MODEL-BASED SUPPORT FOR ENERGY-EFFICENT PODUCTION IN SME

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ABSTRACT
High and still increasing energy costs have led to an increasing relevance of energy efficiency. This paper describes an assistance system that aims to support SME in order to realize energy savings in production and thereby help to increase competitiveness by reducing energy costs. The system is based on a service-oriented architecture. On the server side, several web services provide generic functionality like data management, sensor data and data analysis. In the system's frontend, stakeholder interaction is realized based on Google's Android platform. The system uses data provided by sensors, production orders and additional metadata describing specific properties of the production systems.

A major challenge regarding the realization of such a system is heterogeneity, including different kinds of sensors, a wide range of components within the production systems, third party systems such as ERP systems and mobile devices as frontend for end users. This challenge is addressed by using a model based approach. In addition to the domain models, a stakeholder model is used to customize the user interface for the different stakeholders and a web based user interface is generated to allow system initialization and system configuration.

Keywords
Energy-efficiency, Production, Information Technology, System Architecture, Decision Support, Model based UI Creation

INTRODUCTION
Sustainable production and energy-efficient production are generally seen as the central new paradigms [1] for production research within the next years. More specifically, energy-efficiency has become a more and more important aspect of sustainability, which was originally coined to describe systems allowing for an agile response to competitive challenges [1].

We present a system that provides support for energy-efficient production in SME during both the planning and execution/deployment stages. The system fuses data from sensors reading e.g. energy meters, using metadata and formalized heuristics as well as planning information provided e.g. by an ERP system. From this data the system infers possible actions to reduce energy consumption and is able to notify the stakeholders during production runs via mobile devices. In addition, integrated underlying sensor information is visualized as a strategic decision support tool. Using a model based approach; we create user interfaces from different models to provide basic functionality for system initialization and configuration even if model changes or extensions occur. For end users, a custom user interface for mobile devices is provided.

REQUIREMENTS
There are several technical requirements that have to be addressed by the system's architecture:

Regarding the heterogeneous environment, which includes sensors, ERP systems and several other internal system components, the system's architecture needs to be able to deal with heterogeneity and interoperability aspects. Because of the wide range of application areas in which the system may be used, it has to be extensible and able to integrate into other external environments with minor efforts. Regarding the usage within the production environment, a mobile solution should be provided for end users.

There are also a number of barriers to the adoption of energy-efficiency projects. The barriers are quite heterogeneous, and vary from sector to sector [2][3]. However, offering intermediation through vertical service providers is a well-known strategy for supporting SME [4]. Furthermore, the system should offer a way to identify immediate benefits [5] that could be reaped by e.g. rescheduling tasks.

ARCHITECTURE OVERVIEW
The system is based on a client-server-architecture. On the data layer, mass data such as frequently captured sensor data is stored in a RDBS while domain specific information

is managed using ontologies. We provide two separated frontends, a web based for configuration and initialization of the system and a mobile frontend for end users. While the web based UI can directly access data, the mobile UI indirectly accesses the stored data via web services.

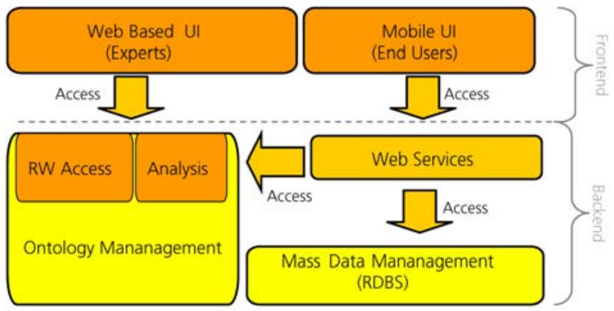

Figure 1: Architecture Overview

BACKEND

Relying on a service-oriented architecture, system's core functionality is realized as a set of key services on the server side. These services are responsible for basic functionalities such as energy meter abstraction, energy consumption monitoring and Analysis, forecasting functionality based on a SARIMA model [6] and Data Management.

Data Management Service

Within the system, different kinds of information have to be collected and managed. Therefore, a data management service is introduced. The service if responsible for providing read/write access to the data and meta-data of the system. Against the background of proprietary implementations and heterogeneous data structures as well as semantic differences in the data provided by energy meters and ERP systems, there is a need for an integrative way to represent this data. We use ontologies to describe the information from various platform-internal and external sources. This approach has already proven to be purposeful, especially in heterogeneous environments [7] [8]. For model realization, we decided to use the web ontology language (OWL) [9]. Based on the Apache Jena Framework [10], ontology individuals can be stored in files and be processed in memory as well as in relational databases. The ontology access and management module is intensively used for storing and retrieving information of the domain description ontologies as well as the user interface customization ontology. The ontology analysis module provides analysis and implements basic analysis functionality for ontology meta-structures such as analysis of ontology concept hierarchies, cardinalities, restrictions and data types. The module also integrates a reasoner [11] which offers a large amount of analysis functionality.

Domain Models

Domain specific Data and meta-data are structured by the following OWL models:

*Production systems model***:** To describe a production system as a whole, a meta-model is provided. It holds a classification of the component types contained in a production system. In addition to types (e.g. motors or lasers), additional properties related to the whole component class (e.g. typical energy consumption ranges, existing component states like on, off, stand-by and valid transitions between states) or relations to other component classes (e.g. interchangeable parts) are included in the model. Based on this information, we are able to infer components of a specific production system that deviate from the typical state in their class.

Production system component model: Furthermore, information about the configuration of the real production system has to be managed. One part of this information is provided by external systems like energy meters or external planning systems. Another part has to be provided during the configuration of the system. The production system component model relies on the high level model described above, which means that a comparison between components that are included in a specific production system and alternative components can be realized.

Manufacturing schedule model: In order to perform scheduling optimizations, we introduce a unified internal scheduling model. The model provides a generic model that contains the relevant scheduling information for the analysis service. In general, any scheduling data that contains the required data (e.g. coming from an ERP system) can be transformed to the internal representation by implementing a translating connector based on a generic interface provided with the platform.

Stakeholder model: Based on the stakeholders of the system, we use a role model which describes which information and which notifications are relevant for which users.

FRONTEND

Regarding the given dynamic environment, user interfaces for basic system interaction have to be adaptable to frequent changes induced by the domain requirements. Therefore, user interfaces for basic system interaction such as the initialisation and configuration of the given production environment in production are created dynamically from the existing domain models and additional configurations for user interface creation.

The system offers a wide range of user interface components, which can be combined to complex web based user interfaces. There are several elements which allow structuring of the user interface (UI) components.

Perspectives: Perspectives are a well known concept, which allow customization of full screen content and also switching between various views.

Containers, Frames and Framesets: Perspectives can be subdivided using Frames and framesets. Within frames, UI elements can be grouped and organized in containers.

Elements: Elements include all non-structuring standalone user interface components such as widgets (buttons, text fields etc).

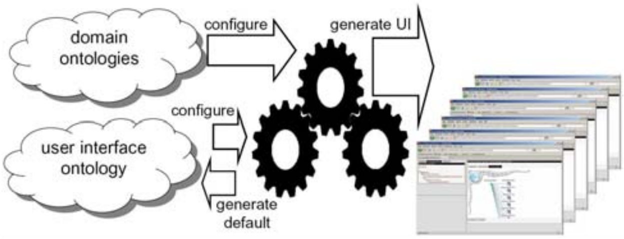

Figure 2: Model Based UI Creation

A User Interface configuration module realizes the functionality required for providing configurable user interfaces based on the domain ontologies. For new or changed domain ontologies, default user interface configurations are created. Missing configurations are created "on the fly" and can be refined afterwards. User interface configurations are realized and stored in user interface ontologies.

The figure below shows a default user interface generated from a non-customized domain ontology. The default user interface ontology provides an instantly working scaffolding mechanism and allows browsing and modification operations on the whole domain ontology.

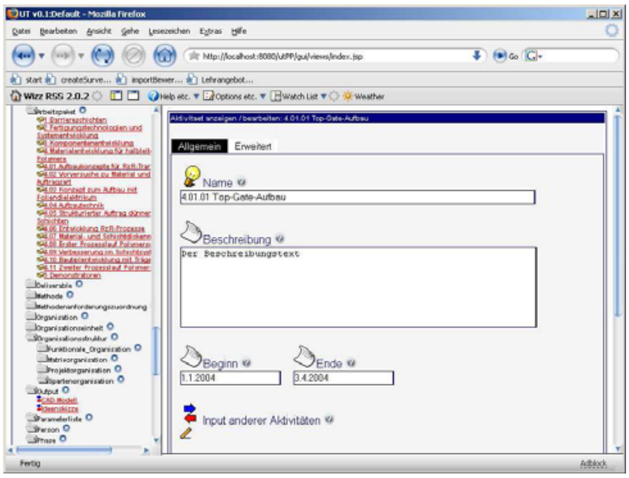

Figure 3: User interface based on default configuration

The generation of default user interface configuration can be adjusted using rules, which are formulated in a UI ontology. Rules can be based on domain ontology content or meta-information, e.g. it can be stated as a rule that specific widgets that visualize textual properties of domain ontologies shall be used based on any of the following criteria:

- Class of the domain ontology concept
- XML datatype of the property
- Defined restrictions defined in the domain ontology
- Defined cardinalities
- Specific URIs of specific domain ontology elements

Specific changes to all parts of the generated user interface configurations can be applied in detail. The figure below shows a configured web based user interface. In the illustrated case, an individual a specific concept is displayed for editing and browsing of related items. The generated configuration is modified regarding the navigation on the left. In addition, a flash based viewer is added which shows the dependencies between the individual and related information.

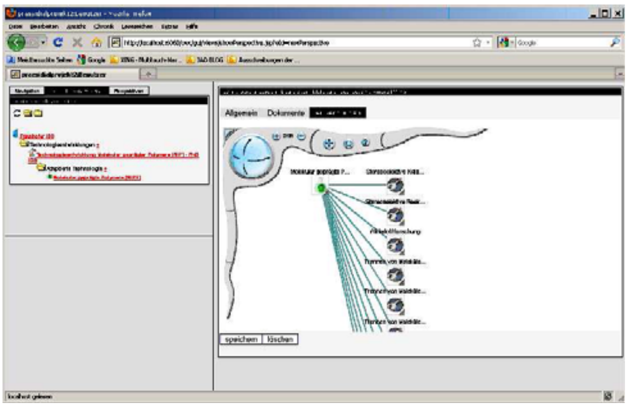

Figure 4: Customized Web User Interface

Mobile Android User Interface

The main objectives of the mobile frontend are to show the current status of energy efficiency of the assembly systems, to notify the stakeholders on identification of any potential to increase energy efficiency and give recommendation on how to achieve savings. To ensure a quick response time to the measures proposed by the assistant system at all times and independent of the current user location, a mobile solution is preferable. This allows the system to be utilized directly in the production environment where the proposed measures can be implemented directly. This also enables the responsible staff to immediately report back the changes made to the production system to the system's back-end, resulting in more up to date, accurate and reliable data. A prototype application for the mobile assistant has been implemented and is being refined using continuous integration and frequent testing using model scenarios.

For the realization of the mobile front-end, the software Framework MT4j is used [12]. MT4j is a java-based open source framework aimed at the creation of visually rich user interfaces which can be interacted with using novel input methods and devices, having a special focus on multi-touch support. First developed for the desktop, it has since been ported to the Android platform, expanding its use onto the various mobile devices relying on that operating system.

The stakeholders of the system have been divided into three different roles: planner and machine operator. The application provides different functionality and options for the different stakeholders and their respective roles. Roles define the entry point of the application regarding the visibility of production facilities stored in the back-end. Deciders have the ability to navigate through all production sites, assembly machines and their components in detail while the machine operators will typically only see the assembly machines and its components at their location. The roles of the decider or planer are offered an additional configuration menu where cost effectiveness of proposed measures can be calculated depending on certain, configurable variables such as aspired amortization dates or electricity costs. The machine operator is offered an up-to-date list of orders for production. Notifications are tailored to the corresponding user role and can only be read if permitted.

The different stakeholders have to be notified about the potential for energy savings in an appropriate manner. For this purpose the frontend regularly queries the backend whether new notifications are available and then transfers them to the front-end. Notifications include information about the measures to be taken in order to capitalize on the saving potential. Notifications conform to the role concept in such a way that every notification can only be read by a specific role or group of roles. The notifications can generally be divided into two different types: Strategic recommendations are mostly aimed at the role of deciders and planners and contain strategic information, e.g. the availability of alternative assembly components consuming less energy, reducing costs in the long term. Operative recommendations aim at the role of machine operators, these notifications are usually more time critical than strategic recommendations containing information about assembly machines that can be shut down temporarily resulting in immediate energy efficiency gains, for example.

CONCLUSION

We described an IT System that aims to support SME in order to realize energy savings in production and to thereby increase SME competitiveness by reducing energy costs. The system is designed to provide decision support both in the planning and execution phases of production. This functionality relies on the combination of data provided by sensors, production orders and additional metadata describing the properties of the production systems.

A service-oriented architecture is used to allow portability of the system across different manufacturing environments. On the server side, a bundle of key services provides generic functionality like data management, sensor data fusion and state data analysis. Based on models and semantic web technologies, user interfaces create user interfaces for system initialisation and configuration are created dynamically to allow for model changes and extensions with minor efforts.

For end users, mobile clients are provided.

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