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A QUALITY ASSURANCE SYSTEM USING NEURAL NETWORKS

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Abstract

This paper concentrates on the structure of a system to be used in the study of products that change some of their properties during the use they are submitted. The system has been applied to inspect products that have changed some of their main characteristics when they are been used in normal conditions. The color of textiles (clothes, for instance) in an example of this kind of situation. The approach is based on pattern recognition techniques and learning methods are used in this application. The system first analysis the original characteristics of the properties and then studies a set of images of the material during its use, after some days or months. A classification system is developed to define if the changes during this period are acceptable or not. The evaluation is made according to the classification that the system has learnt. A neural network is used in this system. Starting with the analysis made in the material in the moment it leaves the factory (patterns), we follow the pieces during the use, comparing them with the patterns. The neural network decides if the changes are acceptable or not.

Introduction

The performance of industrial products and their fitness for the purpose to which they are destined, or the adjustment to the demand that they are to satisfy, depends on two basic production processes: the conception and feasibility of product design and the development of manufacturing procedures.

These aspects are traditionally treated in the context of product quality evaluation, since both the appropriateness of use as well as the adjustment to the market range where the product acts are considered. Thus, it is common to refer to as "design quality" the analysis that is made of the product, in terms of quality, based on the structure of its design and "quality of conformation" to the study made based on the comparison of the finished product with that of the design from which it originated.

If a product was produced in such a way as to conform to its design, other similar products can be produced. At this time, the design came to be considered viable. If, nevertheless, after this moment, there are products issued with alterations, it can be affirmed that there are problems with the productive process, which would not be the case if none of the products had been issued in conformity with the design. It consists of a "lack of quality of conformity."

If the evaluation of quality of conformity points to highly accentuated alterations in the products, corrective and preventative actions must be immediately triggered, to guarantee that the product continues to be manufactured according to its specifications. The experience of the process, of the operators, and the knowledge that they have of the product, are factors that help to define the actions that must be taken - in general - this is not a difficult task. A more complex question is to verify if there are, or are not, deviations of production that can compromise the quality of conformation, that is, detect defects that, although they don't directly affect the functioning of the product, provoke alterations in the product in relation to the original design.

Examples of these alterations can be observed in wall paintings (variations in hue throughout the painted area); in the hue of the floor, tiles, wood, carpeting, wall-paper, or in a broader sense, facings or protective materials; in the alterations in color of fabric and garments after a certain time of use; etc.

These and many other similar examples demonstrate the importance of evaluating, in a permanent way, the quality of conformation of the product, in order to avoid situations that may lead to alterations in its essential characteristics. If these changes are detected, the relevant corrective and preventive actions must be taken which guarantee the maintenance of the product's properties. In this way a well-defined problem arises, which appears to be crucial for the entire process: the objective evaluation of the variations of the relevant properties of products. In fact, it can be observed in an intuitive manner that alterations in a given characteristic of the product are occurring. The following questions are thus raised: How to evaluate the intensity of these variations? How to verify if these variations effectively compromise the quality of conformation? How to identify the area where the alterations are most effective?

There are other relevant aspects to consider. Dimensional stability of a piece of clothing can be easily evaluated, by direct measuring. But there are situations where direct measuring of the variation of properties of a product cannot be undertaken. In this case, the evaluation is made in a subjective manner, which, nevertheless, should not be dangerous for the enterprise, for reasons of reliability and coherence in decision-making.

In case of stability of basic properties of a product, this second type of evaluation is utilized in many cases, such as those that seek to determine the following aspects, for example: Progressive degradation of the product by the appearance of scratches, cracks, chips, holes or bends; alteration of product characteristics by the appearance of stains or blemishes; loss of color; evidence of contamination of substances by alteration of color, viscosity or concentration; inadequate treatment of the product verified by the appearance of scuffs, scratches, or even breaks in its external surface; detection of signs that characterize wear on the pieces, oils or coverings by the analysis of its current hue (such signs call attention to the need to substitute material).

The current study is based upon evaluations of this type, and proposes for this case, a model that seeks to optimize its development. Seen in a wider context, the problem in question consists in evaluating the stability of the basic characteristics of a product when in effective use. These characteristics, are, in general, properties that identify the product and that, for this reason, are essential for their adjustment to the end for which they are directed, the reasons for which are associated, with frequency, to the very quality of the product.

All of these activities and concerns are inserted in the Quality Assurance (Keane 1998). For this reason, a basic system to be utilized in the effort to guarantee the quality of a company's products is proposed here.

Stability and Structure of the Model

"Stability" is understood here as the maintenance of a property that characterizes a dynamic system throughout a given period. In the case of industrial products, this stability concerns the quality level of product conformation. The basic question considered here is the evaluation of stability, that is, the process to determine if the product characteristic in study, presents variations that compromise its utilization. If so, the alterations affect the functional properties of products and its performance.

The problem dealt with in this paper is centered on situations where it is not possible to perform conventional measurements. In this way, initially, a method must be developed that permits a quantitative evaluation of the characteristic under evaluation. This method must examine the characteristic and extract, from it, some data that are considered "entries" of the model. These entries must be processed and, at the end, the model must indicate if there is a variation in characteristics, as well as in the intensity and nature of the alteration - if it is considered relevant. This last phase can be identified as achievement of a solution based on the model.

The formulation of the model involves two distinct phases: to get data to be used and computational procedures in which data will be implemented. The development and the tests of the model were made in Industrial Systems, which perfectly represent Dynamic Systems. In particular, the analysis of the variations that the System can generate will be made in the results of the industrial process, that is, in the products.

The general structure of the model involves the following elements: To begin, consider a given product (or a part) and determine the property or characteristic to be evaluated. It is possible, if required, to select the area of the product where the property to be evaluated is observed and concentrate attention only on this area.

Next, the image of the part is captured by a process that includes an illumination system that falls on the part, cameras that photograph it, and a device that records the captured image. The next phase utilizes a processor that associates a structure to the image. It is a device that associates that image collected to a specific structure, such as a matrix or a histogram. Once the image representation structure is defined, another processor can be utilized to treat or analyze the image. This processor can be software or even the very device that creates the structure of the image. The object, here, is to highlight useful characteristics for the study of the property that is to be evaluated. A scheme is then formulated to analyze the image. With the image already associated to a structure, and properly handled, a process of analysis can be applied to this structure that specifically seeks to evaluate the characteristics or the property in focus. This scheme, which can be a software, will determine two things: the existence or lack of variations and the determination of a form and content of variation, if it exists.

Data Preparation

Usually, the process of evaluation of characteristics considered is developed from the visualization of the characteristic itself. Sometimes, the form it takes is considered; in others, the content. In the first case, stains, breaks, scuffs, cracks, bends, etc. are spotted; in the second, the color variations, with the fading of the original hues, darkening of the product parts, alteration in the bottoms or shadows, etc.

In all of these cases, the procedure is the same: the decision-making agent "sees" the part and decides, subjectively, if variations in the considered characteristics have occurred; what it really does is an analysis of the image of the piece, although the evaluation process is qualitative. In this way, the "result" of the evaluation cannot be reliable.

As the model requires "quantitative" data for its operation, what is planned is, based on the image of the piece, to extract values that identify without a doubt, the characteristic under study, measuring the intensity, with which it occurs. There are two ways to proceed with this measure: in a monochromatic environment, the gray level associated to each pixel that composes the portion of the part under study can be determined; in polychromatic situations, parameters that identify the color and tone gradations, such as saturation, intensity, brightness, etc. can be obtained.

These parameters are, therefore, the data that the model requires. The practical experience demonstrates that monochromatic evaluation can be applied to the first case described above (form) and can identify the occurrence of stains, breaks, scuffs, cracks, bends, etc. On the other hand, in polychromatic environments, content variations can be analyzed, more specifically the colors, as well as the incidence of fading in relation to the original hue, darkening of the external regions of the product, appearance of new hues, etc..

The following procedure to evaluate the variations is adopted: The alterations observed in the results of the basic operations of the system are always considered as the basic element of evaluation. In the case of industrial systems, then, the analysis centers on the characteristics of the product; the first result of the basic process of the system is considered the standard and from it is extracted the first image, or the original image. In the case of industrial systems, it concerns the image captured from the finished product, before initiating its use or, then, the image of the product at the beginning of the study interval; next, images of subsequent moments are captured, or that is done after the elapse of the various specified time intervals. They are the so-called "posterior images" related, for example, to the product after some time of its effective utilization; depending on the nature of the product and the characteristics to be studied, images of the entire extension of the product are never captured, but only of some of its areas, where the probable alterations of the characteristics under study are most visible.

The parameters that represent the original image and the posterior images are obtained through the utilization of specific devices. All of the hardware for the system has already been built and involves the basic devices that capture and process images in a manner appropriate to the evaluation of the stability of the characteristics of industrial products.

Image-Capturing Processes

Various methods of image capturing exist, depending on whether the environment being considered is monochromatic or polychromatic. In case of monochromatic image capture, there are various possibilities, such as "scanning," "line-scanning", frame grabber processing, capturing at the pixel level, etc. Considering the diverse methods, it is concluded that the most appropriate for the current study is that which utilizes the acquisition of the image with the use of digitizing circuit boards. In this case, and keeping in mind the specificity of the problem in question, an image capture system was structured that involves the following elements: (a) a camera, that captures the image; (b) image processing circuit boards; (c) a computer; (d) image processing software and (e) a system to link the circuit board to the computer. The polychromatic image capture methods involve similar devices.

Using Neural Networks

The methods utilized for the evaluation of alterations in properties that characterize a product can be classified in two types: **Analytic methods**: conduct analyses of image representation structure of the parts. These structures are defined as matrixes, functions or histograms and the methods of solution for the problem utilize common properties of these arrays; **learning methods**: are methods that apply Artificial Intelligence techniques. In this case, the process begins with the study of a set of images that demonstrate alterations that have occurred to a given part, that is, the system makes contact with the original image and the posterior images of a part that are presented to it. These images come to be the "standards," contrary to the analytic methods where the standard was only the original image of the piece. The model, then "learns" that the variations presented are compatible with the original image (or are not appropriate for it). In this way, the images presented of the piece are assigned a given classification. From there, the other images of the piece under inspection come to be evaluated according to the models that the system has learnt. A preliminary observation shows that this methodology presents advantages over analytic methods. In fact, this approach has been extremely appropriate for the situation under study, as the entire analytical framework is based upon a well-determined real situation, based on which the part's characteristic evaluation design will be modeled. In addition, the high-efficiency level of the entire process is considered, developed through the utilization of simple, programmable, models that are easy to use and are understandable. The basic tool utilized for the evaluation of the stability of the characteristics of the part by learning processes is precisely a neural network.

Processes of Evaluating by Learning

The process of evaluation by learning emphasizes the development of an evaluation system that would apply to a situation where it would be utilized. In this way, based on the principal that the very system should "observe" the situation in question and "learn," from it what should and what should not be done. In other words, what is desired is that the system imitates, step by step, what a decision making agent would do if it needs to evaluate if variations in characteristics under study are acceptable or not.

The system should seek to imitate the decision-making agent. To do this, the system "memorizes" situations where a particular decision was employed. The classification, in this way, occurs because the system identifies what it is considering in relation to something that had already been analyzed, and was memorized. It should be remembered, therefore, that there is a considerable diversity of situations in a part - principally if in it are detected dynamic characteristics - and that the system could not "memorize" all of them, because the decision making agent would not be able to list them, in their entirety. In this way, it is hoped that the system works as a decision making agent, but that it takes into consideration, that the observed cases are a sample of reality, thus considering the existence of a variety of such situations not presented in the training phase of the system. For these situations, the system should decide alone, using methods and strategies of analogy, attempting to find similarities between what is "observed" at this time and the situations stored in its memory. Its decision, in this case, also will be registered. By offering a re-supply to the system in order to a assign to the analysis conducted a scale according to which it was or was not correct, the system can include this case in its knowledge base, and make use of it from here on. In other words - the system learned how to deal with that context (Lawrence 1992).

By their structure and nature, the neural networks are the proper tool for this case. In addition to working within characteristics of the process described above, the network operates in parallel, processing a variety of information at the same time, with greater efficiency and effectiveness than operate sequential systems.

Description of the Model

Based on the analysis processed in a set of images of a given part, the evaluation of variability of which is known, the model, utilizing a neural network, determines whether a particular part presents or not, for its basic characteristics, compatible variations with its original project and to the demand the product expects to satisfy.

In the case of monochromatic analyses, the program evaluates these variables by the analysis of the gray levels on the surface of the part, keeping in sight, the images furnished to the network in the training phase. In the parts in which the network considers carriers of unacceptable variations, clear or dark stains are detected by the analysis of the gray levels. In the case of polychromatic analysis, once a basic parameter is set (for example intensity, saturation or chromatic hue), the program studies the incidence of the values of this parameter in a set of images that serve for network training. The pieces that present values compatible to the variations with the set of images utilized in the training will be considered "in conformity with the standards." In both cases, the network judges only the conformity of the pieces in relation "to standards," testing if it exists or not. This evaluation is not based on rigid limits, maintained constant through the entire process, but works with flexible standards and attempts to adapt the evaluation model to each case.

In this case, it utilizes representation matrices of the parts. In a monochromatic situation, it concerns a matrix that associates gray levels to each of the pixels; in polychromatic situations, it concerns matrices that associate specific parameters to each pixel. In general, the most relevant parameters are chromatic tone, intensity, saturation, and value, in the case of HSI and HSV systems; in the case of RGB systems, the parameters are the grade of the primary colors that each pixel contains (the primary colors, are in this case green, blue and red). If necessary, the system can operate with complementary colors, such as cyan or magenta.

For the operation of the program, in any of the cases, the decision making agents must select a set of images of a given piece that are judged, a priori, as carriers of acceptable variations. Images that demonstrate incompatible variations with the nature of the part will also be presented to the system, in such a way that the confrontation of the two types of situations will be evident. In this way, selecting the parameter that will be utilized, the system should be supplied with a set of images with compatibility to the acceptable variations of the part.

The program requires a set of images of the part in study, considered as standards, and operates by the confrontation of images under analysis with the standards. Reference values for the upper and lower limits within which the standard should vary can be supplied to determine characteristics of the part (dark stains or chromatic tone much stronger than usual for example).

In general terms, there are various techniques for the establishment of a neural network. In the case of the specific system in question, some preliminary observations have been made. Initially the ease of obtaining data for training of the network was observed, and in the case of dealing with an evaluation by attributes (of each variation observed in the original part), it is not considered too much work to develop a network training scheme. Both the hypotheses were confirmed in practice. Next the analysis in the evaluation was established, which is to separate parts with acceptable variations from those that present incompatible changes with the nature of the part. This shows a simple problem of classification of the parts in study. Attention was paid to the fact that the process tends to follow a trend in its common form of operation: in the occurrence of unacceptable variations, this tendency evolves the massive rejection of the parts; in the absence of relevant variations, the opposite trend occurs with strong incidence of parts accepted.

This reveals three characteristics of the network: ease of training, classification of items with a basic form of operation and convergence to specific values during their development. In addition, the network must work to minimize its errors, that is, emphasize all of the characteristics that can lead to a correct decision concerning the observed variations. Therefore, it becomes important to create favorable devices to the minimization of the deviations between what is desired and what is obtained as a decision of the program. Consequently, a model with a strong and permanent re-feeding must be structured, in such a way that, every time that an advancement towards decision making results it is possible to return to the basic information to check the validity of the entire network operation and in particular, of the specific decision obtained, that is, permanent updating of the data in function of the analysis of each pair of entry/results obtained. Finally, since the data for each part can be numerous, we need to construct intermediary layers in the network structure. The characteristics of the situation under study suggest the use of a "backpropagation" type network, for issues such constant feedback, constant data updating and network training facilities.

Structure of the Neural Network

The main part of the system we describe here is the neural network (the pattern recognition procedure). We consider three layers to the network. So we have: The values of the property associated with each pixel i, denoted by $p(i)$, $i = 1,...,n+1$ represent the first layer; the output of the network is $t(j)$, $j = 1,2$; the hidden layer output is $d(k)$, $k = 1,...,m$. From the first to the second layer there are weights $g(i,j)$, from the input neuron i to the neuron j in the hidden layer. From this layer to the output layer the weights are $h(j,k)$.

The implementation of the network can be described as follows: First, we define: $a(i) = g(i,k) * p(i)$; $b(i) = h(i,j) * d(i)$; $c(i) = h(j,i) * s(i)$. We call **a** the summation of all $a(i)$ (i from 1 to n + 1); **b** is the summation of all $b(i)$ (i from 1 to m + 1) and **c** is the summation of all $c(i)$ (i from 1 to n). To train the network, we have: $d(k) = 1/(1 + \exp(- a))$. From the hidden layer to the output layer we have $t(j) = 1/(1 + \exp(- b))$. At the end of the network, we reach a proposed result (t). From the knowledge of the desired outcome (y), we compute s(j) as follows: $s(j) = t(j) * (1 - t(j)) * (y(j) - t(j))$. By the backpropagation principle, $r(j) = d(j) * (1 - d(j)) * (\quad c)$. To adjust the weights from the hidden layer to the output layer, we have $A(h(i,j)) = K * s(j) * d(i)$, and from the input layer to the hidden layer: $A(g(i,j)) = K * r(j) * p(i)$. We use K as 0.40 (Knight 1990). The error at each interaction will be smaller than the previous interaction if the pieces have smaller variations, that is, if the network is trained (Geszti 1998).

Results and Conclusions

In the tests of the model about 15,000 images were processed, for about 3,000 pieces. Two types of errors were observed: (1) perfect pieces (carriers of acceptable variations) classified as defective (carriers of relevant variations) and (2) defective pieces classified as perfect.

The applications made can reveal that this is a rather simple to use module, although it presents sophisticated theoretical support. Fundamentally, it serves to detect the unacceptable variations that demonstrate the lack of compliance of the piece with a given standard. Its use does not depend on already existing reference values for the limits, although it would be necessary to set tolerances for the errors that a network can generate. The program does not make individual analyses of the pixels, but only a global evaluation of the piece. It is noteworthy that the greatest characteristic of the program is its high adaptability to the productive process where the evaluation is being operated, which permits considerable flexibility in the process of analysis of images of the pieces in study. The program does not require high image resolution.

The results show that the accuracy of the program is high. Observing about 3,000 images of 600 pieces, 99.85% were correctly classified, with an error in only 0.15% of these. These results also hold in the universe studied. It was observed that whenever the number of parts, the images of which show acceptable variation, increase (the defective portion decreases), the margin of error decreases drastically. It is important to remember, however, that for extreme situations, with two pieces that are carriers of unacceptable variations in each three produced or in a base of one to one, no errors are detected in any of the cases. With a defective fraction of 50 percent, the error was of two pieces classified incorrectly in 300. Few pieces were necessary to train the network. There was a case that only 300 images were sufficient.

A good performance of the program is observed, although with two operating restrictions: detailed analyses of the pixels are not made, but only a global evaluation of pieces, and there is little chance of obtaining relevant information for the complete identification of the nature of the variations observed in the non-complying parts. These restrictions are compensated by the benefits of the program like the flexibility in its use and fitness to the productive process where the evaluation is being made.

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