JEERP: Energy Aware Enterprise Resource Planning

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Ever increasing energy costs, and saving requirements, especially in enterprise contexts, are pushing the limits of Enterprise Resource Planning to better account energy, with component-level asset granularity. Using an application-oriented approach we discuss the different aspects involved in designing Energy Aware ERPs and we show a prototypical open source implementation based on the Dog Domotic Gateway and the Oratio ERP.

Enterprise Resource Planning (ERP) is a mature technology playing a pivotal role in business operation, where it allows integrating internal and external management information across entire organizations, embracing: finance/accounting, manufacturing, sales and service, and customer relationship management. While it efficiently handles the entire flow of information between all business functions inside the boundaries of the organization, it mainly applies to traditional assets such as feedstock (semi-processed materials), purchased items, operating machines and employees work. Ever increasing energy costs and saving requirements, however, are fostering ERP design and research [1] to better account energy assets in enterprise planning [2], especially for industrial sectors involving high energy consumptions, e.g., mechanical factories. In this context, IT is used as enabling technology to improve industrial processes both on the green and on the economic standpoint.

While currently available solutions (such as SAP Green IT initiative, http://www.sap.com/lines-of-business/IT/Green-IT) support energy assets very roughly, by considering the aggregate consumption (at the building or at the cost center level), only, increasing granularity is needed to fully evaluate the contribution of energy assets to the overall product economy. Due to the increased changes in energy sector, e.g., the upcoming smart grid, energy optimization should be considered as another key indicator for cross layer optimization. In order to achieve this optimization, energy has to be measured locally and almost in real time, while manufacturing control activities should also be aware of the energy consumed [3] .

Here, we introduce JEERP: an approach to integrate classical ERP systems with energy consumption information at the asset-level, in real time, and, while discussing requirements and peculiarities of involved aspects, we show a real-world solution based on extensions of some of our previous works: the Dog gateway [4] and the Oratio open source ERP (http://oratio-project.org).

IT Challenges

Bringing detailed energy information into ERPs poses several interesting IT research challenges that we analyze and tackle in our solution.

i. *Identification of energy greedy areas and trade-off between pervasive metering and cost-effective solutions*. Pervasive metering, i.e., one meter per device approaches, might be appealing, supporting energy characterization of all elements of the industrial production by drilling down measures to single machine cycles, with the highest possible granularity. Such a solution, however, is too often unfeasible: metering costs in small and medium industrial settings can, in fact, easily overcome the possible savings. A suitable trade-off must therefore be found between measurement granularity and costs, possibly exploiting already existing information (e.g., machine cycles) at the SCADA level.

ii. *Handling of possibly huge amounts of data, with a time-granularity often too fine to be effectively exploited at the ERP level.* Big data flows typical of smart metering are almost impossible to handle at the ERP level, where completely different data rates and behaviors are expected. Raw data (e.g., power consumption) is seldom interesting under the resource planning standpoint whereas aggregate information (e.g., the hourly, daily, weekly energy consumption) is much more appealing. However finer granularity is desired to support analytics and to quickly react to critical situations (alerts).

iii. *Handling of real-time alerts on monitored assets*. While most of the ERP processes work on a day/month scale, the availability of real-time energy and process information allows better addressing of machine failures, both on the production scheduling standpoint and on the maintenance management side, possibly supporting early detection, and solution, of critical issues.

iv. *Persistence of field-level information to perform off-line business intelligence analysis*. Measures extracted from the metering infrastructure and process-related variables computed by the ERP system can be combined by a business intelligence analysis contributing to the identification of hidden correlations between costs and consumption behaviors. This, in turn, results in improvements and optimizations of the production process leading to tangible savings, in terms of time, cost and efficiency. To enable such analysis, however, data shall be persisted and made available for offline processing by using advanced storage solutions, possibly based on the NoSQL paradigm (like Apache Cassandra, http://cassandra.apache.org/).

v. *Integration between ERP and Supervisory Control and Data Acquisition systems (SCADA, i.e., systems that monitor and control industrial processes that exist in the physical world).* Energy consumption measures are more valuable if they can be correlated with a specific industrial process, or even to parts of the process. Although this is typically available at the process control level, thanks to SCADA systems, such information is usually confined in the control network and seldom trespasses the realm of automation towards the domain of resource planning (SCADA-to-ERP). On the other hand, anomalies and alerts sensed, or generated, at the ERP level are usually human-handled, whereas automatic reaction using ERP-to-SCADA communication would be much more effective, both in terms of costs and plant safety.

JEERP: Java Energy-Aware ERP

We tackled the integration of energy information in ERP systems as a joint project, named JEERP, between Proxima Centauri and the Politecnico di Torino. The main goal of the project is to define and validate a software architecture for integrating real-time consumption and asset management in to a ready-to-use open source ERP. This allows business managers and stakeholders to integrate traditional economic indicators with quantitative information about the energy costs related to each single asset of the production system. As reported in literature [2] [3] [5], increased energy consumption awareness, with asset-level detail, can be directly related to improved performance of factories and/or companies, under the business viewpoint.

The logic architecture of the proposed solution (see Figure 1) exploits four main components: a modular SCADA gateway (the Dog2.3 Domotic OSGi Gateway), a data collection layer (Collector) exploiting Complex Event Processing [5] (CEP) (by means of the spChains stream processor), an asset manager extended to deal with energy assets (CMDBuild) and a traditional ERP system (Oratio). All components follow a strict open-source distribution policy supporting the system spread at virtually no costs, thus offering an option for whatever-sized business stakeholders to start accounting energy aspects in their daily operation.

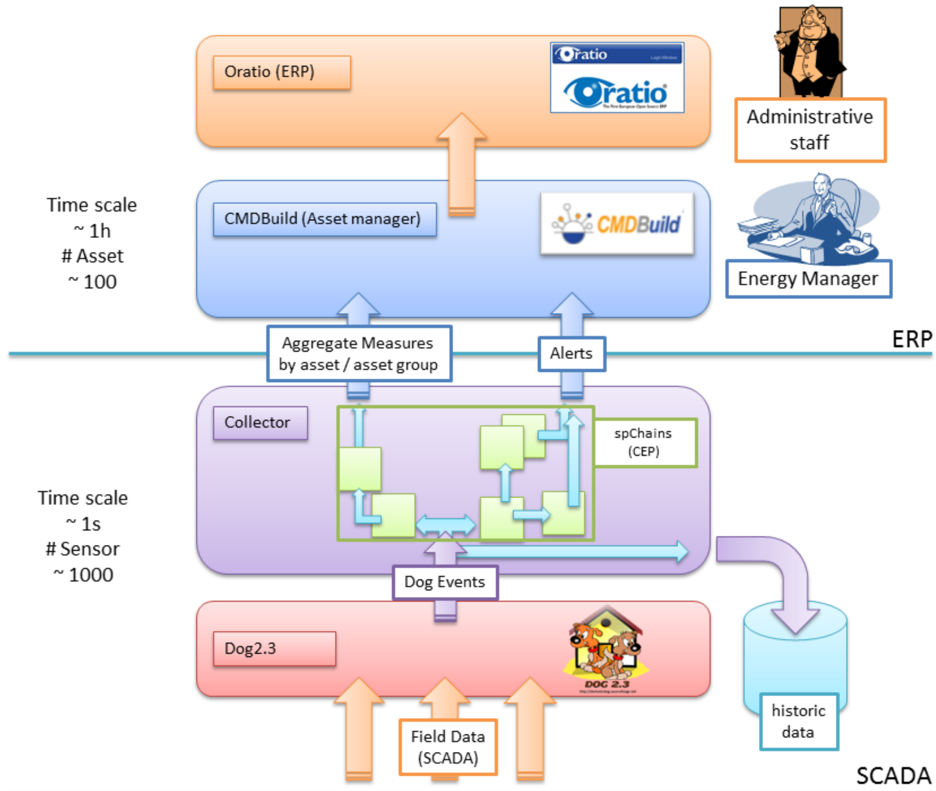


Figure 1. The JEERP logic architecture.

Starting from the metering infrastructure, the JEERP logic architecture involves 4 main components each tackling a subset of the above cited issues.

SCADA Gateway

SCADA-to-ERP and reverse communication is provided by the Dog OSGi gateway. Dog exploits a modular structure based on the OSGi framework, and interfaces both metering and SCADA systems by means of suitable software driver bundles (it currently supports KNX, Modbus, Echelon, and OpenWebNet technologies). Thanks to the adoption of an ontology model of devices (DogOnt [6]), which describes their functionalities, possible states and generated events (notifications), Dog is able to abstract the SCADA and Metering layer protocols to a single, high-level, event-based and technology independent language based on XML messaging (either through XML-RPC or REST). Such an abstraction decouples the measure-handling layer and the ERP systems from the actual plants, thus supporting the portability of the architecture over different industrial settings.

Data Collection Layer

Measures extracted from the field are uniformed, abstracted and delivered to the upper layers as Dog Events. These events preserve the same temporal and cardinality features of field level data, i.e., they are delivered very quickly (1 event/s or faster) and typically involve numerous sensors (>1,000). To avoid overloading the ERP and the Asset management systems, this big data flow shall be aggregated, decimated and persisted, thus enabling higher layers of the architecture to work on more meaningful and actionable data. The Collector module tackles these issues by exploiting two parallel information channels. The former directly delivers full-rate/full-granularity events into the persistent storage (typically a transactional database), by applying suitable event bundling to avoid overloading the underlying DBMS. This provides support for later, off-line business intelligence applied on field data and ERP variables. The latter, instead, exploits Complex Event Processing (CEP) techniques to elaborate events fed by Dog in real-time.

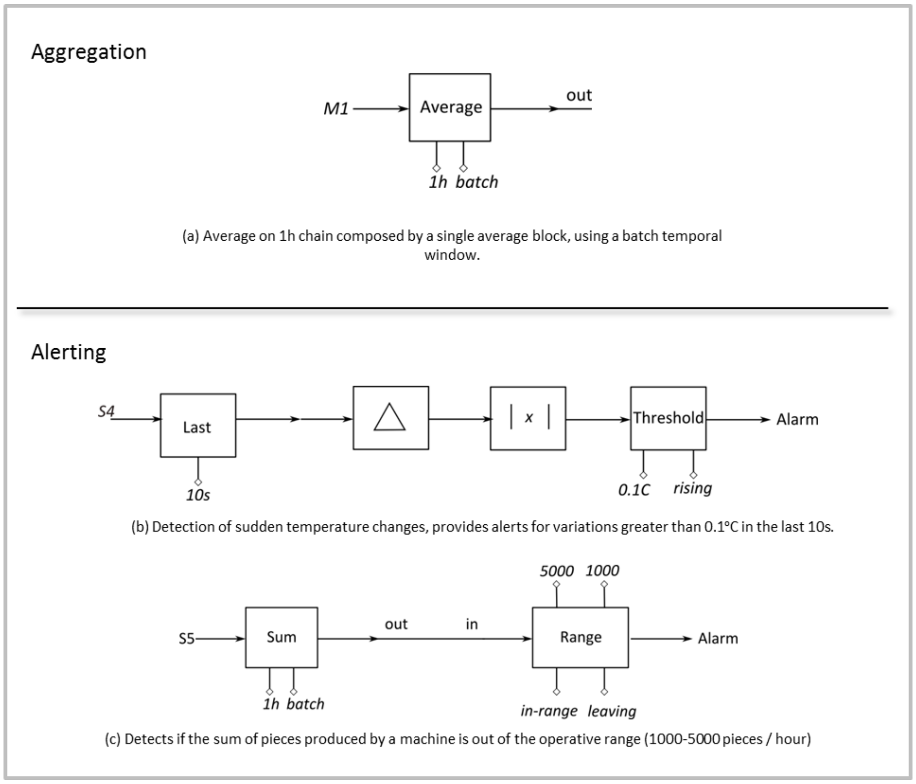
Complex Event Processing Pros and Cons

According to Luckham [5], "Complex Event Processing is a set of tools and techniques for analyzing and controlling the complex series of interrelated events that drive modern distributed information systems." Typical CEP engines effectively handle data at rates between 1,000 to 100k messages per second, thus being suitable to both support real-time data aggregation and alerting.

Event processing computations carried by the collector, however, must be definable by Energy/Asset managers and by the ERP administration staff, depending on the actual analysis needs. This prevents direct adoption of current CEP engines, such as STREAM [7] or ESPER [8], which require specific knowledge and custom programming to be operated. Moreover, direct writing of customized CEP queries (e.g., in CQL) is seldom suited for industrial settings where the ability to reuse validated processes is a key factor to cost reduction. We therefore adopted our spChains framework (Stream Processing Chains, which offers block-based CEP based on ESPER) which enables block-based programming of stream-elaborations while retaining a satisfying processing capability (up to 170k event/s).

spChains

SpChains [9] addresses stream processing by composing elaboration chains (Figure 2) built atop of a set of standard, yet extensible, stream processing blocks, hiding the underlying CEP complexity. SpChains blocks do not represent the complete set of elaborations allowed by full CEP engines; instead they are focused on providing a flexible, reusable and easy-to-learn processing facility for non-experts, with a particular focus on needs emerging from the energy management and ERP domains, while retaining CEP optimization in single block implementations.



(a) Average on 1h chain composed by a single average block, using a batch temporal window.

(b) Detection of sudden temperature changes, provides alerts for variations greater than 0.1°C in the last 10s.

(c) Detects if the sum of pieces produced by a machine is out of the operative range (1000-5000 pieces / hour)

FIGURE 2. STREAM PROCESSING CHAINS FOR (a) AGGREGATION AND (b,c) ALERTING.

Both aggregation (Figure 2a) and alerting (Figure 2b, c) are supported through 2 main families of processing blocks respectively handling Boolean or Real events. Blocks can be mixed and connected according to well-defined composition semantics.

Using spChains, complex elaborations can be easily set-up in the collector, without requiring any CEP knowledge and without binding the solution to a specific stream processing engine: the ESPER backend can in fact be easily replaced with other solutions such as STREAM, etc.

ASSET MANAGER

The asset manager is the first ERP-side component of the JEERP logic architecture. It deals with the systematic process of cost-effectively operating, maintaining, and upgrading enterprise assets. An asset is a tangible or intangible resource capable of being owned or controlled to produce value and that is held to have positive economic value. In JEERP, asset descriptions are extended beyond economic indicators to include energy consumption. The latter information, in particular, can either be represented as a new asset, subject to the same optimization mechanisms used for the other enterprise assets, or as an additional element to evaluate the costs and to manage other existing tangible and intangible assets.

Our proposed solution for asset configuration and management is based on the CMDBuild open source system (http://www.cmdbuild.org), by Tecnoteca. CMDBuild is a web-based application specifically designed to define and manage the asset database of a given enterprise and to support full workflow management. It is distributed under the GPL v2.0 license and strictly follows the Information Technology Infrastructure Library (ITIL) best practices on IT service management. It offers a modular, service-oriented architecture easy to extend and integrate into larger ERP systems. Proxima Centauri (author of the Oratio ERP) and Tecnoteca (an Italian Web Company) collaborated together for integrating energy asset management and evaluation in the current release of CMDBuild.

ERP

Economic values associated to energy consumption, e.g., energy retailer invoices, are accounted at the ERP layer, including all pricing-specific details such as: hourly and daily tariffs, financial penalties, cost disaggregation (energy, taxes, delivery), etc.

Given the energy figures associated to a particular asset, the ERP layer is able to extract all the other economic values characterizing the asset and to correlate them to evaluate the Energy Economy Balance for the given asset and, by induction, for the entire enterprise. The bigger picture involves full integration of energy assets in enterprise planning, with a particular focus on the production process optimization domain, according to the Manufacturing Resource Planning (MRP II) system. The production planning should, in fact, depend on energy availability, at the forecasted costs corresponding to the planned production timeframe, and on the type of energy to be employed in a specific process.

Energy accounting must also be integrated in the economic evaluation of production processes (process accounting) as the availability of energy information supports direct correlation of energy costs and product lots, increasing the accounting granularity and precision in an unprecedented manner.

Prototype

We deployed and tested all the architecture components both separately and jointly and we set up a first complete installation (Figure 3 reports a screenshot of the running system) in the Proxima Centauri premises (the JEERP project description and a demo can be reached at http://www.jeerp.org).

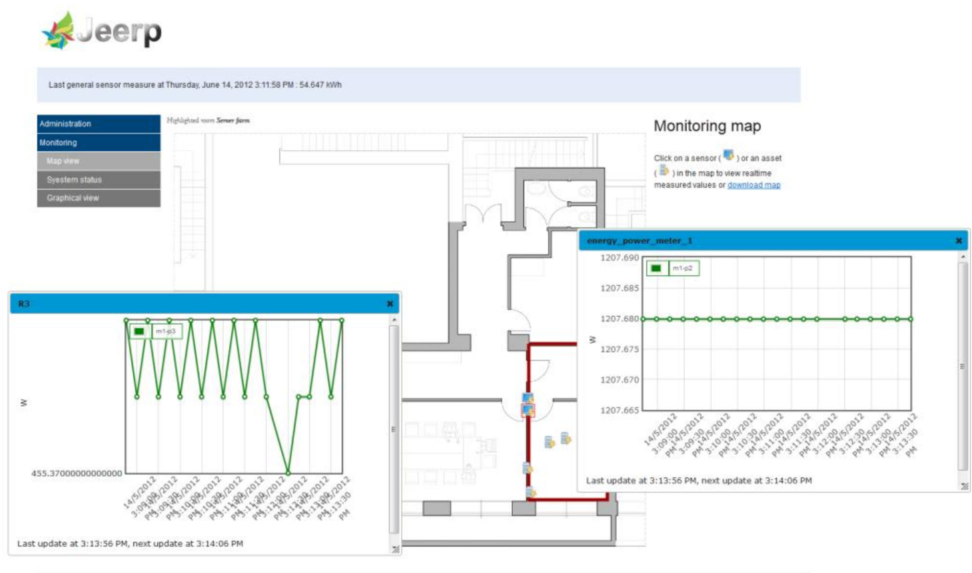


FIGURE 3. A SNAPSHOT OF THE JEERP SYSTEM INSTALLED AT THE PROXIMA CENTAURI PREMISES, WHERE INSTANTANEOUS AND HISTORICAL CONSUMPTIONS FOR BOTH SINGLE (SERVER) AND AGGREGATED ASSETS (ROOMS) ARE SHOWN.

The installation involved the following steps. First, the Proxima Centauri premises have been profiled from the energy point of view, and critical consumption points have been identified: the data center and the HVAC system. Then monitoring granularity has been tuned to achieve a suitable trade-off between infrastructure costs and gains due to forecasted savings. We reached an agreement on a 2 three-phase meters installation with 6 different channels being monitored. The entire monitoring network is based on the KNX system as it was the easiest to integrate in the existing premises plant. The Dog gateway acts as SCADA gateway thanks to its KNX driver, and is deployed on an industrial-grade embedded PC equipped with a 1.6 GHz Intel Atom processor, 2 GBs of RAM and 320 GBs of mass storage. The same hardware also runs the Collector module (exploiting the spChains framework); they can, however, be distributed on several machines in more demanding settings. Energy meters provide measures for instantaneous power (active/reactive/apparent), voltage, current, power factor and energy. Each quantity is sampled at 1 Hz, resulting in an overall data stream of 38 events/s, easy to handle from a stream processing standpoint. Data persistence has been implemented by using a PostgreSQL server instance running in the data center.

For each measured quantity one aggregation chain has been defined, with a 15 minutes time frame, typical in the energy management domain, and with computations depending on the monitored physical quantity: average and peak for power measures, difference (delta) for energy measures, peak values for voltage and current.

Three alert chains have been configured, two monitoring the HVAC system consumptions to prevent possible failures and one on the total power consumption to detect peak absorptions in high-tariff hours.

Events aggregated and filtered by the collector layer are delivered to the subsequent CMDBuild layer by means of a web-service connection, supporting deployment of the higher level of the JEERP architecture on machines located in places typically distant from the field (the enterprise datacenter).

Conclusions

The first-prototype system has been configured and tested on January 2012, and it is running continuously since then, with no failures or downtimes. Energy consumption information integrated in the Proxima ERP system already triggered an increased awareness of related costs, from the business standpoint. The availability of such information, distributed at the single asset granularity, is in fact fostering a migration of the data center facilities to less powerful (Intel Atom-based servers) but more energy efficient hardware and software architectures.

The JEERP architecture is currently in its first stable release and supports building-wide installations involving hundreds of sensors. In the current release the presented architecture is integrated with business intelligence features to better support cost analysis and identification of related factors in decisional processes. In particular, we are collaborating in a France-Italy cooperation project (Alcotra) where 2 educational buildings are monitored for energy consumption, and economic indicators are extracted to drive more informed decision on building management.

Acknowledgements

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