Adapter for Self-Learning Production Systems

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Abstract. To face globalization challenges, modern production companies need to integrate the monitoring and control of secondary processes into shop floor core system to remain competitive and improve system performance and throughput. The research currently being done under the scope of Self-Learning Production Systems tries to fill this gap. Current work introduces the domain and a generic architecture, while focus over the responsible element for executing system adaptations according to current context: the Adapter. The Adapter architecture and its components are introduced as well as the generic Adaptation process. Early prototype scenarios applied to concrete real-world scenarios are also presented.

Keywords: Production Systems, Context Awareness, Service-Oriented Architecture, Machine Learning, Context Adaptation.

1 Introduction

Along with several other domains, production market has deeply felt the effects of globalization on all its different layers [1]. The consumer is continuously demanding for high quality and highly customized products at low cost, with a minimum time-to-market delay [2].

To achieve this goal, modern companies need to take into account not only production control and execution processes but also associated secondary processes in a fully integrated approach. Secondary processes, such as maintenance, energy saving or lifecycle optimization, are typically detached from the core system what leads to poor machine performance and higher lifecycle production costs. As pointed in [3], the merge of these two domains promises to enhance the efficiency of production processes, maintenance and optimization tasks.

Therefore, the way to attain this goal is to embed self-learning skills alongside monitoring and control of a production system to ease the handling of product variations, process changes, equipment performance degradation, etc. A self-learning system must be able to monitor and detect changes of context by continuously verifying process and equipment parameters initiating an adaptation process whenever current context obliges to. Nowadays, there is very little doubt that Service-Oriented

Architecture (SOA) paradigm [4] is already a major topic in many branches of technology, not exclusively in original business layer ICT [5] [6].

The objective of the work presented in this article is to define an Adapter architecture for Self-Learning Production Systems based on SOA premises. The Adapter is responsible for executing an Adaptation process whenever a change of context is detected in the system. It uses learning techniques along system lifecycle to determine the adaptation that best fits current context.

2 Contribution to Value Creation

The application of a generic architecture to support the integration of the monitoring and control of secondary processes into production system core promises to open new perspectives for a new generation of intelligent equipment but also for new tools to control and monitor the lifecycle of future production system.

The application of machine learning techniques allied expert input and feedback can improve system autonomy and reliability, while uncovering new knowledge that can be used in future versions of the equipment in incremental way. Also, the inclusion of three industry partners bringing real industrial challenges to be addressed can validate current generic architecture and approach through its use cases results, as well as it can provide a reliable test-bench for future Self-Learning deployments.

3 Self-Learning Production Systems

The research motivation behind this work relates with the strategic objective of strengthening EU leadership in production technologies in the global marketplace by developing innovative self-learning solutions to enable tight integration of control and maintenance of production systems [7]. This approach requires a paradigm shift in production systems domain aiming to allow adaptation and merging the world of control with other manufacturing activities of the production systems so-called secondary.

To face this, need, the FP7-NMP Self-Learning research project comprising partner organizations from academia, research and industry, experienced in international projects is designing and developing an highly reliable and secure service-oriented based arquitecture to assure effective self-adaptation of the production systems in order to improve control and energy efficiency, utilizing context awareness and machine learning techniques.

3.1 Goals

As mentioned in [8], the main goal of the Self-Learning project is to develop innovative self-learning solutions to enable a tight integration of control and other processes of production systems, through the implementation of a SOA infrastructure used to support the proposed self-learning paradigm.

The self-learning approach is intended to have a high impact on manufacturing industries and solve open questions concerning:

- Reduction of time and efforts needed for development/installation of production lines control systems.
- High degree of flexibility in the development and installation of production control systems.
- Reduction of down times during product exchange and/or conflicts situations.
- Increasing of Overall Equipment Effectiveness (OEE), i.e. plant availability and its productivity over time.

This research initiative is driven by three disparate application scenarios applied to real world industrial environment: Integration of control and energy optimization of production processes, enhancing flexibility of machines, and optimized job dispatching of flexible production cells.

3.2 Architecture

In the envisioned architecture (see Fig. 1), two basic generic components (Extractor and Adapter) are together able to identify the current context under which the production system is operating, and adapt the production system behaviour at run time in order to improve its performance in face of the contextual changes. The result of the extraction and consequent adaptation activity is exposed to the system expert through the Expert Collaboration UI.

Since the system response must take into account not only the particular context, but most important, the entire lifecycle behavior of both system and expert, a Learning module has been provided to learn relying on data mining and operator's decisions over time. All processed data and knowledge generated are stored in repositories (Context Repository and Adaptation Repository). These components of the Data Access Layer allow both Extractor and Adapter to access it when needed.

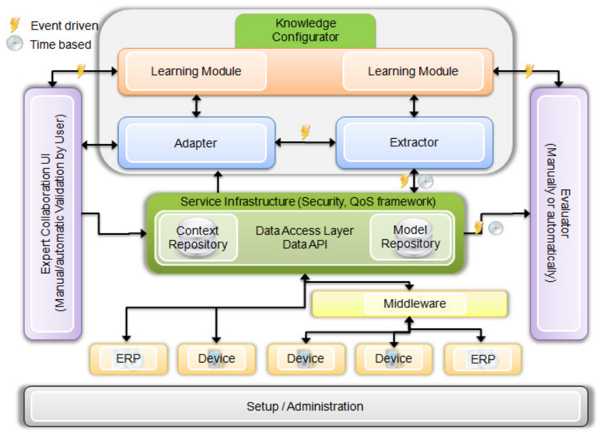

Fig. 1. Self-Learning Architectural overview [9]

The general Self-Learning production system architecture has been designed following a modular and abstract approach in order to remain hardware-independent and still compliant with each application scenario.

4 Adapter

The Adapter is described by focusing on its behavior within the proposed architecture, especially showing the main modules and the interactions between them during the adaptation process.

The issues briefly introduced in the previous sections have been deeply studied during the first stage of the Self-Learning project, reaching a set of features and functionalities for the adapter:

- React to a change of context and provide a suitable adaptation proposal to be validated by the system expert.
- Employ the Learning module as a mean to process large amounts of data concerning a particular context and identify the best suite adaptation proposal to be presented to the system expert.
- Detect expert input and deploy the validated adaptation into the system.
- Manage Adaptation Repository ensuring that each adaptation process is stored for future use.

4.1 Architecture

The generic architecture of the Self-Learning Adapter component is shown in Fig. 2.

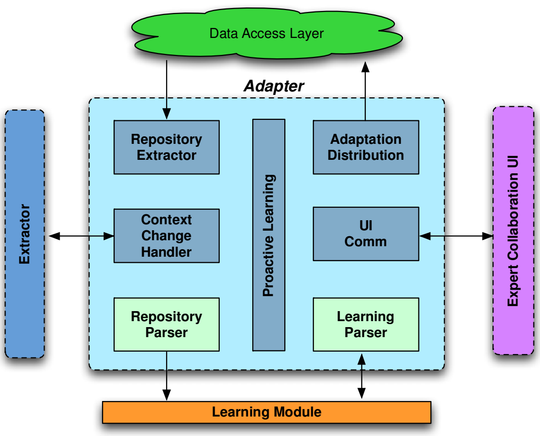

Fig. 2. Adapter architectural overview

The core task-oriented components of the proposed architecture are the following: Repository Extractor, Context Change Handler, Repository Parser, Learning Parser, UI Comm, Adaptation Distribution and Proactive Learning.

Each component has a different scope and role during the process of collaboratively providing adaptation proposals on system behavior and parameters according to the current context. Since Adapter is simply one brick of the overall infrastructure, it needs to interact with other surrounding modules to entirely fulfill its objective. This way the Adapter will interact with the Context Extractor component, Learning module, Expert Collaboration UI component and Data Access Layer.

The envisioned architecture shows a reactive behavior since the adaptation process is triggered by an Extractor notification, but also offers a proactive behavior thanks to continuous learning performed by the Proactive Learning component.

4.2 Adaptation Process Description

The adaptation process (see Fig. 3) consists of a sequence of procedures to be executed whenever the Extractor notifies the Adapter about a change of context with the objective to adapt the system to face that same context change.

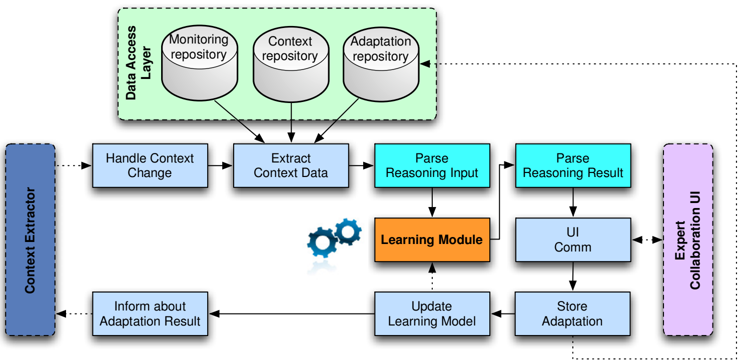

Fig. 3. Adaptation process

After being notified by a context change and launching the Adaptation process, the Repository Extractor component retrieves, from the Data Access Layer, all the necessary data about the current context (Monitoring Data) and models. This collection of data is then transferred to the Repository Parser component to transform it into a generic structure, comprising a context dataset, which can be processed by the Learning module. The result of the Learning module reasoning will be sent to the Learning Parser component which process it and finally creates the Adaptation proposal following a generic template. The Adaptation proposal will be transmitted through the Comm UI component to the Expert Collaboration UI that waits for an expert operator validation or modification of the original proposal. After choosing the final adaptation to be performed, the according Adaptation structure will be distributed to the Self-Learning environment, i.e. the following tasks will be executed: notify the Extractor about the new Adaptation, store the Adaptation into the according repository and send it to the Learning parser component to update existing learning models.

5 Early-Prototype

An early-prototype has been implemented providing a first version of the Self-Learning platform in order to assure that the proposed solution and infrastructure as well as the methodology is generic and valid to be applied at different levels of control & maintenance integration in distinct industrial environments. The Early-Prototype will be integrated and validated in three distinct application scenarios.

5.1 Business Case 1: Optimization of Secondary Processes in Machine Tools

The first business case concerns the optimization of secondary processes on CNC machines, such as maintenance and/or energy efficiency activity, during the machine tools lifecycle, integrating Self-Learning solutions to the existing service platform as introduced in [10]. Thus, the vision in this business case is to improve manufacturing lines sustainability and maintenance systems.

This way, information about machine tools idle times is exchanged between the equipment and the Self-Learning system in order to:

- Automatically synchronize production and maintenance plan by inserting special monitoring services like friction tests with the smallest effect to productivity, etc.
- Increase of machine efficiency especially with respect to the energy consumption.

During the runtime phase all the machine control states will be monitored in order to recognize the idle-time patterns, classified in time domain, which in turn will be sent to the Adapter. Depending on the temporal dimension of the identified idle-times and on the entire lifecycle of the system, i.e. taking into account the different tasks executed in the past, the Adapter will be able to select one of the two main tasks, respectively:

- Save Energy: switch-off the machine or its auxiliary services improving the energy consumption.
- Maintenance: dynamically modify the maintenance plan for the machine reducing the impact that these operations have on the production.

5.2 Business Case 2: Intelligent Monitoring and Adaptation of Machines for Shoe Industry

This business case reports the application of an intelligent monitoring system to extend current monitoring system with the objective of finding and identifying problems that potentially may cause a line stopping.

According to this objective, the Self-Learning platform will be connected to the legacy control system infrastructure improving both the capability of:

- System parameters adaptation based on contextual information coming from shop-floor machines.
- Fault detection and trends in the machines/components behaviour.

According with these two main objectives, two use case scenarios have been provided, respectively: Tanks refilling and Valves synchronization.

The Tanks refilling scenario consists of a hydraulic circuit composed of two liquid material tanks. Whenever a tank is refilled the new colder material causes some environment alteration, in particular, material temperature drop down and increasing of the injection pressure.

During runtime, whenever a context change will be detected tanks conditions are sent, to the Adapter, in order to process all this information to identify a tank refilling condition and adapt the control temperature and pressure limits.

In the Valve synchronization scenario a mechanical system consists of five valves connected to different hydraulic circuits with different components that can be composed selecting which valves to open synchronously. During the components dosing process the synchronicity of the different valve circuits is a fundamental aspect to guarantee the quality of the composition.

In this case all the information about the system will be sent to the Adapter that, based on the entire system lifecycle, will be able to predict for each valve the next opening time alerting the operator about a asynchrony between the valves.

5.3 Business Case 3: Self-Learning Scheduling and Dispatching in Flexible Manufacturing Systems (FMS) for Automotive Industry

The third business case tries to improve the performance of Flexible Manufacturing System cells by optimizing machine scheduling model according to actual context. The Self-Learning solution is aimed to improve the reactive scheduling model by considering the following main aspects:

- Taking into account operator supervision concerning the optimization criteria.
- Introducing resource planning features.
- Identifying process states and operator supervision and learning from them.

A connection between Self-Learning platform and the existing control platform will be necessary to acquire all the necessary contextual information about the system. In the application scenario provided, the main objectives are maximizing the machine utilization rate and avoiding loading stations starvation.

Based on the information about the state of the shop floor environment in a specific point in time and on the previous knowledge about the entire system lifecycle, the Adapter will be able to select the appropriate rule to determine if the clamping job queue is simultaneously satisfying the two main objectives.

The Adapter is allowed to provide output to the process only if the operator validation will be positive otherwise the Adapter will learn from the operator feedback.

6 Conclusions and Further Work

Current work presents an innovative input to the Self-Learning production systems research domain by introducing the Adapter architecture, features and early prototype specifications. The proposed solution addresses the adaptation of various process/control parameters and procedures to achieve integration of control and secondary processes all based on the same generic architecture. This approach relies on context awareness to be able to adapt to contextual changes at run time and learn from adaptation and operator's input.

As future work, a final prototype will be specified and implemented by covering Adaptations procedures more complex based on further extensive machine learning techniques. The automated Adaptation behavior will be also integrated to increase equipment autonomy for tasks where the Self-Learning system already proved to offer accurate and reliable Adaptation proposals.

As a service-based Self-Learning approach, it will be also necessary to address aspects related to reliability, availability, interoperability and security & trust of services, specifically real-time services in device space.

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