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Sensor Data Analysis in Shop Fabrication //

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Introduction

Analyzing industrial sensor data has tremendous potential in the era of Industry 4.0. When machines and processes are connected, huge volumes of data are created that contain valuable information about controlling and monitoring production. For companies to react promptly to changes in production and on the market, this information must be made available at planning and management level. Today's automation systems, which also use sensor data to control and monitor production processes, usually only forward the data to the upper decision-making echelons in aggregated form. The associated information loss is one of the biggest weaknesses of these systems. One possible solution is to integrate granular sensor data into a data warehouse (DWH) environment with mass data capabilities. The greatest benefit of a data warehouse is that it offers many possibilities for data analysis, and for reporting based on these analyses.

The current situation

Most industrial companies have a classic automation structure that evolved over decades and can be described with the automation pyramid (see Fig. 1) which illustrates all the technical components that exist in an automated installation. The whole automation system is broken down into sublevels, so we can also see the individual levels in the hierarchy. The individual levels are connected via different industrial-strength communication links and protocols.

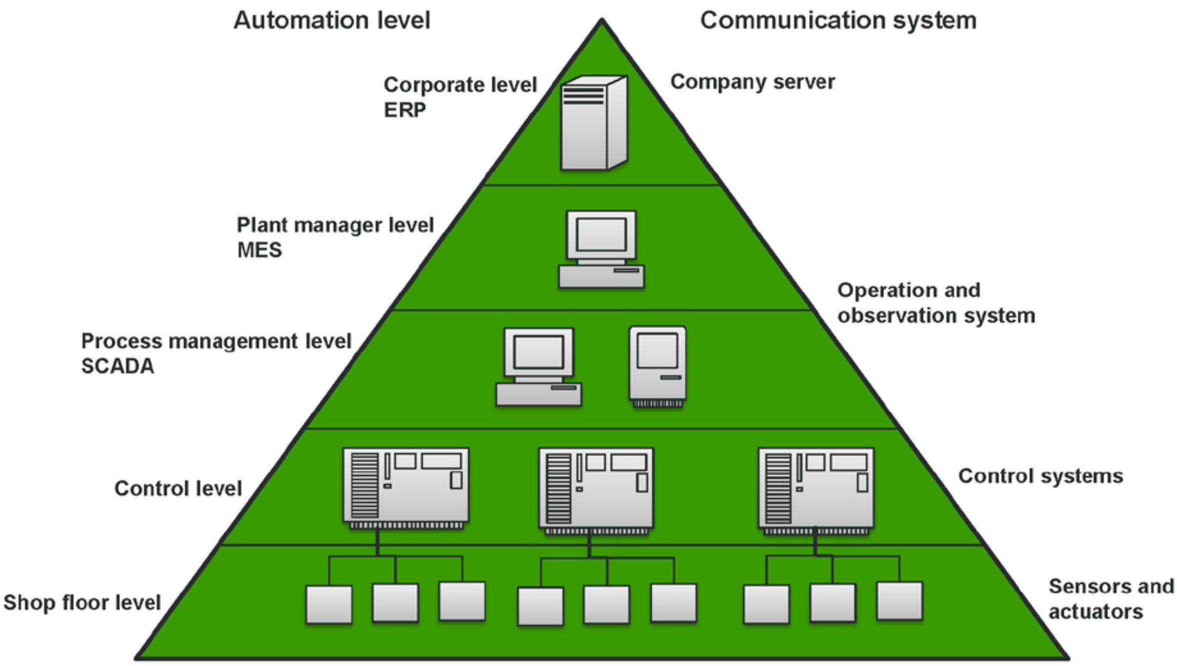

Figure 1: Automation pyramid

Many small and midsize companies have not connected all their production installations across all levels of the pyramid. If we think of classic, commonly found shop fabrication with separate, isolated workstations, it's often very difficult to connect these production units in practice. In many of these companies, the individual levels exist completely independently of one another. Some levels in the automation pyramid – for example, the process and plant manager level with its MES and SCADA systems – do not exist at all.

Despite these hurdles, companies are endeavoring to close the gaps in their automation systems and tap into the great opportunities created by gathering and analyzing sensor data.

The following example describes ways in which sensor data can be used successfully for monitoring and analyses, even with today's automation structures.

Example

A manufacturer operates several turning and milling centers at its facility. Toothed components of different sizes are produced on the machines. The machines are used for both make-to-order production and repetitive manufacturing, depending on the order and the size of the component. Besides the production of toothed components, the machines are used for many other kinds of metalworking in line with the customers' specific needs.

The unfinished parts are machined on various pieces of equipment from different manufacturers, such as Mazak, Viper, FAT, or ACE. The heterogeneous machine structure with its proprietary control technology emerged because the company expanded, different production parts had different requirements, and equipment had to be replaced. We can assume that the production facilities will not be standardized in the future, either, due to the machines' differing specifications and lifespans.

The complete manufacturing process for a purchase order at the company takes place as follows: After the order is received from the customer, it is entered in the ERP system and a production order is sent to the shop floor. The production manager responsible allocates the work based on the available capacities. The part is then manufactured on a suitable machine and its completion is confirmed. Finally, the finished part is shipped.

Difficulties often occur in this process and prevent it from running smoothly:

- The sales department does not have an overview of the current situation on the shop floor. This means no reliable delivery dates can be calculated for sales orders.
- There is no overview of machine capacities due to wrong or missing production confirmations.
- The information about the current production situation is out-of-date or does not exist at all.
- Information about delayed orders due to machine downtimes is only passed on sporadically.
- Parts produced with flaws are reported with considerable delay, which makes a reaction in the form of transferring orders to other machines only possible at a late stage. This leads to delays in delivery and therefore complaints, that may end in contractual penalties.
- Logistics planning is very difficult because of delayed orders and a lack of information.

Storing and analyzing ERP and machine data in a data warehouse with subsequent monitoring and reporting options offers a solution to the problems described above.

The order data – for example, number of pieces, delivery dates, proportion of parts manufactured in-house, and much more – is stored in the data warehouse and correlated with the machine data. This includes the individual sensor values that enable conclusions to be made about the condition or status of a certain machine. Such sensor values provide, amongst others, information about machine downtimes (drops in voltage), production errors (termination of a production program), and the number of pieces manufactured. Furthermore, it is possible to monitor the state of an installation based on the sensor values produced.

As well as the transaction data described above, which can vary widely from order to order, it is important to also include master data. Master data can be used to identify individual production units and find out what proportion of order parts are manufactured in-house. It also enables companies to link data with customers and customer-specific information, such as whether contractual penalties are imposed if there is a delivery delay. Connecting to an existing CRM (customer relationship management) system is also an option.

While companies have been analyzing and visualizing their ERP data for many years now – for example, in the form of sales or cost reports for the management – the use of sensor data in reporting is still not that straightforward. One of the main problems is reading the data from the installations' proprietary control systems and describing it semantically. Even a small machine can deliver hundreds of sensor values. Each value contains certain pieces of information that are important for controlling the machine. The challenge is to separate out the relevant values and prepare them for analysis.

Furthermore, the control of production facilities is designed for operation in hard real-time. This means sensors measure certain states in the range of a few milliseconds to a few microseconds. The term "real time" is much more flexible when used in the database context for analyses and visualizations, where the range can vary from a few seconds to several minutes. This difference in the understanding of real time has to be solved by aggregating the sensor data suitably.

The architecture in Figure 2 offers a possible solution. Sensor values are read from various machine controls with the help of a gateway and then pre-aggregated. In a preparational step the relevant sensor values must be identified in collaboration with the process experts. The gateway has the advantage that it can understand and consistently translate the various communication protocols from the different controls. The sensor values are then stored in an entry layer of the data warehouse. If required, certain values can be visualized in real time, so that for example information about machine downtimes or production quantities can be provided,. In order to process and visualize the values in the defined real time, streaming technologies are required that make it possible to process high-frequency data. SAP Event Stream Processor (ESP), for example, provides many options for real-time processing and analysis.

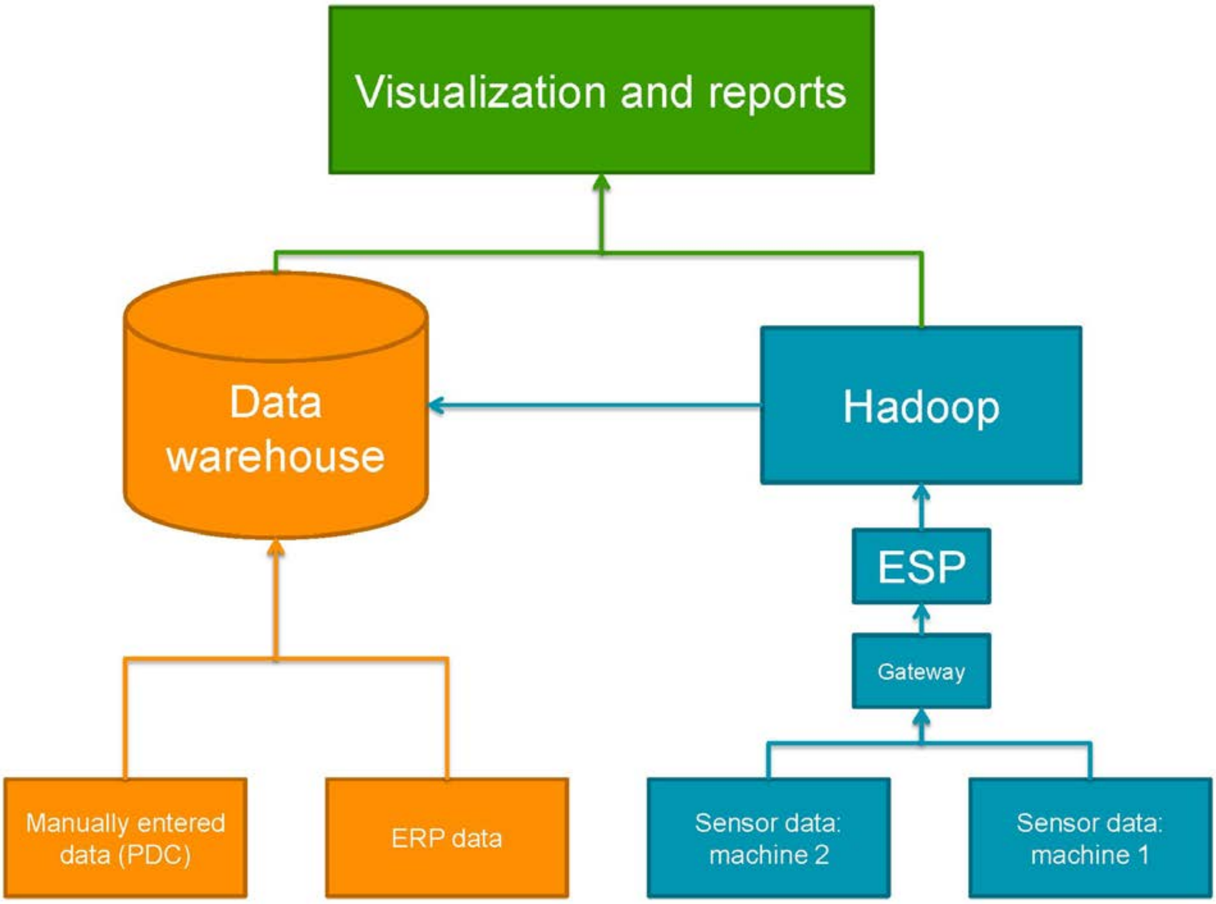

Figure 2: Architecture for the analysis of industrial sensor data

Due to the large number of sensor values that a production unit's sensors transmit in very short intervals of just a few milliseconds, very large volumes of data accumulate. Therefore, the entry layer should be inexpensive and highly scalable in terms of memory. One suitable system for storing large volumes of data is the Hadoop distributed file system. Hadoop's biggest advantages are the operation with reasonably priced hardware, its scalability, and its wide range of data analysis options.

The data quantities in an ERP system are relatively small and easy to process compared to sensor data. But above all, the data there are already structured thematically. If they are relevant for analyses or reports, they usually have to be loaded into the data warehouse, but this process is much easier due to the existing structure. Examples of such data are: scheduled number of units, deadlines, machine information, component information, and proportions of parts manufactured in-house. Such context information is also essential for analyzing sensor data.

Furthermore, it is still common practice to record completed numbers of units and other information (for example, machine downtimes, service times, maintenance reports) manually outside the ERP system. Such data can also be integrated into a data warehouse.

All the data described is now brought together, connected in the data warehouse and converted into reports or dashboards using analysis tools such as Tableau or SAP Design Studio. The schematic diagram below visualizes a possible structure:

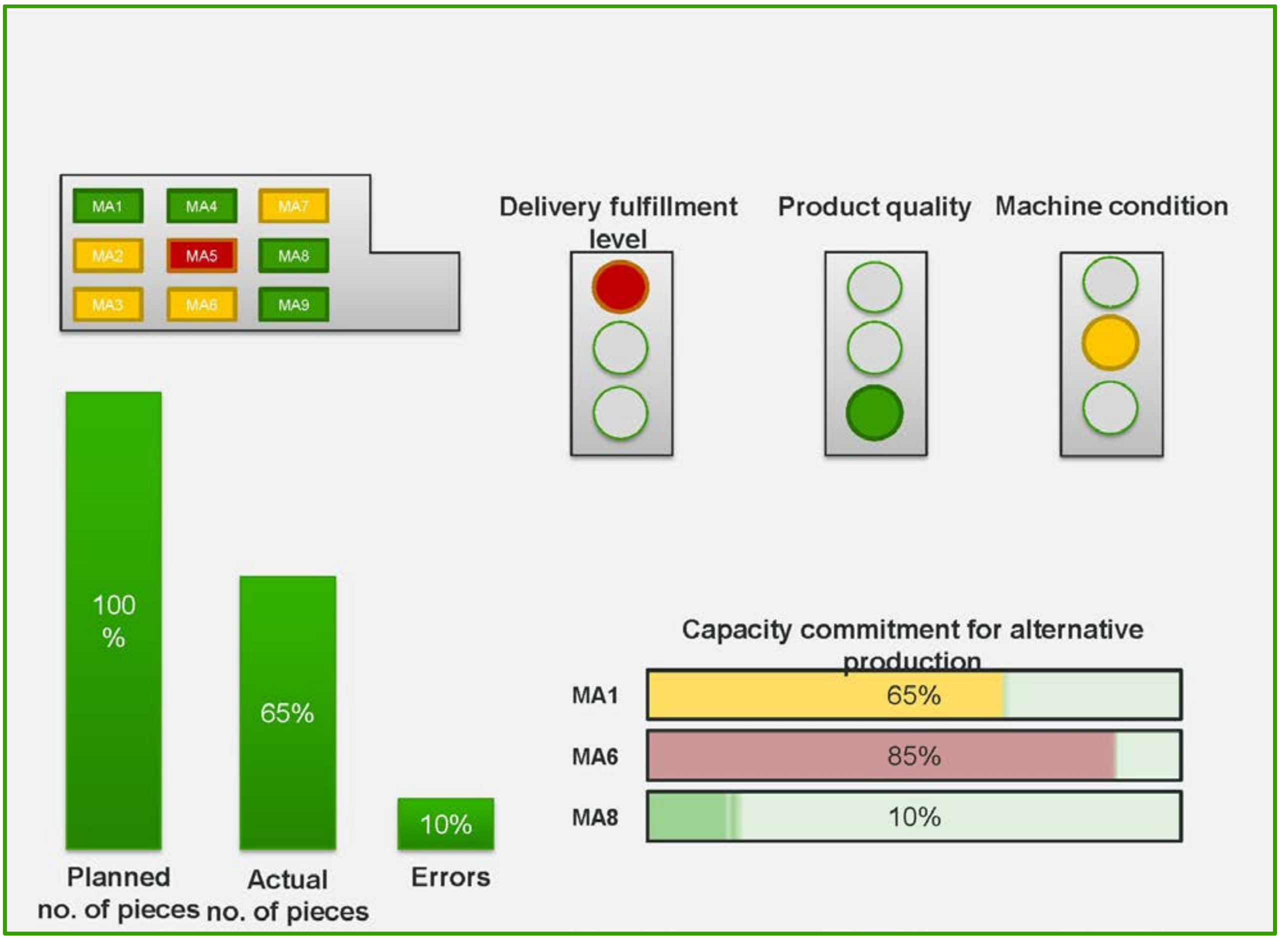

Figure 3: Dashboard for machine monitoring (schematic diagram)

Not only can companies create reports using information from the data warehouse, where usually much of the data is not available in great detail, but they can also take advantage of Hadoop's diverse options for providing its granular data right as far as report level. Furthermore, Hadoop is ideal for statistical evaluations. For example, predictive maintenance or predictive quality scenarios can be mapped very well with Hadoop and the tools supplied with it.

Predictive quality involves detecting deviations from thresholds in sensor values that are decisive for product quality. These deviations are detected before they actually happen. This means it is possible to determine deviations in the quality of the future product and possibly prevent them by using the sensor values supplied by the machine. If we take the example above, where gear wheels are produced on a turning and milling machine, it is possible to detect whether manufacturing tolerances are within the defined limits using sensor data such as the tool's feed speed, the torque of the component holder, or the processing time.

But what does this look like in practice? The above sensor values are either read directly from the controls – if the controls are enabled for such a function – or are determined indirectly via the activity input for each of the drive motors. Thresholds must be determined in advance that, for example, describe which feed speeds are acceptable and which feed speeds impair the quality of the turned part. The thresholds are defined in SAP Event Stream Processor (ESP). The machine's sensor values are read in real time with SAP ESP and compared with the thresholds that were set. At the same time, the scenario is visualized on a screen in a representation of the machine. If the values obtained deviate from the defined thresholds, the machine operator can react immediately and stop production before serious damage occurs to the piece being manufactured. Depending on the component and the order, this can result in considerable cost savings and the identification of poor-quality components.

The sensor values are stored in Hadoop and visualized in real time. They can thus be used for analyses at a later stage, to ascertain why the deviations happened. This means any machine damage or wear and tear can be detected in good time. In relation to this, we often hear the term "predictive maintenance" or "condition-based maintenance" come up and must be differentiated.

Predictive maintenance uses sensor values and experience from defects that already occurred to predict when which machine component should be replaced and how likely it needs replacing. Besides being able to select the right statistical tools to use for this type of sensor data analysis, it is also important to have specific knowledge of the monitored manufacturing processes. Before the suitable algorithm can be found that identifies the probable defect, the relevant data must be extracted from a huge number of sensor values. This can only happen in collaboration with the expert for each process, because he or she has the necessary experience and the knowledge about the manufacturing process.

Condition monitoring (CM) systems are an important prerequisite for predictive maintenance. By using such systems, companies can detect and locate breakdowns at an early stage. Condition monitoring systems are often confused with vibration monitoring systems, which are not equal. Vibration monitoring is only a part of condition monitoring, which also encompasses thermal monitoring, torque monitoring, stock control, lubricant analysis, and ultrasound testing, to name just the main techniques. When such systems are deployed, we differentiate between online and offline monitoring. With online CM systems, conditions are monitored permanently. In the case of offline CM systems, monitoring is done on a spot-check basis. The decision about the type of monitoring often depends on the security requirements and the costs. Many CM systems use sensors specially constructed for monitoring. This restriction means that the systems only detects breakdowns that these sensors are designed to detect. Data from the other sensors involved in the production process are not used for the analysis.

Despite this limitation, CM systems can be considered the first step toward predictive maintenance. The sensor values gathered by CM systems and the effect of these values on the condition of a whole machine or individual parts represent the first steps in handling sensor data and the anomalies that this sensor data reveals. Furthermore, major progress in wireless and energy-self-sufficient sensor technology open up a multitude of possibilities for condition monitoring. Sensors can be integrated into the production process – long-term and maintenance-free – at points where process monitoring was previously impossible. For example, an energy-self-sufficient vibration sensor can be attached to the turning tool itself. Wear and tear on the tool can be detected directly by observing the vibrations on the tool, because the vibration patterns change as the tool wears-off.

Conclusion

The example here shows many ways sensor data can be used. From comparatively simple order monitoring through quality control, condition-based monitoring, and predictive maintenance, scenarios are possible that empower companies to add value from their information. For example, decisions concerning necessary maintenance are no longer pursued with gut instinct but based on sound data. Processes are monitored more effectively and reaction is immediate if there are any deviations.

Of course, it is not enough just to read the sensor data and display it clearly. Often, a company's entire production cycle must be scrutinized, too. Existing processes must be critically examined and adapted to the new technologies. Employees must learn how to work with these new technologies in daily practice. Instead of thinking in terms of small, isolated manufacturing centers and process steps, companies must embrace a connected structure.

Connecting sensor data not only has a positive influence on the immediate process, but also on the company's entire value chain. Possible benefits are:

- ⇨ Production planning can be put on a sound basis because downtimes and quantities processed are determined accurately.
- ⇨ Order receipt and material procurement can be coordinated and planned more effectively.
- ⇨ Internal logistics processes are centrally coordinated and can be reliably planned.
- ⇨ Companies can identify quality risks in the manufactured products at an early stage and can react to them promptly to maintain good customer relationships.
- ⇨ Machine and process downtimes are minimized thanks to predictive maintenance.
- ⇨ Capacity planning and order distribution within the machine facilities can be performed at short notice and flexibly.
- ⇨ Ways to optimize the process become visible and verifiable.

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