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Methodology and model for predicting energy consumption in manufacturing at multiple scales

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Abstract

Certain fields of manufacturing, like casting, forming or cutting, may cause high energy load. Especially under the consideration of renewable energy sources it is beneficial to negotiate production schedules and consumption forecasts with the energy supplier. This would enable an optimized management of energy sources and infrastructure components on the supplier side, helping to reduce costs. Optimal and balanced expenses for production would be the consequence.

The problem of power consumption prediction in manufacturing was subject of many studies in the past. Most of them either consider the physical modeling of processes at a very detailed level, or they introduce tailored prediction models for specific production processes. Thus, it is hard to apply their results to other uses cases in different scenarios.

As a consequence, a generic methodology and model regarding power consumption prediction in manufacturing is required in order to cover the variety of processes, machines and materials. Furthermore, an approach must support flexible levels of granularity for predicting the energy consumption of manufacturing processes. On the one hand, a whole factory may be the object of investigation while, on the other hand, predictions for finer-grained levels, such as certain parts of a machine, are required to allow for specific optimizations.

Our contribution is twofold. First, we propose a generic model for the specification of the power-consuming machine. A tree-based compositional approach supports arbitrary levels, depending on the structure of the machine, or external factors, such as company policies. This approach is highly extensible since the models are stored in ontologies. Second, we propose a methodology for static and dynamic modeling of power consumption for every structural level. Based on that model the prediction can be realized. In addition, we provide an example implementation and prediction for a continuous casting machine process.

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Keywords: Energy efficiency; Predictive Model; Ontology

1. Introduction

Current change and trends in German and European energy markets demand for a transition to flexible energy consumption in industry wrt. the produced energy [1]. Production planning must take the energy supply into account which is decentralized due to both the German Renewable Energies Act (EEG) and Europe's climate and energy

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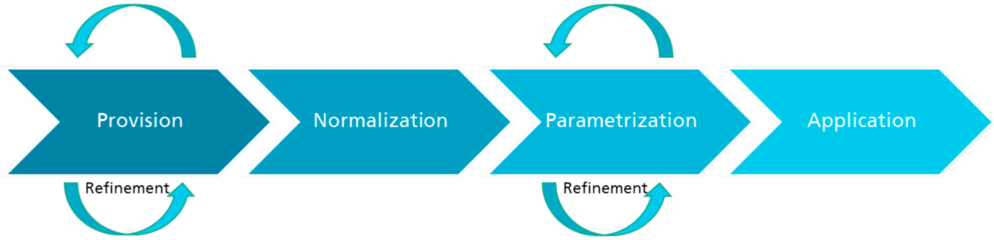

Fig. 1. Methodology for predicting energy consumption in manufacturing processes.

targets [2]. In order to realize flexible control of industrial energy consumption energy-related data must be made accessible from both the consumers and the suppliers.

Consumers have to provide information about their energy-consuming infrastructure. The level of abstraction of such data can vary depending on, e.g., technical prerequisites or just internal regulations. As a consequence, energy-related data might be available for a whole factory only or, in the best case, for concrete aggregates of the machines. The finer grained the provided information is the more flexible the control of consumers can be achieved. More precise information means more potential for energy-related optimization of production processes.

On the other side, suppliers should publish their financing models so that the best point in time of a costumer's production can be scheduled. In this paper, the authors will cover only the part related to the industrial energy consumers.

Due to the lack of a standard which can be used to exchange energy-related data, consumers are free to decide which data format to use. As a consequence, the main problem is that there are two distinct dimensions, *data source* and *data access*, to retrieve data formats from. On the one hand, *data sources* can be, e.g., estimated or measured (historical) data or even a physical model of the energy consumption. On the other hand, such sources can potentially be *accessed* in various kinds, such as, e.g., through an Excel sheet, databases, time series or even via Matlab/Simulink models. We consider this fact as a required freedom for data suppliers, but as a consequence we are faced with an amount of potential data formats to be supported as the cross product data source × data access.

To overcome this problem, a normalized data format is needed that is flexible enough to support all the properties and requirements of the existing conventional data sources. Our approach presented in this paper is based on an ontological representation in order to ensure flexibility. It is divided into two parts: 1) structure of the energy consumer, and 2) specification of its energy behaviour. The former follows a given schema which enables the hierarchical definition of consumers on arbitrary levels of granularity. The latter provides core concepts for specifying static and/or dynamic behaviour of consuming energy. These are needed to be accessed and processed automatically.

In the remainder of this paper we describe a methodology for the iterative specification of energy consumers in Sect. 2. Based on this, the formal grounding for defining the structure and our approach of specifying the static energy behaviour models is presented in Sect. 3. To complete the approach, our solution for defining the dynamic energy behaviour is described in Sect. 4. Our implementation and a demonstration for a continuous casting process is given in Sect. 5. The related work in Sect. 6 and the future work outlined in Sect. 7 conclude the paper.

2. Methodology to enable iterative specification of consumers

As mentioned before, a general approach and a normalized data format is required to support the exchange of arbitrary energy-related data. To enable prediction of energy consumption for manufacturing processes we propose the high-level methodology in Fig. 1 which is refined and explained in the following.

Our proposed methodology consists of four main steps. In the beginning, the **provision** of energy-related data initiates the process. To predict energy consumption such data is separated into the consumer's structure and the relevant consumption information corresponding to the structure. We explicitly link this information in order to emphasize which unit consumes a particular amount of energy. Furthermore, we propose an iterative approach for providing the energy-related data to respect the hierarchical nature of an energy-consuming entity. Consider, e.g., a *continuous casting machine* located in a *factory*. The machine consists of several *aggregates* and *units*, such as