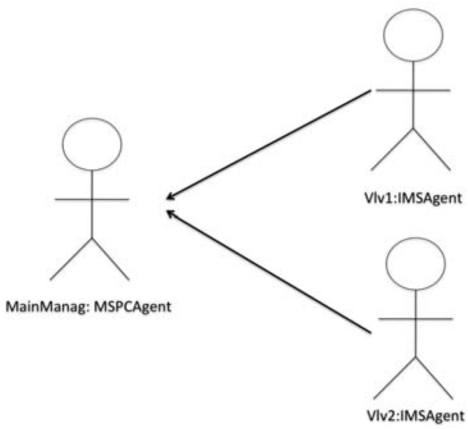

Figure 2 – Relation between MSPCAgent and IMSAgents

The Jade framework provides a Yellow Page Service, to publish the services and agents available in the system. This is carry out by a DF agent and the first step in establishing communication between the agents is to publish the characteristics of the service provider (MSPCAgent). So, the IMSAgent, as client could find it. Figure 3 shows the communication model. A major aspect of the I2MS2C project is the integration of different information domains, as maintenance, spare parts supply chain and mixed-reality vision systems. To fulfill this requirement, the data models PDKM and CARMMI are applied. The PDKM is a UML data modeling proposed by CASSINA(2006) that represent the information about parts in different stages of the product life-cycle. PDKM is able to identify and tracking each product´s part in the assembling/disassembling fase and describe the use and operation features of the equipment along its life cycle. CARMII is a data model to integrate the Virtual Reality (VR), CAD/ CAM and Intelligent Maintenance in the PDKM model, proposed by Espíndola (2009).

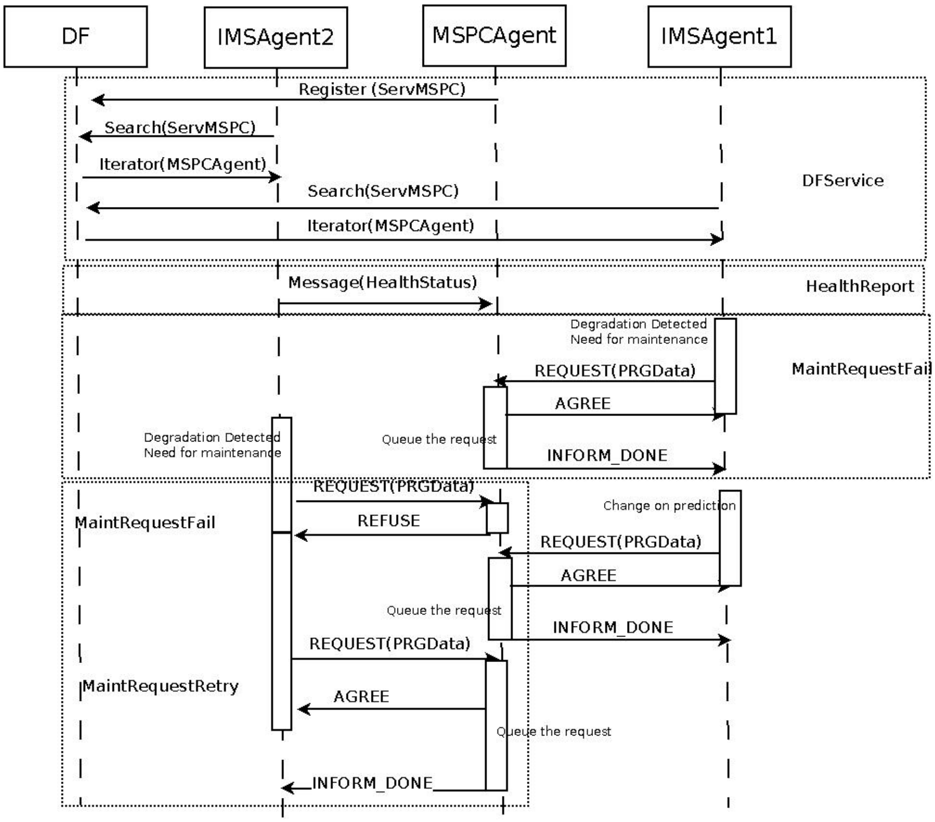

Figure 3. – Communication model for maintenance supervision

The proposed architecture is implemented according to the following structure: the Watchdog Agent is running in a cRio platform, as described in session 2, the IMSAgent and the SPSC2Agent are running in PC platform under Windows OS. Communication between IMSAgent and the Watcdog Agent, reporting the current state of the equipment and the prognosis information, is executed through an Internet Socket.

5. Conclusions

This paper proposed the architecture for an Intelligent Maintenance System (IMS) considering the integration of maintenance services within a spare parts supply chains. The objective of integrating Intelligent Maintenance Systems and Spare Parts Supply Chains is improving the effectiveness and efficiency of service management operations for complex technical systems.

IMS comprises a maintenance strategy that involves the monitoring the equipment health using measurement sensors that measure signals that could be associated with equipment performance, thus forecasting the rest of utile life, and supporting a better scheduling of maintenance and potentially improving the execution of associated spare parts supply chain.

For executing the IMS strategy, the proposed architecture is implemented through a service-oriented architecture and uses a multi agent system. To face the challenge of aligning different information domains, solutions based on the Jade framework and tested data models are used.

Several tests and experiments are in progress for assessing the performance of the proposed integrated system. The test cases consider industrial situations and scenarios, using the test bench presented.

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