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Platform using contextualized energy consumption data to provide energy-efficiency related decision support for manufacturing industry

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Abstract This paper presents the concept of a software platform, currently under development, that shall provide context-sensitive decision support related to energy efficiency and emissions trading in manufacturing industry. The main focus of the paper is on the functionality to support acquisition of energy use and context data from various sources, enriching energy consumption data with information about the context in which the use actually occurred. The aim of this data acquisition and pre-processing is to build a knowledge base that shall enable to context-sensitively provide decision support to different target audiences in manufacturing companies.
The platform aims to be as generic as possible to allow application in different companies and application scenarios with minor adaptation efforts. To ensure its industrial applicability the platform is, already in parallel to the development, tested and initially validated in three application scenarios. One of those industrial case studies is presented here, which is addressing the energy efficiency optimisation in a large paint production company.

1. Introduction

Energy efficiency in an industrial context has become more and more important in the last decades, as the share of overall production costs that is related to energy consumption has gained significance. Due to new European legislation that penalizes CO2 emissions, the industry has an additional economic motivation to optimise its production processes concerning energy consumption.
When addressing the energy efficiency in industry it has to be considered that modern industrial processes are increasingly complex and flexible, leading to highly dynamic energy usage patterns and difficulties in identification of correlation between overall energy consumption/CO2 emissions and specific processes. To cope with such a dynamics of energy patterns and to enable an efficient energy management in manufacturing processes, the currently running LifeSaver project

([1]) aims to complement measured energy consumption data with diverse information from existing systems, e.g. ERP, PPC and SCADA systems, ambient intelligent (AmI) systems (e.g. interactions between human operators and machines or processes) and process related measurements (e.g. temperature or oil level of a specific machine). The main objective is to enrich energy consumption data with information about the context in which the consumption actually occurred. The use of this additional information shall enable the creation of a “high resolution image” of the energy consumption in the different manufacturing operations. This new (or up to now unused) information is expected to have a significant potential to support decisions in the scope of maximising energy savings as well as minimising and trading with CO2 emissions.
To provide the targeted decision support services based on contextualised energy consumption data to end users in daily industrial operation, a LifeSaver software platform is currently under development. This paper describes the overall approach of the LifeSaver software platform with a particular focus on the functionality to support acquisition of diverse data from different sources as well as to support context-aware pre-processing and provision of the acquired data.
The LifeSaver platform aims to be as generic as possible to allow its application in different companies and application scenarios with just minor adaptations. To ensure its industrial applicability the developed platform is, already in parallel to the development, tested and initially validated in three application scenarios in real industrial environment. One of those industrial case studies, addressing the energy efficiency optimisation in a large paint production company, is also presented in this paper.

2. Approach of the software platform

The LifeSaver project aims to provide a generic software solution supporting the LifeSaver core requirements of energy consumption and context monitoring, energy modelling and prediction as well as emissions calculation and finally the decision support to different types of users. Therefore for each of these requirements a dedicated software module shall be developed that covers the necessary functionality. These functional modules, which are called “building blocks” (BBs) in LifeSaver, shall be combined in a service-oriented architecture platform, which aims to be loosely coupled and open for integration with other systems. In addition the platform aims to be easily extensible with new functionality as well as flexibly configurable to allow its application in different industrial scenarios with only low programming efforts, allowing an adaptation mainly by configuration rather than by changing the source code.
The BBs with above mentioned functionalities form the core of the LifeSaver reference architecture, which is illustrated in Figure 1. This main functionality is enhanced by a number of supportive components like the knowledge repository,

managing different types of information in a centralized location, accessible by the different BBs, and user interfaces for setup and administration as needed to allow easy administration of the platform.

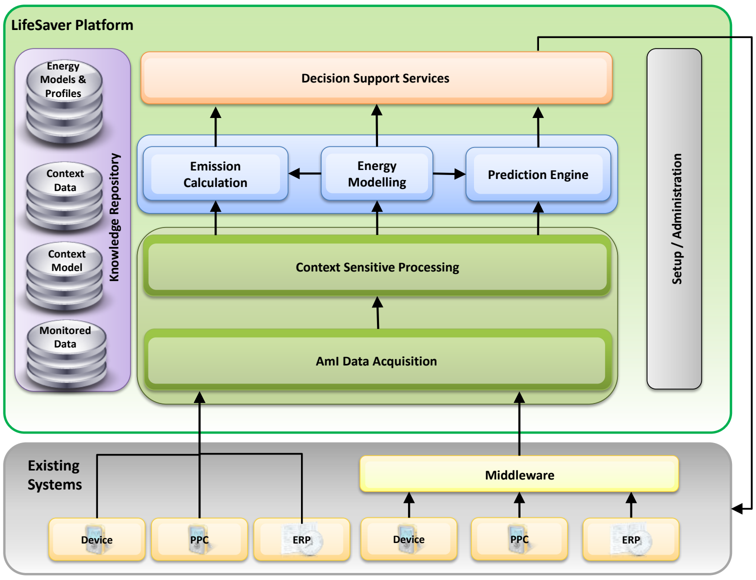

Figure 1: LifeSaver reference architecture

The arrows between the components in Figure 1 indicate just the main information flow, starting from the different sources of information (e.g. sensors, measurement devices or existing systems, connected to LifeSaver either directly or via existing middleware solutions) through the BB for AmI data acquisition and context sensitive processing, enhancing energy measurement data with context information. The functionality of this BB is the main focus of this paper and therefore described in more detail in the following section

The results of data acquisition and preprocessing are provided to the other BBs in order to enable different types of calculations/predictions and eventually provide decision support to the users, either via graphical user interfaces (GUIs) or in the form of a “feedback loop” into existing systems, meaning that LifeSaver could pass energy efficient control parameters directly to the existing production control systems. For the sake of clearness the access to the knowledge repository as well as the control flows between software BBs are not indicated in this figure. In general, all components are expected to exchange data via the knowledge repository but also direct communication is used to invoke the different services.

The BB for energy modelling, emission calculation and prediction engine congregates different information, like the measurements acquired, the context extracted and energy models to forecast the energy consumption of the company for a defined upcoming period. According to the LifeSaver approach, an energy model refers to a simulation of the energy use in an industrial plant. The

elaboration of the energy profile of a company or a section of the company, combining individual data on machines or processes, is the key prerequisite for the optimisation and reduction of energy consumption, raw material use and negative environmental impacts. The core elements of the energy model of an industrial factory are the so called energy cost centres ([2]). An energy cost centre can be any department, section or machine that uses a significant amount of energy or creates significant environmental impacts, for example whole production lines, single machines or furnaces. More information about the LifeSaver approach for energy modelling and prediction is given in [3].
All mentioned functionality for data acquisition, pre-processing, calculations and predictions together with the knowledge repository forms the foundation for the LifeSaver decision support services, which aim to provide a systematic mechanism for decisions on how to save energy in current operations, how to reduce emissions in a company and also on how to trade emission coupons. A detailed explanation of the LifeSaver approach for decision support is given in [4].

3. Data acquisition and context-sensitive processing

To enable the identification of energy consumption and emission patterns and to be able to give advice for optimizing energy performance, it is important to know the context in which a specific monitored energy use pattern occurred. In addition, to be able to provide an end user with the knowledge that is needed to support decisions in a particular situation, the system has to be aware of the context the user is currently working in. For these reasons an approach for context awareness is seen as a core element of the LifeSaver platform.
Context awareness is a concept propagated in the domains of AmI and ubiquitous computing. It describes the idea that computers can be both sensitive and reactive, based on their environment. It is difficult to find a single definition for the notion of context, but its importance in communication, categorization, intelligent information retrieval and knowledge representation has been recognized for many years. In the artificial intelligence domain, the concept of context is usually defined as the generalization of a collection of assumptions ([5], [6]). A common, pragmatic definition for context-aware applications, defines context as any information that can be used to characterize the situation of an entity ([7]).
Related to the LifeSaver focus on energy efficiency in manufacturing the notion of context refers to (actual) characteristics of the manufacturing process and products, devices, physical capabilities of the equipment, the environment conditions and the user.
To get the necessary information about the context of the energy use, LifeSaver intends to use information/knowledge from different existing systems, serving different applications in shop-floor, also those not primarily oriented towards energy use optimization. Besides others also ambient intelligent (AmI) systems are seen

as possibly interesting information sources for LifeSaver, as they could provide knowledge about the interaction of the human operator with the production processes ([8], [9]). In addition, if data cannot be received from existing systems it could also be necessary that new AmI or other measurement devices would have to be installed, or data would have to be manually inserted by end users of the software platform.

To support the aforementioned acquisition of data from different sources as well as the context-sensitive preprocessing and data provision the LifeSaver platform provides the BB for AmI data acquisition and context-sensitive processing (in the following referred to as AmI/Context BB). The software components that make up this BB, its interactions with end users as well as the basic relationships/information flows between this BB and other elements of the LifeSaver reference architecture are depicted in Figure 2.

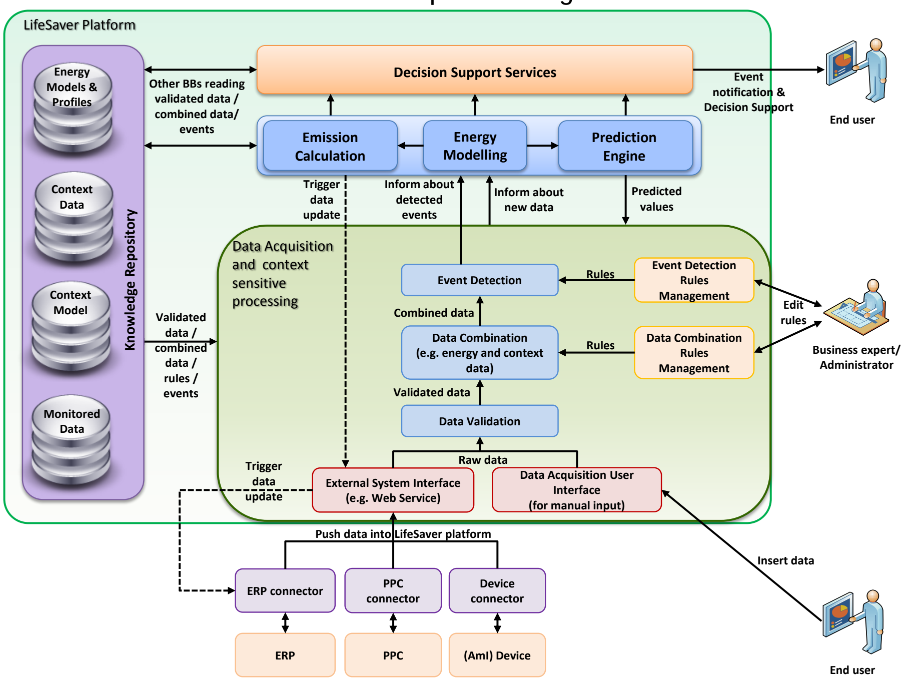

Figure 2: Components of the AmI/Context BB and interfaces to its environment

The internal software components of the AmI/Context BB are explained in the following:

- *External System Interface:* This component shall provide a single unified API (Application Programming Interface), able to receive data in a format according to a pre-defined common LifeSaver data model. Arbitrary external systems can be connected to this interface, but for each type of system a specific connector is necessary that is able to do the data format conversion between the external system's data output format and the LifeSaver data input format.

- *Data Acquisition User Interface:* This component provides an interface for users to insert data that is required by LifeSaver but cannot be read from existing systems, either because it is not available at all or not accessible due to missing interfaces or missing access rights.
- *Data Validation:* This component validates all incoming data from the external system interface and the data acquisition user interface. Depending on the validation result it either passes the data to the upper components or rejects it.
- *Data Combination:* This component combines input data (possibly from different sources) to get more meaningful information (e.g. contextualised energy consumption data). The data combination component uses configurable rules for the data combination, for example:
  - Connect energy consumption values measured by a specific device with temperature values measured by a sensor, using identical timestamps as criterion to map the data from the different sources.
  - Calculate the data “Power” by multiplying the input data values for “Voltage” and “Ampere”.
- *Data Combination Rules Management:* This component manages the rules for the data combination component. It provides a GUI enabling an administrator/expert user to add, edit or remove data combination rules.
- *Event Detection:* This component is responsible for detecting events based on context-enhanced energy consumption data. Based on configurable event detection rules it notifies other BBs in the LifeSaver platform that need information about specific types of events. For example, a user shall be able to define thresholds for energy consumption levels in a specific context, so that consumption higher than the threshold should trigger a warning/alarm. It should be noted that also “events that are expected for the future“ could be detected by this component, because the prediction engine will pass predicted values to the AmI/Context BB, which will process these values the same way as it does with actually measured values.
- *Event Detection Rules Management:* This component manages the rules for the event detection component. It provides a GUI enabling an administrator/expert user to add, edit or remove event detection rules (e.g. “If the power of a certain machine ‘X’ in operation mode ‘Y’ exceeds 120 kW, then send a notification to the decision support BB”).

As mentioned before, to connect external data sources to the LifeSaver platform, a connector is needed, which has to be implemented for each type of external system (e.g. for each specific type of SCADA system a new connector will have to be developed; in case two companies use the exact same type of system, such a connector will be reusable). To ease the implementation of new connectors, LifeSaver aims to provide a generic “software stub” that is able to communicate with the external system interface of the AmI/Context BB. It is foreseen that such a

connector can also be “triggered” by the LifeSaver platform to get the latest data from the external data source.
To ensure that the data processing of the Ami/Context BB will be adaptable to different application scenarios, the rules for data combination, transformation and event detection will be configurable by administrator/expert users, as already indicated by the aforementioned functionality for rules management.
It should be noted that specific needs for decision support related to energy efficiency optimisation and emissions trading should be pre-defined as starting point to define and implement external system connectors as well as data processing rules in a particular company. Based on a clear definition of the required decision support functionality the requirements for data acquisition and processing should be derived in a top-down approach, aiming to ensure that the gathered and pre-processed data will be sufficient and in the appropriate form [10].

4. Case study: application of the platform for decision support in a large paint production company

Commerce and industry are responsible for about three-fifths of the electricity consumption in Germany, while about two-thirds of the electricity needed by the German industry is consumed by electrical drives. Especially in the process industry large amounts of electricity are consumed, leading to energy costs being an important driver of the overall production costs.
One of the industrial end users participating in the LifeSaver project is J.W. Ostendorf GmbH & Co. KG (JWO), a large producer and supplier of paints and varnishes, located in Coesfeld, Germany. The technology provider company OAS AG supports the paint production by providing JWO with highly automated process technology in a combination with weighing, measuring and control technology.
The energy consumption by JWO’s production processes represents one of three industrial application scenarios that are addressed in the LifeSaver project (another scenario, dealing with energy efficiency and CO2 emissions of a large cement producer in Slovenia, is presented in [3]). As industrial end user, JWO will provide a real testing environment for the validation of the project results. OAS as technology provider will support the development and the validation of results, particularly regarding the platform development and its integration with existing control systems at JWO.
The main objective of JWO in the LifeSaver project is to establish an optimized energy efficient production planning and control. It was decided to first focus on large-scale consumers of electricity in the context of the production of white dispersion paint. The intention of this clear selection of a process area to look at is to first focus on particularly energy intensive areas of the production processes, where the expected potentials for energy and cost savings are the highest.

The production of dispersion paint is basically about mixing/dispersion of powdery, liquid and pasty recipe components, following a stored recipe. The laboratory formula is deposited in the form of a flow formulation in a software system provided by OAS, which is a process visualisation system for SCADA and a control system for the process and production control level (MES). The production start is initiated manually by an operator, and subsequently the procedural recipe is automatically controlled by the OAS software system.

After the dispersion of a batch is completed, the product is transferred via pumps and piping into one large tank, where it is completed. After the final quality control the product gets to the canning machine where it is canned in different packaging shapes and sizes, and then gets stored.

A major part of the production process is controlled by the OAS software system, namely the dosing, manual additions, the dispersing/mixing, and the transfer between tanks. Looking at the energy consumption related to the production of white dispersion paint, large-scale consumers of electricity are mixers with a drive power of up to 215 kW, cooling units with a demand of up to 200 kW as well as compressors with a demand of up to 90 kW.

In the scope of LifeSaver the business objectives of JWO in this production area are the following:

- *Load management:* The cost for energy raises exceptionally when load peaks occur that are above the load defined in the contract with the electricity supplier. This is due to the fact that the installed grid capacities need to be much higher if there are big peaks in the load curve of large-scale energy consumers. JWO expects that there is a significant potential to avoid or diminish the load peaks by optimization of the production planning and control. A precondition for such an improved load management is the monitoring of the energy usage of (large-scale) consumers as well as the “production context”, in order to get knowledge about the load curve against the status of the production processes.
- *Energy efficient control of installations:* Currently, the startup times and operating times of some of the manufacturing installations are controlled manually by human operators. With the availability of the data about energy usage and “production context” the operating times of these installations shall be optimized in order to keep them running only as long as required by the current production plan, enabling an energy optimal operation of production equipment.
- *Selection of energy efficient production lines:* The dispersion paint can be produced on different production lines, equipped with different dispersers, resulting in varying energy consumption for the production of the same product type and batch size. Hence, decision support for the selection of the most energy efficient production line is expected to be an appropriate means for JWO to reduce energy consumption in production processes. A precondition for this decision support is the collection and provision of historical energy consumption profiles for all different types of dispersion paint, also taking into account the

batch size produced, in order to provide the knowledge required for the selection process.

- *Information provision:* Another envisaged type of decision support, in addition to support for process planning and control, is to provide, ad-hoc on user request, historic information and/or predicted information about energy consumption as basis for contract negotiations with energy suppliers.

To support the aforementioned business objectives, the LifeSaver platform shall provide different types of decision support services to different types of users at JWO. These services will be based on information from existing systems and measurement devices as well as user inputs. An overview of the envisaged integration of the LifeSaver Platform in the JWO scenario is depicted in Figure 3, while some details about the different interactions between the LifeSaver platform and end users as well as existing systems are explained in the following.

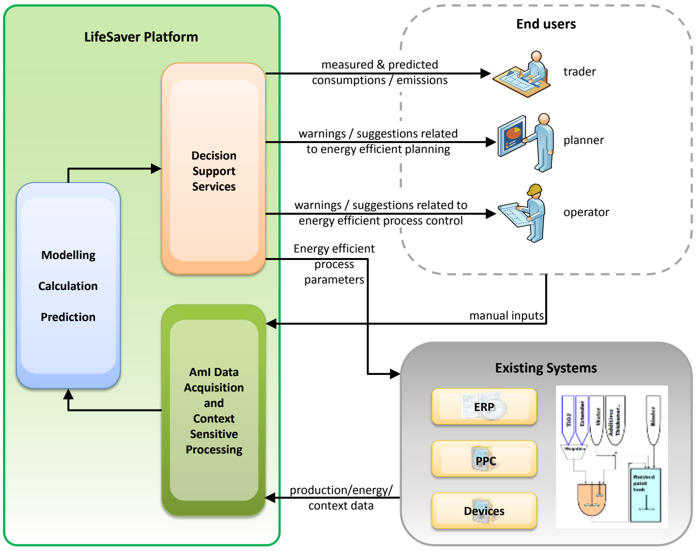

Figure 3: Envisaged integration of the LifeSaver platform at JWO and its communication with users and existing systems

The main objective of the LifeSaver decision support in the JWO case is to improve the production planning and control by integrating energy efficiency as an additional target, besides productivity and cost efficiency, into the existing planning and control procedures. As an example, the production planner as well as the production control operator shall get warnings and/or suggestions like:

- Which production orders should run (or not run) at the same time
- What would be the optimal sequence to start the production orders
- What would be the energy optimal production line for each order
- Which minimum time delay should be kept between the starts of two consecutive production orders

- Which machines are (or will be) running longer than necessary and could be switched off earlier (or switched on later) in order to save energy

A simplified example of suggestions related to the electricity load management is indicated in Figure 4 and Figure 5, where the X axis denotes time and the Y axis denotes the electricity load. Each figure shows the load curves caused by two production orders A and B, which are starting at the same time, as well as the overall load curve, which is in this example just the sum of A and B. Figure 4 shows the initial plan which leads to a high peak load at time t=4.

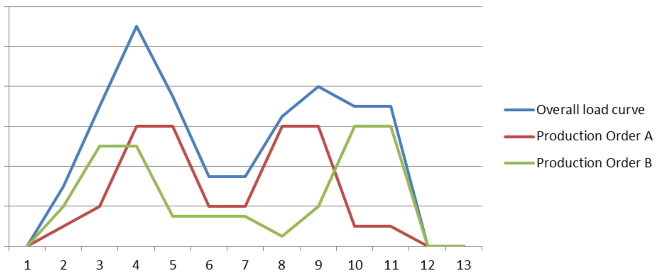

Figure 4: Load management example – initial load curve

Figure 5 shows a suggestion how to smoothen the load curve. The first suggested adjustment would be to delay the start of A in order to avoid the high peak load at t=4. Obviously the downside of this would be an even higher peak load at t=10, therefore the second suggestion is to add a short waiting time in B at t=8. The result is a smoothed load curve but also a slightly prolonged runtime of the production orders. Therefore, although suggestions for energy efficiency improvement should be provided by LifeSaver, the human planner/operator should in any case have the final decision, because in some situations the due dates for delivery to customers could force the planner to select the most time-efficient programme, not necessarily being energy efficient.

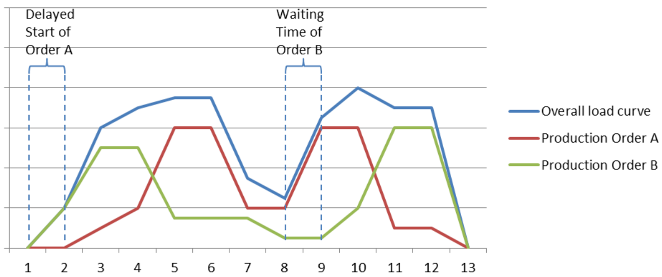

Figure 5: Load management example – suggested improvements in production planning to smoothen the load curve

Besides the direct information presentation to end users the JWO application scenario will probably also require a kind of "feedback loop" into the existing systems, where the decision support module should provide optimal settings/adjustments of process control parameters in order to improve energy efficiency. Based on this information the production control systems could for example automatically delay particular process steps of already running production orders for a short time in order to avoid peak loads.

5. Conclusions and outlook

This paper presents the concept of the LifeSaver software platform, currently under development, that shall support energy consumption monitoring and context-sensitive decision support related to energy efficiency and emissions trading in manufacturing industry. To build a knowledge base as foundation for the decision support the platform shall support acquisition of various types of data from different sources as well as pre-processing of the acquired data based on user-defined rules, to enhance energy consumption data with information about the context in which the consumption occurred.
To ensure its industrial applicability the LifeSaver platform is, already in parallel to its development, tested and initially validated in three application scenarios. Based on the validation results from the industrial applications it will be iteratively improved and optimized. The long-term goal is to further develop the platform components to be as generic as possible, so that the platform can be easily adapted to different industrial requirements in other companies, mainly by usage of its configuration features.

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