WEAR MONITORING OF A TOOL FOR MARBLE CUTTING

Alessandro Bartolini*[1], and Roberta Pompilio[2]

[1]Institute of Industrial Technology and Automation of National Research Council
V.le Lombardia 20/A, 20131 Milano, Italy
alessandro.bartolini@itia.cnr.it
[2]Polytechnic of Milano, Faculty of Information Engineering, Italy

Abstract
Nowadays, in the current situation of global market, it becomes more and more important to introduce into the market machines with a concrete added value, for example a system able to detect the wear of the tool for the marble cutting in order to improve the surface finishing and to prevent the tool breakage that means a long downtime. That means also economical benefits because the reduction of maintenance interventions caused by failures, reduction of maintenance time and optimization of the spare parts. The target is to increase the availability of the machine and so the production level. The machine under test was designed for the cutting of marble blocks in some slices, the time necessary to cut every slice is four or five hours, so we have to assure that the tool is good for the whole time of working. In this study we analyzed the most significant field signals (torque, current, velocity and so on) as inputs to a neural network. We considered also the acoustic signals as important indicator of the tool wear in order to identify the frequency, or the frequencies involved in the wear process by FFT analysis. The use of neural network is particularly suitable in this case, because we have a large amount of experimental data at our disposal in order to carry on the training of the neural network itself.

INTRODUCTION

The main target of this work is the condition monitoring of the tool of a machine for marble cutting in order to avoid the breakage of the tool during the working, because it increases the machine downtime and furthermore the good condition of the tool assures a good working of the marble block in terms of surface finishing and operators safety.

We decided to use an algorithm of artificial intelligence as a neural network able to process the most significant field signals in order to provide an output indicative of the tool wear.

The update software tools allow to build a model starting from the historical data concerning the process: the predictive model created is able to reply to external changes, in other words to reply to the change of input data and experimental conditions, so the user can manage with autonomy a large amount of information. Such tools allow to analyze a certain kind of data to understand their behaviour and the eventual correlations existing among them.

On the basis there is a measure phase on the field that provides a large amount of data; more data more is the capability of generalization of the neural network (less data make to converge the network faster but logically with a lower generalization); generally the information are processed following well defined steps.

At first the user has to import the available data in the working environment: the user decides what is not eventually to consider; from this large amount of data, representable in m dimensional model, we change to a bidimensional representation as showed in figure 2: this transformation happens by the application of Principal Component Analysis PCA, described later.

The projection is more comprehensible for the successive analysis, then the variables are represented as a set of points whose particular configuration already provides indications regarding their characteristics. Each single point is representative of a single measure and their configuration allows to the user some opportune considerations.

The zones with more concentration of points are considered macro areas; eventual scattered points are considered as possible errors, insubstantial data: the user could want to understand the meaning of these points, what they represent about the process, the instant when they occurred; besides for every instant of time it is possible to individuate which are the variables that changed in significant way.

It is important to point out the necessity to have more available data as possible, but still more important the data are more correct as possible for the training of the neural network; it follows the processing of various parts of data, the choice is based on what concretely one wants to observe.

The following step is a predictive model and it is analyzed the delay between input data and obtained output; the successive simulations, in other words activities that can be carried out in the working environment, allow the user to understand how much the predictive model is aligned with the real process.

By the analysis of opportune indexes it is possible to carry out an evaluation of the model quality (generally are considered the mean squared deviation and the correlation coefficient) and the obtained model can be exported into an expert system.

We particularly took into account also the analysis of sound pressure level detected close to the machine in order to check if it was sufficient as input to neural network to control the tool wear and so to simplify the condition monitoring system also in order to export this methodology to more complex machines for the marble cutting.

Before the use of a condition monitoring system, the good condition of the tool, that is a metal plait with inserted diamonds, was carried out by the operator by a visual analysis of the tool and the surface finishing quality, if the latter was not good it was necessary to spend more time for the finishing work.

The test marble cutting machine

The figure 1 shows the architecture of the machine under test: an electric motor moves the tool that rotates during the running and the support of the tool goes down with a defined velocity for the cutting; during the running, the tool is cooled by a water jet. The machine under test is able to cut marble blocks with a dimension of about 1500 x 1500 x 2700 mm in slabs of about 30 mm. The steps of the cutting process are basically three: during the first step the machine is running but the tool doesn't attack the marble block, in the second step the tool starts the cutting but not yet in the optimal condition, in the third step the tool is completely inside the block and this is the most significant phase. The cutting process needs about five hours and so the tool condition is very important to avoid economical damage for the company.

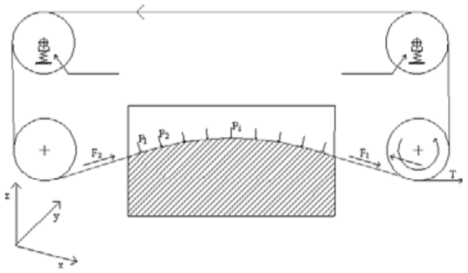

Figure 1 - Architecture of the machine

Sensors

The machine is arranged with sensors and a data acquisition system able to monitor the condition of the machine itself and the working parameters. We can detect the torque measured close the shaft of the fly-wheel, able to determine the cutting force, the revolution per minute of the fly-wheel, the current consumption of the fly-wheel motor, the flow of the cooling water, the feed velocity, the cutting velocity, the internal pressure of pneumatic cylinder able to determine the contact force between matchboard and marble. In addition we provided a microphone and FFT analyzer to study the sound pressure level emitted by the machine during the working before and during the attack of marble block, in order to avoid the background noise emitted by machine components and other sound sources like other machines in the environment.

Field signals analysis

In order to detect the tool wear to prevent the breakage, the first step is to individuate the most significant field signals and to process them by intelligent algorithms like fuzzy logic or neural network to get our target. Tool wear analysis depends on many factors like working conditions, geometric shape of the tool, characteristic of cooling fluid, characteristic of the material and to design a mathematical model is not always feasible and reliable and besides the our past experience in the use of a method based on neural network assessed that it is particularly suitable when the working condition are always the same in function of the material that has to be worked and we can provide a large amount of experimental data for the training of the neural network for the different kind of materials.

Principal Component Analysis PCA

As we carried out many experimental tests, we gathered a large amount of field signals. A not skilled user is not able to understand which are the fundamental characteristics necessary to understand the phenomenon on approval. Considering the Cartesian representation of data it is clear that a tridimensional system is in some cases not much understandable; to switch to a system with n dimensions doesn't allow a right comprehension of information. We risk to storage useless information with waste of memory space necessary for the optimization of a production process.
If we have a large amount of data, it is necessary to understand which are the most significant variables and we need to find out a systematic way to choose from a large set of data a sub system representative of the system where the information spread is the lowest. The Principal Component Analysis is a technique for the simplification of data that is currently used in the multi varied statistics, the field of statistics where are analyzed objects characterized by at least two components; it is clear that such kind of analysis can be useful for a production process characterized by a lot of variables. This technique, starting from an arbitrary set of variables X_1, X_2…..X_m, , produces a new set of variables X_1*, X_2*…..X_p*, with $p \leq m$, sub system of the start set where the each variable represents a linear combination of the start variables X_1, X_2….X_m. The target is the reduction of the number of the original variables into a new variables set X_1*,X_2*….X_p* not correlated among them. By a linear transformation, the original variables are projected into a new Cartesian system where the new variable characterized by the greatest variance is projected on the first axis, the second one in terms of variance is projected on the second axis. The other variables are processed in the same way: by a linear combination of these new variables, called principal components, are defined new axis that don't modify the structure of the points, because there is a rotation of original axis. The values of the new variables are called scores of the principal components; if instead to project both the principal components we decide to project only the component characterized by the greatest variance, we get a representation in the one dimension space. It was realized a reduction of the p dimensional space; by the difference between the total variance, characteristic of the p dimensional space and the sum of variances of the principal

components, we get an estimate of the information loss because the reduction of the dimensional space. In conclusion the new variables got after such analysis are characterized by decreasing variability (they are set in order in terms of variance) and by null correlation coefficients: such variables are able to make easier the interpretation of information because a reduction of the start variables, assuring no correlation of them and to minimize the information loss.

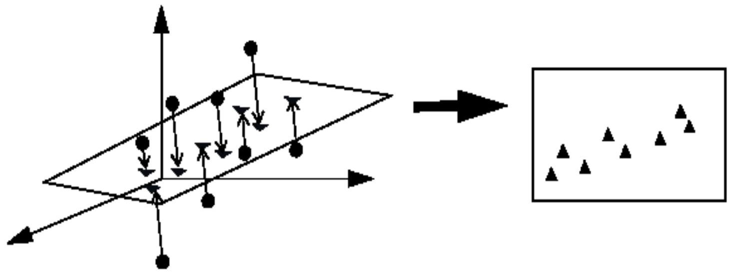

Figure 2 - Transformation of coordinates by PCA

Neural network

The human brain has about 10 milliards of neurons, they cannot be reproducible, and this number decreases because the age, accident or illness. The neurons are linked among them and when a neuron starts, it provides an electrochemical impulse to the other linked neurons. The biologic neuron, as showed in figure 3, is composed by a cell body, where there is the nucleus, characterized by 46 chromosomes necessary to identify our genetic map, and cytoplasm.

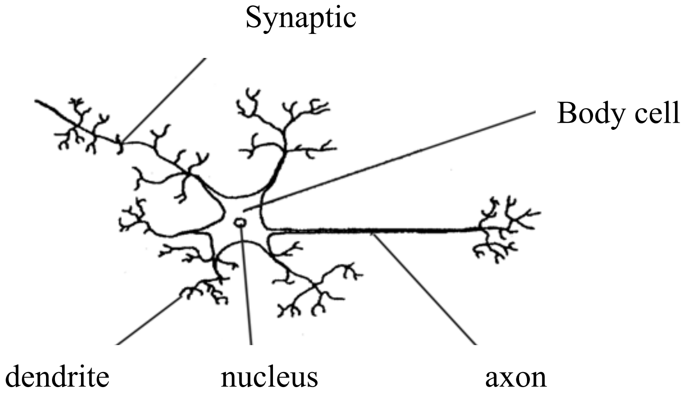

Figure 3 – Scheme of a biologic neuron

The cell body is coated by a membrane able to hold on a polarization and it is linked with one or more dendrites, ramate extensions, linked to other neurons. The dendrites of a neuron excite the cell body that, over a threshold, discharge its activation along the axon to other cells by electrochemical process. The contact point between the axon and the dendrites is called synapse, this is a narrow gap between the axon of a cell and the dendrite of another cell; this gap can vary in function of the time and it can grow up or weaken the connection between two neurons. The transmission of the signal through the synapse is generated by the so called neurotransmitters, molecules like adrenalin and acetylcholine. The transmitted signals are characterized by different weights and can be excitatory (positive) or inhibitory (negative), never both. When the sum of the set of the weighted inputs is over a threshold, the neuron starts and transmits an output to the other linked neurons. The frequency of transmission is low, but we must consider that if we make a comparison to a computer, where the processing happens in a sequential way by CPU and then stored in RAM, the neurons provide both processing and storing and they work in a parallel way. In conclusion we can say that the biologic process happens by a stimulation of a cell by impulses coming from the sensorial system, so the neuron changes its electric polarization, and when the threshold is exceeded a signal is transmitted to another neuron and the first one returns in its original status. The figure 4 shows an artificial neuron, represented by a circle with the weighted inputs according to their importance, coming from outside or as outputs of other neurons.

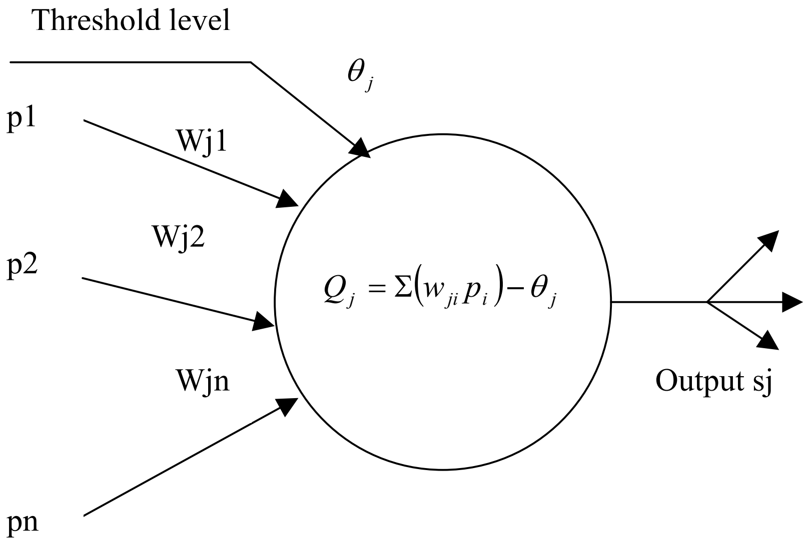

Figure 4 – An artificial neuron

When the sum of these inputs is over an “activation threshold” the neuron starts and provides an output, otherwise it is inactive, but both the status are meaningful. A neural network doesn’t need a programming, but a training by experimental data. The training doesn’t mean to provide to the neural network the algorithm that defines a process, in some cases it is difficult to find the algorithm, but some examples in order that the neural network itself is able to get the knowledge of that process. There are some kind of neural network, according to different applications. The potential of the neuron is defined from the following formula as the sum of n inputs minus the activation threshold θ_j :

$$Q_j = \sum_{1}^{n}\left(w_{ji} p_i\right) - \theta_j \qquad (1)$$

If $Q_j > 0$ the output will be unitary, while if $Q_j < 0$ the output will be null, that is represented by a step function showed in figure 5 (a), to stop the neuron activation. Generally it is used the following signal function:

$$s_j = f_T\left(Q_j\right) \qquad (2)$$

which tends to the step as the smooth function called "sigmoid" as showed in figure 5 (b).

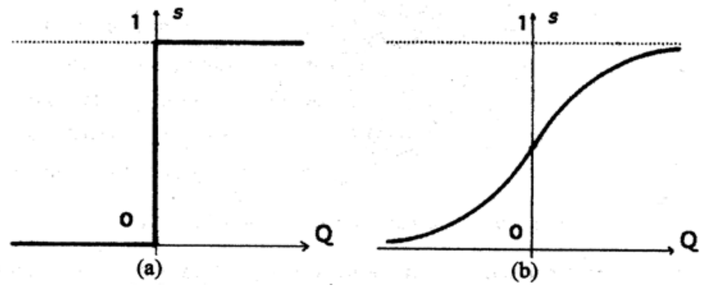

Figure 5 – Common neural network signal function

Acoustic signal analysis

In order to check if the acoustic signal can be considered meaningful to determine the tool wear of the machine, we carried out some experimental test with a ½" condenser microphone, the measured sound pressure level, free from the contribute of background noise caused by other noise source in the surrounding of the machine under test and other components of the machine and so considering only the technological contribute of the tool during the cutting time, was analyzed by FFT algorithm to find out in the frequency domain versus time if one or more spectrum components increased their amplitude level according to the tool velocity and the rotation velocity of the inserted diamonds.

CONCLUSIONS

After many experimental tests carried out on the machine and the analysis of the obtained results we can say that the use of the technique based on neural network is a powerful methodology to find out the tool wear in order to prevent the breakage during the long enough cutting time to improve the productivity and at the same time the safety of the machine.

Also the analysis of the sound pressure level got good results and this is important because this kind of measure doesn't compromise the operativeness of the machine, also in terms of maintenance, and allows to not modify the design of the machine to arrange a sensors system on board.

This study represents a first step to determine the tool wear in this kind of machine.

The next step will be to check if the neural network processing only the sound pressure level could be a powerful tool and if it could be exported for other more complex machines for the marble cutting.

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