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Real-time assessment of machine performance through the use of an intelligent sensorial system

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Abstract. This paper addresses the subject of process monitoring of self-organizing production chains. It proposes a strategy to assess in real time the production volume and quality by making use of a monitoring system that includes sensors and a program developed to this aim. The system is implemented in a critical node of the production chain and provides information used for unsupervised industrial processes conducting. In addition, the data is transmitted via the Ethernet or WiFi to the different departments (production planning, accounting, maintenance, quality assurance) as information or to request taking of measures if human intervention is needed. The efficiency of the proposed strategy is illustrated by an experimental case study in which the functioning of a machine in different states is simulated. The monitoring system's capability to recognize in real time changes in the machine state and its effectiveness to identify malfunctioning in the production chain is discussed.

1. Introduction

After the first industrial revolution, a succession of other revolutions followed in the manufacturing process (see Figure 1). Thus, with the spread of electricity production, industrial facilities have evolved from steam and water machines to mass production based on electrical power, and later to automated and digitized manufacturing. Presently, the need to operate the production facilities in a simpler, more efficient and sustainable way, has led to the emergence of a new trend in industrial development [1], which is known as Industry 4.0. This term originates from a high-tech strategy program of the German government and is generally referred to as the fourth industrial revolution.

Creating what we designate as a "smart factory," Industry 4.0 defines a new level of organization and control over the whole life cycle of products, being developed by the increasingly individualized requirements of customers [2-4]. Therefore, one of the main objectives of Industry 4.0 is to fulfil the specific needs of customers. This goal influences activities like order management, research and development, product design, manufacturing process, delivery, commissioning, and very often recycling activities [5-6].

At the beginning of the concept, specialists were tempted to crumble Industry 4.0 with Computer Integrated Manufacturing (CIM). The main difference between them concerns the human role in the fabrication setting. Thus, unlike CIM, that considers human factor as workless production, in Industry 4.0 the workers are playing an essential role in performing the production [7].

The scope of Industry 4.0 is to transform ordinary machines in self-learning and self-aware ones, in order to improve their performances, maintenance and the interaction with the surrounding environment [8-10].

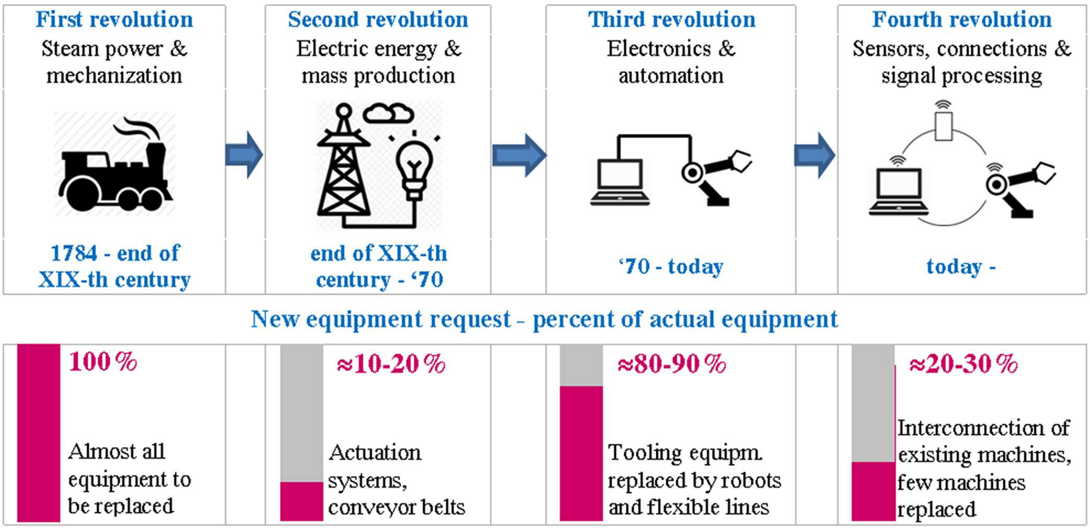

Figure 1. Industrial revolutions.

The Boston Consulting Group (BCS) has recognized the existence of nine technological advancements, which are considered the pillars of Industry 4.0. For assuming that a manufacturing facility has implemented the Industry 4.0 system, the most of these nine elements have to be integrated (see Figure 2).

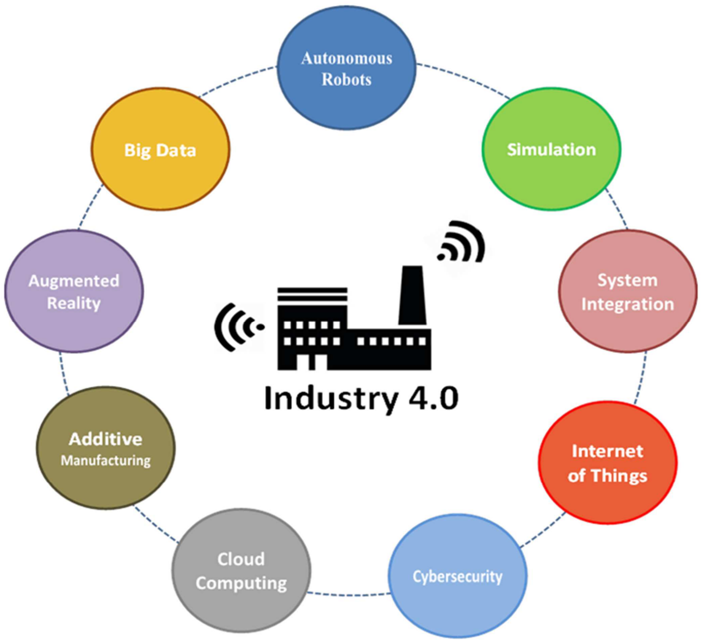

Figure 2. The nine pillars of Industry 4.0.

Current legislation requires that production facilities operate with the vibration and noise level limited by clearly defined values [11–12]. These values can be used to assess the machine's normal operating regime, any overrun of legally established levels indicating an abnormal operation. We exemplify in this paper how an intelligent sensorial system, based on vibration monitoring of a milling center, is able to recognize in real time any changes in the machine state and to identify malfunctioning in the production chain.

2. Problem formulation and experimental setup

Continuing the research initiated in the field of production process monitoring [13-14], the focus of this work was the use of an accelerometer to assess the performance of an EMCO Concept Mill 155 milling centre, which is part of the production chain of a plastic injection mold (see Figure 3). As with other similar research [15-18], the accelerometer was involved to get various data associated with the prediction of the machine status, which were transformed by algorithms in information that can be used to organize the production chain and for self-assessing the status of the machine.

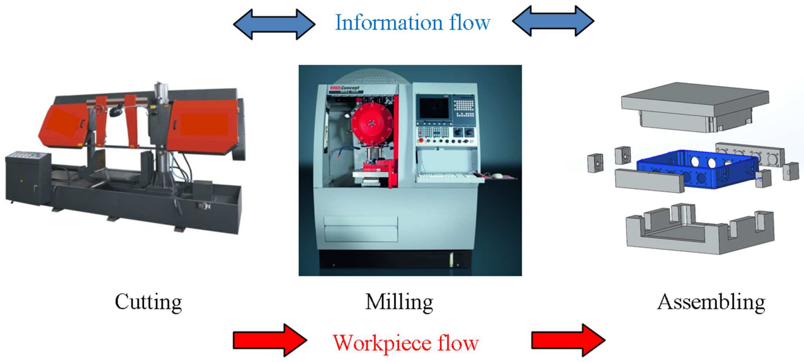

Figure 3. View of the production chain.

Based on the fact that the most common faults which are affecting the machine performance are related to vibrations, we decided to place a Kistler 8772 accelerometer on the machine's vise. The collected data were sent through an NI 9234 acquisition module to a laptop. For feature extraction and storing we used a special application developed in LabVIEW. Figure 4 shows the main components of the experimental setup and the measuring chain. To view the position of the accelerometer, the picture was made with the open door of the machine. Forwards, Figure 5 illustrates an example of how data was collected in this study.

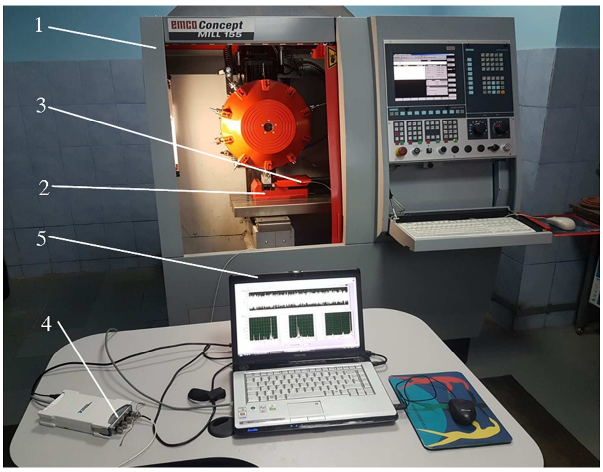

Figure 4. Experimental setup and measuring chain: 1- milling centre, 2- vise, 3- accelerometer, 4- acquisition module, 5- laptop.

In this way, a certain technological phase that is carried out in predefined conditions (speed, feed, depth, tool and so on) can easily be associated with the acceleration magnitude measured by the sensor located on the machine's vice. Figure 6 illustrates how the data can be parsed when the fabrication of a product includes only one technological phase (i.e. when the machining is done with the same tool and cutting regime). In this case, the collected signal may be easily associated with each piece produced on the machine.

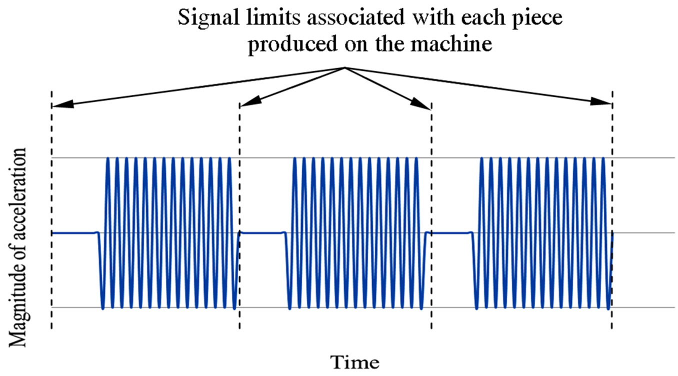

Figure 6. Result of data parsing.

3. State estimation methodology

Usually, milling centers are not equipped with any digital equipment to transmit information for processing to a central control unit. Thus, by implementing an accelerometer, the behavior of the machine tool can be monitored to obtain useful information that may be used for production and maintenance planning. Based on the gathered information and depending on the automation degree of the production process, a human operator or the central control unit can make the necessary decisions.

In the case of continuous production monitoring, similar to those illustrated in Figure 7, the central control unit receives information on the duration of the machining process. As long as the measured acceleration is different from zero, it means that the machine is in a manufacturing cycle. The time T_o in which the measured acceleration is zero gives information about the period in which a machined piece is detached from the vise, and a new one is loaded. As long $T_0 \leq T_{0lim}$, the process proceeds normally. Otherwise, there is, for example, an indication that the flow of raw material is interrupted and an intervention of the maintenance is required in order to normalize the situation.

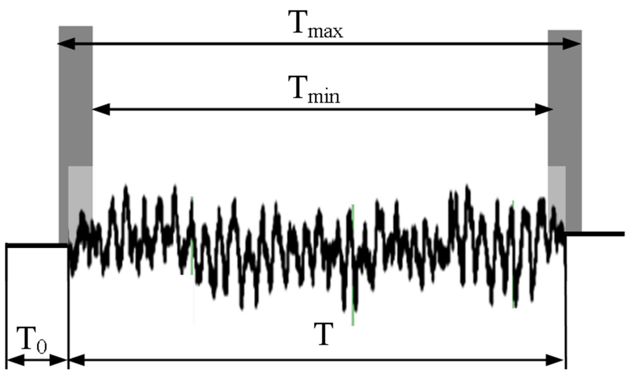

Figure 7. Continuous production monitoring.

Additionally, the central unit receives information regarding the number of the processed pieces. As long as the actual processing time remains within certain predetermined limits $T_{min} \leq T \leq T_{max}$, the process is normal. Under other conditions, there is a clue to a problem that needs to be removed. The processes described above can be synthesized by the flow chart shown in Figure 8.

The evolution of the acceleration amplitude over time can also provide information about the manufacturing process. As illustrated in Figure 9, three work areas can be set according to the acceleration magnitude. The green area corresponds to the normal operating regime, while the yellow area indicates the appearance of some processing malfunctions, like tool wear or larger manufacturing allowance. The functioning in the red area indicates the occurrence of unacceptable operating conditions in which the processing should be stopped.

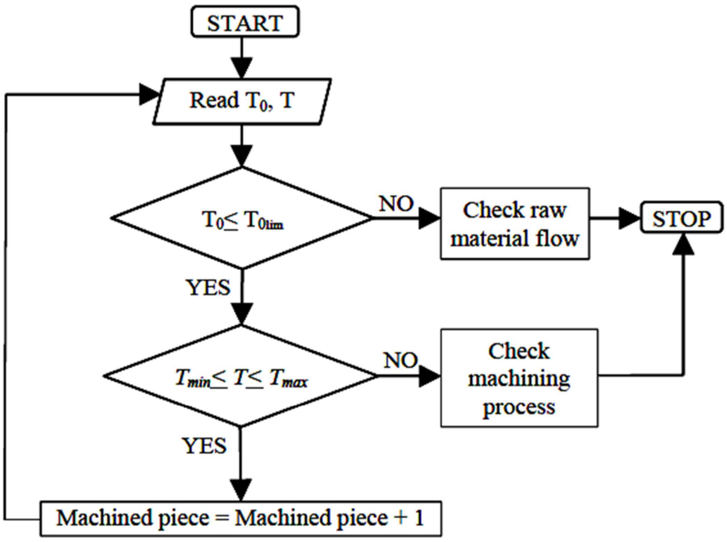

Figure 8. Flowchart of the machining process.

However, when the machining process is complex, assuming the use of several tools and working modes, the simple comparison of the acceleration amplitude with certain preset limit values does not give information about the source which causes that unacceptable vibration level. Therefore, in this case, it is necessary to perform a Fast Fourier Transformation (FFT) in order to determine the cause responsible for the increase of the vibration level from the frequency spectrum.

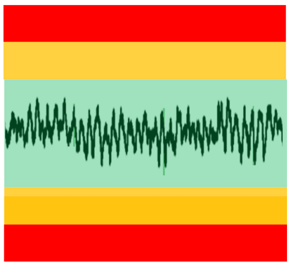

Figure 9. Setting acceptable vibration limits.

The above-suggested state estimation methodology may be used to implement a real-time assessment procedure of any manufacturing process, with the final scope of setting a completely independent and self-managing production system.

4. Conclusion

The present paper demonstrates how a CNC milling center, which is originally not equipped with particular monitoring systems, may be foreseen with an intelligent sensorial system in order to collect and transfer digital data to the computer controlling the production chain. Specially developed algorithms convert the data received by the computer into relevant information for both the manufacturing units composing the production chain, as well as for the departments sustaining the production (e.g. maintenance department and quality control unit). Thus, a self-managing and independent production system is acquired, the process having the ability to adjust itself very fast at every occurred malfunction. The resulting system facilitates the transition of any existent production structure to operations inside the Industry 4.0 pattern. We presume our findings will be able to contribute as reference values to the seeking of factories to overcome the barriers that separate them from the aspirations of the paradigm of Industry 4.0.

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