Determination of real-time operating data by means of pattern recognition from energy profile in production

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Abstract. Manufacturing companies operate in increasingly turbulent and discontinuous environments. The rapid speed of change, coupled with a high complexity of cause-effect relationships of industries, globally-dispersed markets, technologies and economic areas create great challenges to the manufacturing systems. This particularly concerns SME's, whose competitiveness is increasingly dependent on their ability to dynamically respond to these in an adequate fashion. Adding to this, is the growing awareness of natural resources, requiring consistent energy conservation measures.
The following article addresses this problem and introduces the concept, developments and first application experience of the research project iKnowControl, which enables to identify real-time operational data using pattern recognition from energy profiles based on existing energy data collection systems. Using suitable pattern recognition methods, energy consumption data, among other things, could be read, and thus the part currently being manufactured on a particular machine, or the number of parts already being manufactured plus the average production time is recognizable. The described method offers a sufficient transparency and significantly improved options for increasing the level of automation and integrating suitable Industry 4.0 solutions, especially for small and medium production companies.

Keywords: Resource Efficiency, Manufacturing System, Pattern Recognition

Motivation

Constantly increasing competitive and cost pressures, as well as increased demands on technology and flexibility pose major challenges for manufacturing companies. Adding to this, is the growing awareness of natural resources, requiring consistent energy conservation measures. According to a study by the FELTEN Group, energy efficiency in terms of production has reached a leading position in the ranking of strategic priorities. It is now on the same level as the goal of increasing cost-effectiveness in production.

According to this study 59 percent, 57 percent respectively of the 250 companies surveyed, attach great importance to these two goals, followed by the improvement of production management (53 percent) and process optimization [1]. There are large numbers of providers of energy data collection systems, so that producing companies recognize energy waste and increase their energy efficiency through targeted, mostly organizational measures. Examples include employee awareness, on-demand switching on and off of less heavily used machines, and systems/modules to avoid high base-load consumption. In addition, this can be used to meet certification requirements that have a monetary impact [2][3]. However, in all these solutions it must be criticized that they are very much subject to manual evaluations and interpretations for the implementation of measures. This means, that the exploitation of the potential of energy efficiency in production is far too much dependent on the knowledge, the motivation and the implementation capacity of the persons responsible for energy management. Additional relevance lies in answering the question as to what extent the insights gained are implemented in the company, in particular by the production staff, which often have a hard time identifying the topic of energy efficiency in its corporate relevance in practice.

Considering the international state of the art, there are various solutions that incorporate energy efficiency in the production calculus, such as the control of peak load in production. The disadvantage of such solutions lies in the fact, that they relate exclusively to the energy consumption of controllable systems and units. Nowadays, it is possible to regulate ovens, compressors or ventilation, to name some examples, when a fixed peak load is exceeded or threatens to be exceeded in a certain power range. However, the inclusion of planned and released production orders with their routings and quantities does not take place. Despite recorded energy requirements for individual work operations, potentials are wasted since they are not considered in operational planning. Short-term adjustments within production control do not take place due to energetic aspects [1] [2] [3].

The possibility of feedback - based on the existing energy consumption of machines/facilities and their work operations - on current production progress and status messages on machine conditions is not being used. Using suitable pattern recognition methods, energy consumption data, among other things, could be read, and thus the part currently being manufactured on a particular machine, or the number of parts already being manufactured plus the average production time is recognizable. In the event of large individual deviations or machine downtimes, that are due to prolonged base load operation, this information should immediately be reported to the responsible parties. The continuous collection of this classic real-time operational data is only possible through the integrated networking of machines and systems based on modern MES systems (Manufacturing Execution System). However, such solutions - even in smaller versions - are very cost-intensive and thus hardly ever used in smaller companies and only to a limited extent in medium-sized companies. As a result, there are no efficiency advantages that could result from greater process transparency and significantly improved options for increasing the level of automation and integrating suitable Industry 4.0 solutions.

State of the art

In literature there are different approaches which try to consider the planning of the energy consumption into the production control. Newer interesting approaches shall be presented in the following:

- The research project EnHiPro (Energie- und Hilfsstoffoptimierte Produktion) is funded by the BMBF and based on a continuous energy data collection. It addresses the question of how the efficiency of energy and auxiliary materials can be improved. Therefore technical and organisational methods are developed to evaluate the energy efficiency as well as their effects [4].
- AssiEff (Assistenzsysteme für die auftragsbezogene, effiziente Produktion) is a research project which try to improve the operational excellence in production facilities during operation. A special start-stop control allows an automatic shutdown of not needed machine components to save energy. In addition, an energy efficient sequence of order should lead to further reductions [5] [6].
- Similar to the AssiEff in the reaserch project EWOTeK (“Effizienzsteigerung von Werkzeugmaschinen durch Optimierung der Technologien zum Komponentenbetrieb”) intelligent strategies to shift order sequences were developed. Because of a continuous energy data collection pending production orders are evaluated and adjusted as needed [7].
- In the project E-SimPro is the focus at the reduction of production costs of production facilities. With the help of a developed software the cost-effectiveness of the whole production infrastructure can be evaluated by simulating the energy need. So a machine based quantification of energy needs for defined production orders is expected [8].

Moreover, existing software solutions shall be introduced which integrate energetic aspects into functionalities of production planning and control systems (PPC):

- The company FertigungsLeitSysteme GmbH has developed the software tool which use PPC data and point up improvements in the production process and needed adjustments to save energy [9].
- The factory-planning software IMValidation produced by iFAKT GmbH simulate and compare different planning scenarios. For each planning alternative different production figures (e.g. capacity, buffer, cycle time) will be shown. This data among can be analysed to find the most energy efficient production strategy other things [10].
- ProModel is a software toll from the company ProAspect GmbH. It helps to achieve sustainable improvements in the production by planning, evaluation and optimisation of production processes. Due to an integrated simulation different aspects of a production infrastructure can be modified to analyse to effects and find the most efficient production strategy by considering the energy consumption [11].

Considering the analyzed state of the art, there are various solutions and techniques to improve the energy efficiency in production by using new information and communication technologies. So different solutions allow a direct integration of energy data into production planning and control systems. The disadvantage of all of them is the need of cost intensive machine networking. Because of the high investments especially small and medium enterprises (SME) have reservations to implement such an infrastructure. A more suitable and cheaper approach is the use of electrical wiring in production infrastructures to draw conclusions to the current production process.

The project iKnowControl

Based on the described problem situation, the research project "iKnowControl" was initiated, which is funded within the framework of the Hessian LOEWE 3 program by the Hessen Agentur GmbH in the period from 01.01.2017 to 31.12.2018. The project consortium led by Prof. Sven Rogalski consists of a system development company and two application companies as well as the University of applied sciences Darmstadt.

Project goal

The aim is to identify real-time operational data using pattern recognition from energy profiles based on existing energy data collection systems that many German companies are already using as a result of legal guidelines and tax reductions. By using the existing communication structure of an energy acquisition system, this data should be made available to production management without the construction of additional structures / system solutions (such as MES). At the same time, it is intended to detect energy load peaks in the planning phase of production and disposal processes by providing the energy requirements corresponding to the planning systems (usually Enterprise Resource Planning (ERP) is used). The hardware and software components to be explored and prototypically developed should on one hand be tested in the area of product manufacturing, using the example of cutting CNC production. On the other hand, a trial of these solution components should be tested in the field of waste recovery processes.
As a result, it should be demonstrated that for smaller and medium sized companies or company location sites it is also possible to record and evaluate energy-relevant process relationships cost-effectively on a continuous basis and to make the resulting information available to operational management in form of operating data.

System concept

The figure below shows the system concept of iKnowControl, which is explained in more detail below:

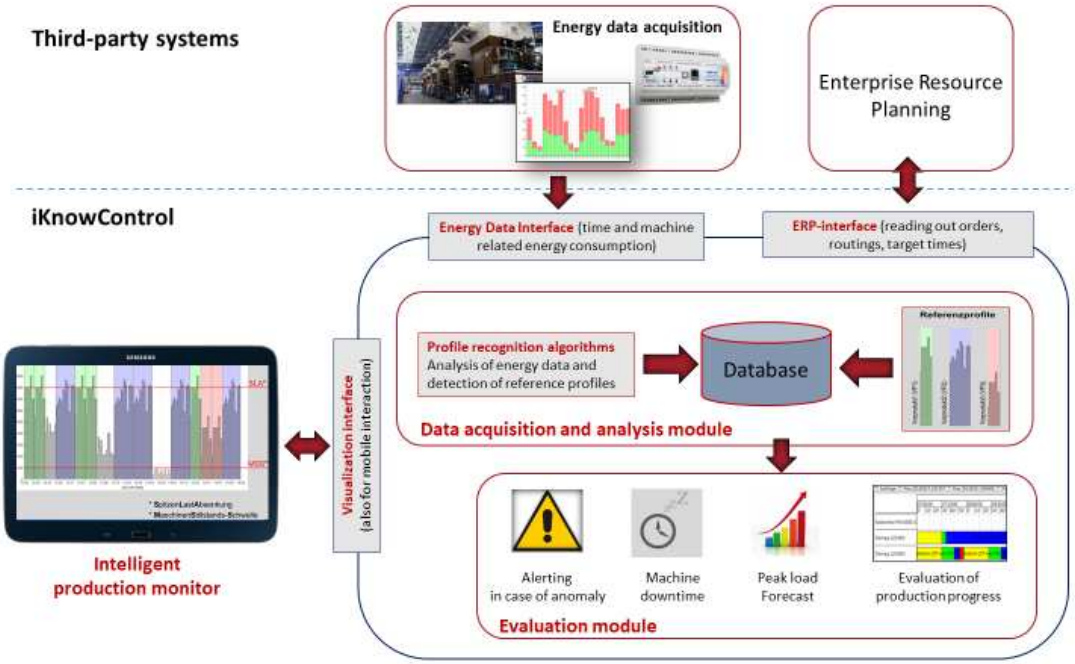

Fig. 1. System architecture of the iKnowControl solution

To carry out the required evaluations with the iKnowControl system, it is necessary to continuously record the energy consumption of machines/facilities in relation to time and machine. For this purpose, a hardware interface for energy data acquisition via external systems is required (see Figure 1). It is used to detect analog and digital signals in industrial environments and is a hardware that provides various interfaces (Ethernet, RS485, USB, etc.). A second software-technical interface enables the information coupling with the system world of the ERP in order to record time and product-relevant order and work plan data.

All data collected by iKnowControl are stored in a uniform database (see Figure 1). By creating semantic relations between machine operation, product, process duration and energy demand, the prerequisite for context-based queries is created. Using so-called reference profiles, which are collected once for a product by reading its energy profile under technical-personal evaluation. The occurrence of a stored reference profile in the database is detected in real time and assigned to the referenced product by using a profile detection algorithm.

As a result of available relations in the data base, the automatically recognized reference profiles and intelligent queries can be generated dynamically via a so-called evaluation module (see Figure 1). On one hand, it is possible to call up classic operating data, such as the number and type of products already processed on one or more machines, as well as their average energy requirement and process time. On the other hand, machine utilization and standstill times can be determined by the definition of limit values for the base load operation of machines /facilities. The same applies to forecasts and anomalies, since the necessary energy requirements of individual work operations are known, and these only have to be calculated cumulatively, which leads to a corresponding alarm when a limit value is exceeded.

On the one hand, the information determined with the evaluation module can be made available directly in the ERP via the existing ERP interface in order to initiate measures (for example, rescheduling). On the other hand, using the visualization interface provided in the iKnowControl system, you can use your own web-based visualization called "intelligent process monitor" (see Figure 1). All information obtained based on the evaluation module is individually retrievable to indicate to the persons responsible (e.g., PPS planner, master, machine operator).

Service experience

In this chapter the first project results, which were made based on prototype solution modules at the CNC cutting production as well as the waste recovery company, will be presented.

Energy data evaluation in the field of waste disposal

At waste recovery company, the field of waste crushing was chosen as the subject of investigation. First, energy-intensive station within the waste processing facility, the various wastes are delivered, transported to a conveyor belt with an excavator and fed to the crushing plants, which has different levels of energy demand and load peaks depending on the type of waste. Using an app specially developed for this project, the excavator driver uses a tablet to determine the type of waste he is currently unloading. The waste-related weight of an excavator bucket is reviewed here at regular intervals to ensure the most accurate possible evaluations. By combining this information (type of waste and weight) with the energy needs of the waste crusher, a dynamic determination of the energy input for an explicit type of waste per bucket is possible (see Figure 2). This opens up new evaluation and planning options for the company. Among others ensuring the early determination of the energy demand for shredding processes, which already plays an important role in the planning of the waste supply to avoid cumulative peak loads in relation to the entire site. The same applies to the controlling at the site, since the newly gained transparency has led to a significantly improved cost calculation for the waste to be disposed.

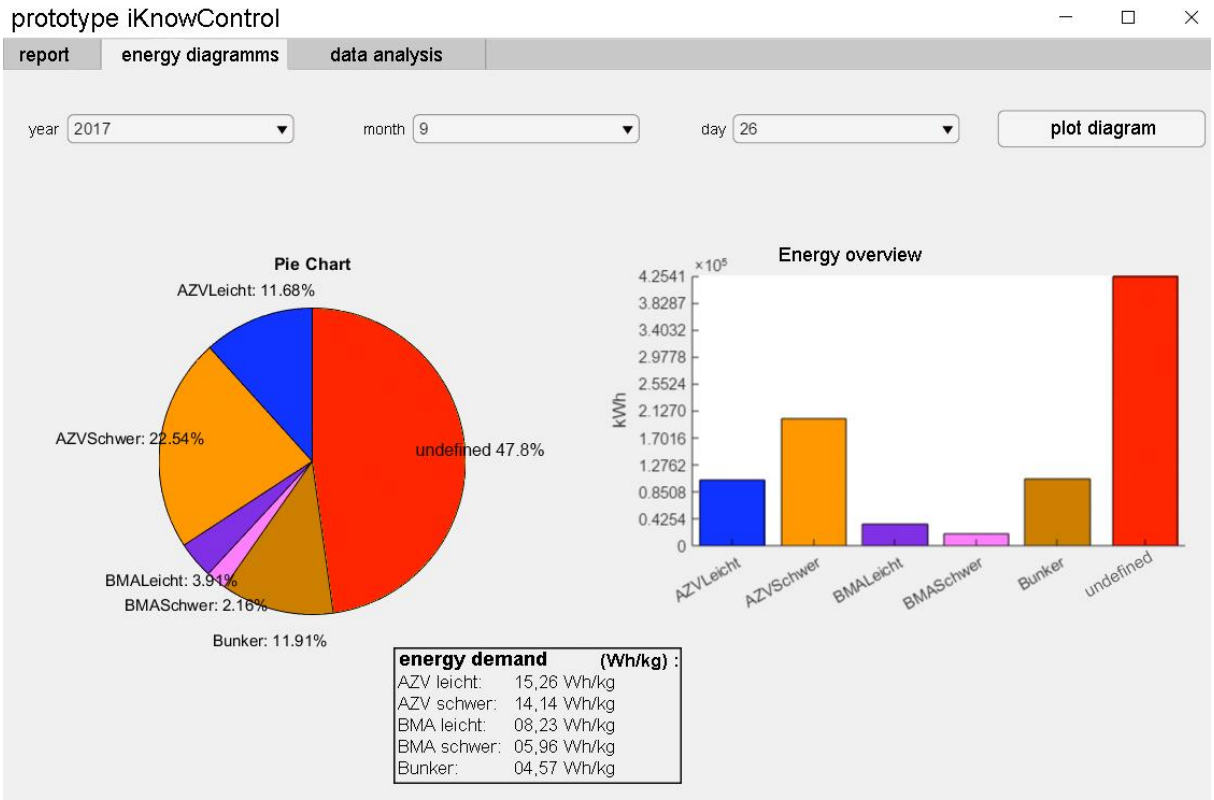

Fig. 2. Presentation of different types of waste with the corresponding energy requirement at the iKnowControl process monitor at waste recovery

Energy data evaluation in the field of CNC machining

With approximately 30 employees the CNC cutting company produces various precision parts on CNC lathes and milling machines, from small to large series production. Due to the lack of continuous, digital operational data acquisition, an energy measuring system was installed, which records the power consumption for two selected machines. During the investigation period a total of four different types of repeating parts were produced on these machines which made it possible to achieve a high degree of reproducibility and thus a good recognition of the reference profiles in the live energy data. After the so-called learning of the collected reference profiles into the system, it was shown that the profile recognition algorithm explored in the project already shows a very good level of realization. As a result, the products manufactured on the two machines could be automatically identified based on their specific energy profiles and further processed for the purposes of operational data analysis. The detection rate of the currently pre-prototypic algorithm is over 99%. The following figure shows a screenshot of the iKnowControl process monitor with the results of the reference profile recognition.

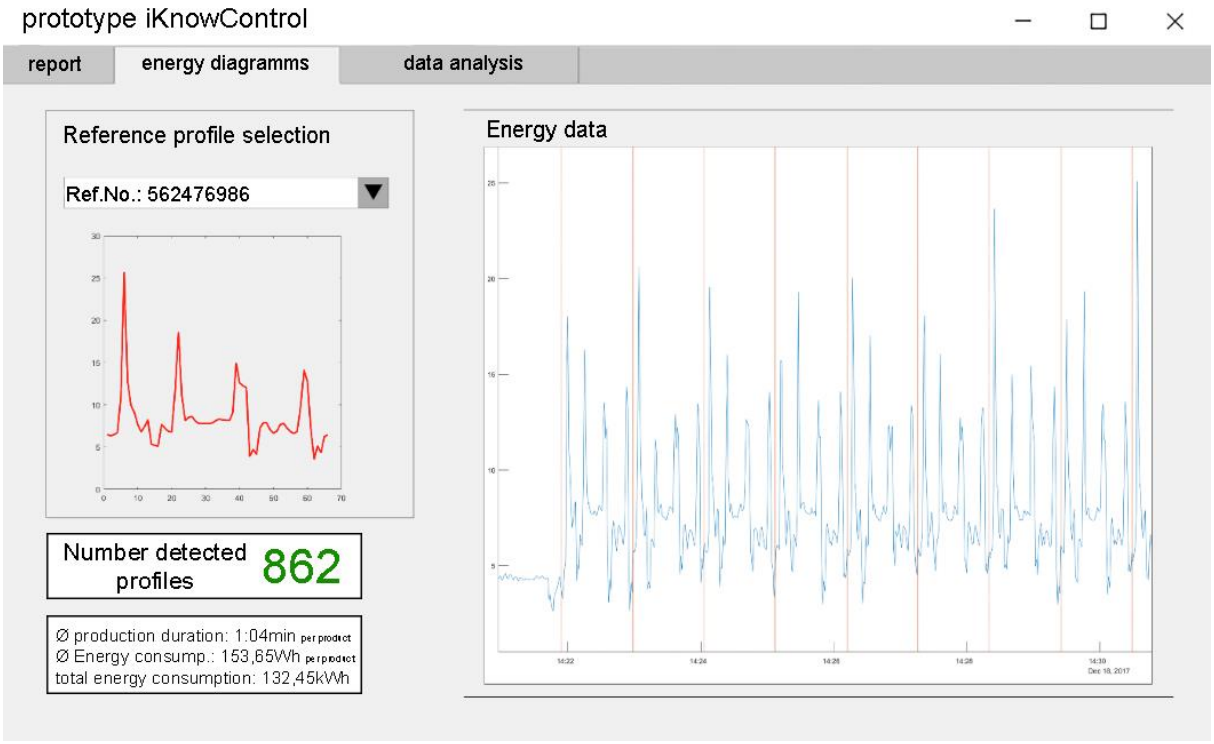

Fig. 3. Presentation of the results of the profile recognition algorithm on the iKnowControl process monitor at CNC production

Summary and outlook

So far, the results of the project provide a promising picture of the use of pure energy measuring systems for the prediction, planning and control of production and disposal processes. Thus, even smaller companies can benefit from a modern information provision in real time, which opens further possibilities for this target group in the context of Industry 4.0. It has been demonstrated, if only in selected case studies with limited complexity, that intelligent data evaluations based on the developed energy profile recognition algorithm are possible. A much more comprehensive use of the iKnowControl solution is to be expected. The results described here have already been achieved after a relatively short realization time and form an excellent platform for the outstanding R & D activities in the remaining nine-month project period.

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