PRODUCTION MONITORING SYSTEM CONCEPT DEVELOPMENT

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Abstract: The main goal of this paper is to offer the concept of the production monitoring system that will help to provide an accurate overview of the shop floor activities, improve asset management, machinery utilisation and production process stability. It will provide diverse information appearance by support of data collection, analysis and storage modules. Key words: production monitoring system, remote monitoring, manufacturing execution system, shop floor visibility.

1. INTRODUCTION

The main aim is to offer a design concept of easy-to-use, configurable and cost effective production monitoring system (PMS) for small and medium sized enterprises (SMEs).

One of the problems facing a wide range of manufacturers is how to effectively monitor production lines and machinery to avoid malfunction and unplanned downtime and improve machine and manpower utilization [1]. Resource planning systems should calculate utilization on planning stage and PMS is an instrument that supports keeping this plan in place by supervising the resource state on production stage, together with advanced prognostics tools [2].

Production line and machinery monitoring is the necessary component of the information systems that are used in the production industry to improve efficiency and reduce losses [3]. Despite the fact that a huge number of different production monitoring solutions are offered on the market, there is always place for improvements and simplifications.

Large enterprises are used to a huge number of data to be processed. They have full time staff with expertise to manage specific applications related to production monitoring, data analysis and optimization. At the same time, SMEs also have to deal with the growing number of data to be processed, but normally they cannot afford fully dedicated data experts. Solution to that can be to outsource some of these tasks to a third part or apply simple, affordable and easily configurable monitoring system.

It is clear that successful implementation requires a firm knowledge of the operating principles of PMS. That is why each module of proposed concept will be described first in order to explain how the system should work.

2. PRODUCTION MONITORING SYSTEM

The main task of PMS is to analyse and distribute data collected from the workshop and production line. The data should help the management and operators to get an overview of the machinery and production state.

Additionally to production plan management, there is growing interest in SMEs for asset health and utilisation monitoring, as operating costs of the machinery are considerable part of the total costs. Here special attention is paid to minimize the maintenance cost and time.

Machine state and production monitoring is one of the Manufacturing Execution...
System (MES) functions [3]. The main idea of the MES is to integrate separate functions and provide linkage between business and plant floor control systems (see Fig. 1).

But if we look through the MES solutions of the leading providers of industrial automation systems and software (like Emerson, Honeywell, Rockwell, Invensys, Schneider Electric, Siemens, etc.), we can see that the core functions of MES are: material and inventory management, scheduling and collection of production data with limited information about equipment state. Support functions are: performance analysis and maintenance management. Most of the solutions are focused on midsize and large companies in chemical, oil and gas, food and beverage, and automotive industries. The process industries have all traditionally been heavy users of MES software, where it ensured that different variables don’t exceed set parameters. But the complexity of production processes and machinery are increasing in all industries and more companies may require improved factory shop floor visibility.

3. CONCEPT

Proposed production monitoring system should be comprised of at least five main functions [3,5]: data collection, visualisation, analysis, prognostics and storage (see Fig. 2). Functionality and complexity of each component depends on customers’ system specific requirements. Only the base functions and relations are described and additional modules may be added or even removed if required. The concept described below gives the idea of the system functionality.

Fig. 2. Concept of a production monitoring system.
3.1 Data collection
Reduced personnel on the shop floors make it necessary to install automated data collection systems. The most critical part is to identify what to measure, as collected data should help to acquire knowledge. Questionnaires and analysis methods may be used to specify what information is needed. Data not used for decision making could be discarded. Different factors and criteria should be taken into account when choosing a measurement method and sensor type, like: cost; working range; ease of installation; robustness; uncertainty; signal type, sample rate and availability. Preference should be given to wireless sensors. With the use of energy harvesting it will even more enable sensor remote placement and lower installation costs [6]. The second approach is to maximally apply direct measurements methods, like machine vision systems instead of indirect methods, where collected signal is compared to the optimized signal. But when direct method is used, signal is measured and analysed directly using suitable algorithms. As an example, a smart camera used in machine vision is able to measure tool wear directly. Therefore, direct methods are more preferred than indirect methods [7]. Monitored parameter may be wrongly interpreted if there is no wide feature separation between failure and normal mode.

3.2 Visualisation
Data can be presented through LCD displays, andon boards, mobile device apps or web-based interfaces. First data should be presented to operators, who will use this information in routine way to get indication of their job and machine state. Data could be customized to be shown in the simplest way (e.g. quantitative measurements replaced by qualitative and KPIs). Contrary, supervisors and service personnel should see more precise reports (historical data of operations performed, measured parameters etc.) for evaluation and finding the areas that may need improvements. Each company should choose its own key performance indicators (KPIs) and the calculation methods. Most commonly KPIs are related to production output, quality and availability. Additionally to availability (idle; production; stoppage) rate system must record the reasons of downtime. Operators can input it using touch sensitive screens, keyboard, voice recognition, etc. Multilevel tree structure may be formed to provide more detailed reason description. The figure below represents a three level downtime reason menu for a milling machine (see Fig. 3).

![Multilevel stoppage description](image)

Fig. 3. Multilevel stoppage description.

After each stoppage operator selects the reason from the list, which may be updated by adding new reasons or removing obsolete ones based on the usage statistics. For undescribed reasons the choice “unspecified” can be in the list. When number of such “unspecified” downtime reasons increase to the number of interest, the list of reasons may be revised. To make downtime cause analysis a PMS should have statistical module to track the downtime changes over the time. Additional module may be developed to measure the maintenance time effectiveness that is related to average time needed to eliminate the reason of stoppage - mean time to repair (MTTR).

3.3 Data analysis
Use of statistics is the most common approach for data analysis to extract useful information from the datasets. Different
data mining techniques in analysis are used with its own application area (Table 1.).

<table>
<thead>
<tr>
<th>Method</th>
<th>Possible application area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision tree</td>
<td>Data pre-processing and classification.</td>
</tr>
<tr>
<td>Neural network</td>
<td>Pattern detection and predictive models.</td>
</tr>
<tr>
<td>Genetic algorithm</td>
<td>Data optimization.</td>
</tr>
<tr>
<td>Rule induction</td>
<td>Define relations between different data streams.</td>
</tr>
</tbody>
</table>

Table 1. Example of data mining methods.

Diagnostics, data analysis and prognostics help with the questions that arise during the operation:

- May system continue to operate or should be shut down for maintenance?
- How change of regime will affect the lifetime of the system and KPIs?
- What are the performance, efficiency and quality rate in real time?

### 3.4. Prognostics

Only if the remaining useful lifetime (RUL) and real state of equipment is known, preventive maintenance may be replaced by condition based maintenance. By use of prognostic methods preparation to maintenance can be done in advance when the system is still running and the failure is known early enough. Resources could be focused on parameters of high value systems to determine the most likely scenarios with maximally eliminated inaccuracy and uncertainty. Knowledge about the physical process determines the regression type to apply (linear, polynomial, exponential, etc.). Prognostic methods are normally divided into the three main groups: Data-driven Method, Stress-based method and Effects based method. These methods can be summarized as follows (see Fig. 4.):

![Fig. 4. Prognostic methods description.](image)

### 3.4 Data storage:

Collected data should be transmitted to a database server. Different database technologies may be used like SQL (e.g. MySQL, Postgres, Oracle Database) or even NoSQL databases (e.g. MongoDB, Cassandra, HBase, Neo4j.). SQL based database systems are more widely used at the moment, as they can be easily accessed via standard Structured Query Language (SQL) statements and effectively solve data storage and replication challenges. The amount of data saved in the database should be sufficient for data mining. Deciding what to store in the database could improve or reduce performance and thereby influence the time of analysis. It is not reasonable to store every single measurement or even analysed data set in the database when the data is not relevant in the decision making process. If we take measurements with high sample rate it may be better to transfer already selected data (e.g. in WSN node) to database. At the same time, cloud based database platforms could be used for more effective resource allocation. The main challenge here is connectivity and fusion of data form different systems like ERP - enterprise resource planning CMMS - Computerized maintenance management system, etc. One of the solutions can be data integration using XML (Extensible Mark-up Language) platform.

### 5. CASE STUDY

The proposed monitoring system was applied and tested on the milling machine DYNA MECH. EM3116 in Tallinn University of Technology (TUT) laboratory. Data acquisition was performed using National Instruments (NI) equipment: Gateway WSN 9791 with NI WSN 3212 thermocouple input node for temperature measure and NI WSN 3202 Analogue input node for Voltage measure. Nodes were secured by magnet brackets to simplify installation. Data visualization
was performed through LCD monitor secured to the housing of the machine (see Fig. 5.).

![Milling machine monitoring system](image)

**Fig. 5. Milling machine monitoring system.**

The choice of NI instead of other solutions was made due to flexibility and optimality of the hardware and software in the concrete case study and using NI LabVIEW software with a graphical programming tool, helped to reduce time for programming.

High sample rate of acceleration measurements didn’t allow using analogue NI WSN due to ZigBee (802.15.4) wireless standard and hardware limitations: WSN 3202 sample rate 1 sample/second and ZigBee RF data rate 250 kbit/s.

As an alternative for the future research open source hardware platforms like Arduino or Raspberry Pi may be used due to more acceptable price level for SMEs.

Data was saved remotely to PostgreSQL database and to local host as a separate file (see Fig. 6.).

![Example of collected data set](image)

**Fig. 6. Example of collected data set.**

During the test were determined the set points for idle, production and heavy load operation for different cutting regimes of S235JRG2 steel (Fig. 7.).

<table>
<thead>
<tr>
<th>Cutting depth</th>
<th>RPM</th>
<th>Workable movement</th>
<th>Current Ampere</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>300</td>
<td>150</td>
<td>3.0</td>
</tr>
<tr>
<td>1</td>
<td>300</td>
<td>150</td>
<td>3.2</td>
</tr>
<tr>
<td>1.5</td>
<td>300</td>
<td>150</td>
<td>3.4</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>150</td>
<td>3.7</td>
</tr>
<tr>
<td>0.5</td>
<td>450</td>
<td>300</td>
<td>3.2</td>
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<tr>
<td>1</td>
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<td>300</td>
<td>3.5</td>
</tr>
<tr>
<td>1.5</td>
<td>450</td>
<td>300</td>
<td>4</td>
</tr>
<tr>
<td>1.75</td>
<td>450</td>
<td>300</td>
<td>4.3</td>
</tr>
</tbody>
</table>

**Fig. 7. Current for different regimes.**

Obtaining sample data of the failure progressions to define alarm set points for measured parameters posed to be a real challenge, as systems are normally not allowed to run until failure and the vital parts are always tried to be replaced before they fail. Therefore, as an alternative, statistical process control (SPC) was proposed for continuous automatic calculation and update of warning limits (upper/lover limit control).

After the survey (interview of operator) were determined the most common breakdown and quality problems for such type of milling machine that helped to make the list of problems for visual model. Main window of visual module was developed using PHP language, jQuery, jqPlot allowing seamless object-oriented data updating without refreshing the whole page (see Fig. 8.).

![Developed visual module for PMS](image)

**Fig. 8. Developed visual module for PMS.**

6. **FURTHER RESEARCH**

Standardized metrics of production monitoring system will help to compare different solutions on the market and evaluate effectiveness of the existing ones. Methodology should be described how to determine what critical data to monitor and visualise. Also solutions for integration and data fusion with higher level systems (e.g.
ERP) should be developed. Proposed concept should be optimised for production lines and group of machines, where you can compare the status of all equipment to provide the total production area overview.

9. CONCLUSION

PMS concept was offered and applied for the milling machine. It provides transparency on the shop floor and improves manufacturing competitiveness. System offers predictive functionality and helps to prevent the critical components breaks.

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11. REFERENCES


12. CORRESPONDING AUTHORS

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