Intelligent system for defect detection

Edson Pacheco Paladini

Abstract - This article describes an intelligent system for defect detection in industrial factories. The system makes an image analysis. The study shows a structure to detect, classify and identifies defects in industrial pieces during the processes they are being produced. The paper explains an automatic process control to detect failures on product appearance, it means, in their externals areas. The evaluation processes consider unlimited defects, it means, those defects whose limits are not clearly defined. Because of common characteristics, the defects appear in inaccurate parts of each analyzed piece. The hardware support involves pattern recognition devices and they are used to detect, identify and classify the defects. The structure of image capture and analysis do not need any human operator to reach a decision about the considered pieces. In addition to describing the model, a typical application is discussed. The practical results obtained are detailed and evaluated.

Keywords - - Automatic Structure, Pattern Recognition, Quality Control, Quality Inspection.

I. Introduction

This paper works with quality control. Specifically, attention is focused on procedures related to identification and analysis of defects on the surface of products. This is the case of metal surfaces, materials resultant from iron, steel or alloys. It is the same situation of the analysis of the external area of products that have these materials in their composition. An example of this case: the external area of car shells. The quality control techniques devoted to this kind of evaluation have made a considerable progress, specially taking into account automation procedures. The tools most common here is part of Pattern Recognition Analysis, or part of Artificial Intelligence Devices or even theorist approaches, like Fuzzy Logic. The use of all these methods have possible the development and application of highly efficient, reliable and practical procedures to quality inspection. Especially when the evaluation system has to make detailed study and, at the same time, classify defects with reasonable costs.

This paper shows an additional outcome in this research area. It is related to structuring a new method to detect defects on the external area of pieces of metallic materials, for instance, and develop a critical analysis of these defects.

The author is with the Production Engineering Department
Federal University of Santa Catarina, Santa Catarina, Brazil

The application of the proposed method involves a specific condition. However, it is a common situation and involves pieces where the borders of each defect are not well defined and limited.

Consider, for instance, the spots caused by imperfections during the production process. Also it can be considered failures resulting from corrosion processes and cracks that appear as an effect of internal breaks or damage from inadequate handling or material accumulation as a result of warping. This study describes a method which yields a quantitative analysis of the image of the piece under evaluation (quality inspection). The model uses a quite simple mathematical support. The image of the pieces is produced by means of relatively common devices (such as cameras connected to digitalizing boards).

The structure, that includes theoretical approach and physical equipments, make possible to determine the occurrence of defects. Besides this information, the structure can quantify the extension and the seriousness level of each defect. The devices inside the inspection structure are operated by highly sensitive elements. The results produced are able to detect defects. Mainly in situations where the borders of the imperfection are not well defined. It can be a great problem to usual devices for capture images since the indefinite borders disfigure the image of the product and distort the evaluation.

II. Practical Support For Defect Detection

The structure described here begins with the image capture process. It can be observed that there are various image-capturing methods. To select one of them, it is necessary to consider the type of environment of work. For instance, it is necessary to determine if the environment is monochromatic or polychromatic. In the first case, the image capturing methods allow three possibilities: scanning, line scanning and processing with the use of digitalizing boards. In the second case, for polychromatic images, it can be used systems which scan color images. These systems define values (from a continuous scale) associated with each pixel of the image. Scanning processes usually employ specific color scheme, as is the case of the well-known (and old) systems RGB or HSI. Line-scanning systems for color images are not useful in the present study. Normally, the use of boards is considered a simpler way to get good image from digitalizing polychromatic systems.

The devices for image capturing systems include cameras, which capture the image and image processing boards. Some image processing software is always necessary. The connection between the board and a computer (to analyze the images) is quite simple to do.

Different uses of the image may require different adaptation of the image capturing procedures. Nowadays, there are many software and hardware mechanisms available for different employs.

The main point to be considered in this study is the lack of borders in the defects. So, image segmentation processes play a fundamental role in the analysis of the picture captured.

All image capture processes consider some treatment method. The idea is to improve specific particularities of the image, providing more effective conditions for decision-making through the system of capture and analysis according to the objectives of the analysis. For the detection of imprecise defects, it is necessary to make a preliminary analysis in order to segment the obtained image, in such a way that a partition of the structure (grid) of the points may create a specific sample image. This segmentation aims to highlight specific situations of the image, disregarding limits (which are fuzzy in defects with indefinite borders).

The chromatic properties of the pixels selected in the captured image are the characteristics of greatest interest for this study. Therefore, we consider relevant such aspects as factors influencing color perception [1], [2], color classification (achromatic, chromatic and parachromatic), color description [3] and color models [4].

It must be noted that the system to capture and to process images must have some characteristics which are not required (and not found) in other situations previously considered in the specific literature. In fact, practical applications show that is necessary to store in a vast and easily accessible memory the images of the patterns with which the pieces studied are to be compared. It is necessary also to create a basic model of colors to define which will be used as a reference in the analysis of the image, since it is essential to have an objective (quantitative) comparison between the pieces under inspection and the patterns. To develop this comparison, arithmetical and logical operations must be elaborated and used. These aspects show characteristics that will be available in the structured inspection system, which, as it can be seen, must have a better and much more consistent support in terms of software and hardware resources than in the monochromatic analysis.

In the latest years, many color models have been built and now are available. So it is important to select the color system which best suits the objectives of this project, taking into account the specificity of the present investigation. The (old but still efficient) HSI system was chosen because of the independence that the analysis of each component makes possible to develop. It makes this system more efficient in computation terms [5] HSI systems have also greater proximity with form effectively used by inspectors (humans resources of quality control) to visualize color environments.

Both aspects are relevant. In fact, the quality inspection structure needs to create a system which can be adapted to the productive process, since the pieces under analysis will be collected from it and the results of the quality evaluation will be applied to it. So the simplest and most practical way to develop inspection will be necessary, since the devices should facilitate a quick and objective evaluation of a piece. These requirements demand a computationally efficient system.

To guarantee the perfect fitness of the inspection structure to production process, it is highly desirable that the system plays as a conventional inspector. The system should imitate the procedures of a human inspector and because of this similarity it is necessary to taking into account the same values considered by the inspector when a piece is evaluated. That is one more reason why the required adequacy of the HSI system to the present project is so relevant. Also the possibility of converting the HSI system to RGB is very interesting. It shows that is possible to use other types of analysis starting from the same representation of the image of a piece, since it has been carried out from HSI models [6].

There is no difference in logic processing for polychromatic image matching and the same operation developed for monochromatic environments. In fact, it is possible because of the adoption of HIS color model. In this model, the basic elements identifying the colors are independent from one another. Practical experiments with RGB systems have produced some difficulties in adopting the same processing model precisely because of the interdependence of the basic model coordinates.

III. Theoretical Support FOR Defect Analysis

Taking into account the type of defect that usually appears in products like wall tiles or paving-tiles, there are no clear definition and no precise delimitation to each defect, like a risk, for instance. In this case, there is no way to identify the borderlines of the damaged area.

In this situation, it is critical to highlight on the image of the piece the relevant characteristics for the detection of the defect. If this treatment of the image is well done, the subsequent identification of the defect is easily reached.

The primary element of the image is the pixel. Hence, pixels are the fundamental aspects of any digital image. The pixel is the picture element, the basic form of the point that composes the image. Each pixel can be associated to some coordinate system so that is easy to determine the position of the point on the image. Associated to the pixels are basic characteristics of an image. These factors are chromatic pattern structure and the gray level. These factors are fundamental components of the analyses herein carried out, since these data provide information as to the presence or absence of certain properties of an image or of some specific part of it. Chromatic pattern structure and the gray level will determine the presence of some defect on the piece.

The structure developed here is able tom associate quantifiable values to the color of the piece. If monochromatic images are being used, its gray level is considered. These numerical values make possible to determine the intensity of the property under study. The theoretical approach here is similar to the well know and, thus, quality evaluation by variable [7]. In fact, quality evaluation by attributes could not be used here just because the lack of precise and numerical evaluation results. It can be observed that quality evaluation by attributes is a typical situation as regards the occurrence of defects with indefinite borders. In the new structure proposed here, it will be replaced by quality evaluation by variables since it is necessary to associate quantitative values to the images captured.

So it is possible to conclude that, in general, defect analysis of the external areas of pieces and products under analysis is carried out for the images representing these areas. The process of obtaining information which makes up the image of the pieces consists of the above described devices which will replace visual and tactile evaluation developed by inspectors, who normally do it in the traditional model. This image capturing process allows excluding human resources of the quality inspection. Through this procedure, the image representation structures upon which the defect detection system is to work are defined. Practical applications of the present study may to say that the technical feasibility of the system structuring is ensured. The image representation structures are the inputs to the software and hardware programs that make possible the recognition of defects.

The technology that supports the study is not recent but it works efficiently. In fact, the most widely used model for the situation described in this paper is the HSI [5] that consists of a more neutral way of describing colors than the traditional RGB model. The components of model HSI give important information in a straightforward way: chromatic hue is the effective color (blue or yellow, for example); saturation is the depth of the color (pink or dark red, for example) and intensity has to do with brightness.

The next step to construct the inspection structure is the piece analysis scheme.

The defect detection process begins with a piece being selected from a productive process. There are two kinds of analysis here. First, we can consider the piece in a sample: this is the static position. In a second possibility, the piece can be considered while in process. This is the dynamic situation; such is the case of pieces going through a belt, for example.

Some specific procedure captures the image of the piece. This procedure consists of an illumination system to throw light on the piece, cameras to photograph it and a device to store the image captured. Next, a processor creates a structure associated to the image. In this study there are two structures to be used: a matrix or a histogram that represent the image. A second operation in the same processor develops a specific treatment for the image. Here, this processor is a software program, installed on the same device which created the structure of the image. The procedure here is to improve and detach properties necessary to detect the damaged area on the piece. At the end of this operation it is possible to have the image associated to a structure, in the form of a matrix. The structure can be submitted to an analytical procedure aimed specifically at detecting the defect. The final processing of this software reached two results: the presence (or absence) of defects and their possible classification.

When a defect is identified by the system, a decision about the piece (accept/reject) is proposed. At the same time, a basic identification of the defect and some relevant additional information about it is displayed. Corrective and preventive actions should be suggested for each defect found as well.

This whole system has been set up experimentally.

Another important theoretical support for the structured quality inspection model comes from matrix decomposition [8]. Specifically, matrix decomposition into singular values is a relatively well-known technique in classic algebra. In broad terms, the conceptual background applicable to this case can be summarized as follows:

(1) Any symmetric real matrix can be converted into a diagonal matrix by means of orthogonal transformations and so can any general rectangular matrix A(m x n), through the decomposition of this matrix into its singular values, according to the following theorem: Given a real rectangular matrix A(m x n), with rank k, then there are two orthogonal matrixes U(m x m) and V(n x n) and one diagonal S(m x n), so that $A = U.S.V^t$ (F1), where $S = diag(L_1,L_2,...., L_K, 0, 0, ..., 0)$ and $L_1>L_2>...>L_K$.

(2) Within the approach of this paper, which considers a matrix to be a representation of an image, the formula (F1) means that the original image A was decomposed into the three matrixes in an unequivocally defined operation.

(3) In particular, matrix S, i.e., the singular values L_1, L_2, ..., L_K plus the null values, can be represented on a single vector, $x(n \times 1)^t = S_e=(L_1, L_2,.., L_K, 0, ..,0)$, where the column vector 'e' is formed by n x 1 components of equal value and all equal to a 1. x(n x 1) is called characteristic vector of singular values of image A.

(4) If Frobenius's norm is employed, it is possible to ensure that the square root of the summation of the differences (L_i - G_i), for i ranging from 1 to n, will always be equal to or less than Frobenius's norm applied to the difference of the matrixes (A - B). As it is known, Frobenius's norm is given by the summation of the square root of the square of all the elements of the matrix [9].

(5) Due to its high stability, the characteristic vector is little sensitive to noises from the image or minor alterations on gray level values caused, for example, by changes on the illumination system. This even makes possible that the image pre-processing phase, in this case, be disregarded. Experimental results are already available to show the validity of this property [10].

It can be noted that other properties that might be of interest are those referring to spatial transformations of the image. It is possible to prove that the characteristic vector is invariant in face of the transformations of transposition, rotation, translation and reflex in mirrors [11].

IV. The Quality Inspection Structure

The quality inspection structure that is proposed here begins with the hardware devices described before. Considering the way the structure works, it has been defined as a quality inspection. These devices produce the image representation. The operations developed on image representation for the pieces under analysis can be divided into three well-defined phases: (1) Selection of the data necessary to carry out the operations; (2) The actions to processes the required data; (3) The production of results. Table 1 shows the general view of this part of the system.

Table 1: System operation

O1	Primary Inputs	Outputs of the image captured from the pieces under inspection by the devices.
O2	Secondary Inputs	Analysis of the captured images.
O3	Data processing 1	Operating the data to determine the analysis of a specific piece.
O4	Data processing 2	Analysis by matching the piece with the patterns selected.
O5	Output 1	Basic information: on (or more) defect(s) has (have) been detected. OR: No defect detected.
O6	Output 2	General Information: Particularities of the defect that can be useful for its identification.

The activities of the system include 15 steps:

S01: Process of capturing the image of the piece under inspection.
S02: Primary analysis of the image.
S03: Execution of the operations on a mathematical arrangement (bidirectional matrix) that is associated to the image.
S04: Formatting of the results of the set of operations.
S05: Definition of the first result: presence or absence of defects.
S06: Definition of the complementary results, it means, additional information that can be useful for further defect identification.
S07: Determination of the probable actions to be executed from the results of the operations.
S08: Classification of defects (see below).
S09: List of actions compatible to each type of defect (see below the types of defects).
S10: Selection of the activities to be done according to defect classification (steps 8 and 9).
S11: Identification of the detected defects.
S12: List of the actions to be taken to each identified defect.
S13: Identifying the defect as to its nature and suggested actions.
S14: Identifying the defect as to its area of occurrence and suggested actions.
S15: Complete list of corrective and preventive actions to be taken directly in the production line.

In step 08, the classification of defects includes three possibilities: critical defects; acceptable defects and minor defects. The first type of defect refers to a defect that makes the use of the part unfeasible. The second requires further analysis regarding the use of the part. And the third type of defect is tolerable and does not remove the part from the production process.

These 15 steps need a quantitative model that initially checks whether a piece has basic defects. As we have pointed out, these defects are indefinite, which means that the image captured represents a fuzzy surface, with no borders well determined. Basic defects are similar to critical defects: they determine the immediate rejection of the piece. To detect basic defects, a comparison of the image has to be done: the image of the piece and the image of the correspondent pattern.

Observing the above 15 steps, it is possible to understand that the model first gives a preliminary evaluation of the piece. If the piece has no basic defects, it goes on to next steps, where the presence of defects is checked by means of image deviance shown by the piece when compared with a selected pattern. In this second situation (no basic defects detected), the comparison between the piece and some selected patterns also takes into account characteristics of indefiniteness on the limits of the specific areas of the images. A very important observation: the model also allows the creation of new patterns if this situation will be desirable.

Practical experiments show that this quantitative model can be used both for monochromatic and polychromatic images. In the first case, gray levels are evaluated. It is a quite simple operation. In the second case, some matrix analysis are developed which associate parameters related to chromatic motivation to each pixel of the piece.

So the model is useful determining elementary surface defects. It determines the complete rejection of the piece. But it is valuable to detect deviance of the piece when considering a selected pattern. In both cases, analyses are carried out of the parameter being investigated by decomposing each matrix considered into singular values (SVD technique). It is convenient to remember that each matrix represents a piece or some specific pattern.

SVD mathematical support makes possible to proceed with the evaluation of the piece without relating a given image property to the place where it occurs. It is very important here since this study considers defects with no definite borders. So the model used here is perfectly adapted to the situation where the occurrence of the property does not depend of the area of the piece. So it is not relevant to take into consideration whether a specific, delimited or defined area has always the same chromatic pattern. As always occurs in the quality evaluation of wall tiles, the uniformity of the piece is considered in the surface as a whole, regardless of observing the occurrence of certain chromatic motivations or figures or, still, specific parts of the image always in the same place or in a delimited place.

Practical experiments have shown that this property of the model is helpful to the cases where the image of the piece is subject to variations due to the way in which the piece was photographed. This ideia can be applied to situations where the environment (production process) is not always the same. Also it can be useful to the situations where there are possible to have the occurrence of frequent noises during the capturing process or even during the analysis of the image. The defect detection process, here, shows low sensitivity to such problems.

Again with practical support of the developed experiments, it is important to mention that these situations are typical of cases where defect borders are not clearly defined.

It is worth to remember that the mathematical model makes use of piece representation matrixes. In the monochromatic case, a matrix that relates gray levels to each pixel is built. In the polychromatic case, matrixes which relate specific parameters to each pixel are considered.

After analyzing several methods to evaluate polychromatic characteristics [12], the practical experience show that the most relevant parameters are chromatic hue, intensity, saturation and value in the case of the HSI and HSV systems; in the case of the RGB system, the parameters are the amount primary colors contained in each pixel (the primary colors here are green, blue and red). If necessary, the system can operate with complementary colors, such as ciano or magenta, for example. In this latest case, the user should alter the environment where the analysis is being carried out.

In order to use recurrent and similar operations in the different phases of the model, it was necessary to separate the various phases of the operation of the model. That is the reason why the phases have been well defining and delimited.

Some practical models have been developed to detect and identify defects. The model presented here, however, operates in a totally different way from those models. The main differences are:

(1) The proposed model here does not consider visual characteristics of the piece.
(2) There is no need to transform specific values of image representation.
(3) There is no statistical evaluation of individual image pixels.
(4) What we have here is an (quite simple) algebraic evaluation of the characteristics of the image.
(5) The piece is considered as a whole with no attention paid to specific areas.
(6) It is not necessary particularize properties and neither consider the borders of certain areas of the image.

On the other hand, the proposed model uses an evaluation that represents intrinsic attributes of the image, evaluated within a mathematical method which considers that, if an image can be represented by a matrix, then various algebraic transformations or decompositions of this matrix can be used to make possible the extraction of specific aspects of the image in question. It can noted that singular values decompositions are related to intrinsic attributes of the image, which are not deviated on account of visual specific problems.

In this particular study, the decomposition of the matrix into singular values (SVD) can be used both because of adequacy of the technique to the usual space of matrixes and because of aspects that make it suitable for use in extremely common situations in the process of capturing and analyzing images of pieces like wall or floor tiles and even in textile products.

Also it can be noted that the technical support for decomposing the matrix into singular values has properties extremely desirable for the development of image recognition methods. Such properties refer, fundamentally to the extreme stability of singular values. In fact, when small disturbances occur in the original matrix as consequence of slight alterations on the image or noises during the process of capturing or even in the retrieving of its characteristics, there are no significant alterations on the singular values. With a specific type of image characterization, SVD has properties of geometrical and algebraic invariance, which are extremely useful. Such is the case, for instance, of invariance in relation to movements of rotation and translation of the piece [11]. In order to such methods to be used, it is enough to obtain the matrix of the parameters related to the piece.

When analyzing basic defects, the model does not need patterns and operates directly on a matrix representing the piece. So, the system has to provide the reference values for the singular values. When matching pieces and patterns, the model uses Frobenius's norm, of easy calculation, applied to the same representation matrixes of the pieces and of the patterns considered.

V. General Description Of The Model

Considering the goals of this study, the decomposition properties of the matrix representing the image in its singular values is useful and suitable. So a model has been constructed which works with matrix (image representation). And next decomposes this matrix into its singular values. As described before, initially the model tries to detect basic defects (working in the matrix). This is done by considering a relation proposed between the arithmetic average of the values of the property being studied (gray levels of the piece in the monochromatic environment, for example) and the highest singular value of the characteristic vector. Whenever this relation exceeds a certain limit, the piece has basic defects and is immediately discarded. The relation proposed is the following:

1. Analysis: For a piece k, we determine W(k) as W(k) = ABS [XM(k)* n - L_1], where XM is the average of the values of the properties studied, n the number of columns and L_1 the highest singular value of the matrix.
2. Decision: The piece will present basic defects whenever W(k)>(0.4)*L_1 (for instance, it is broken).
3. Continuing the process: If the piece does not have any basic defects, it is compared with a set of patterns.
4. The decomposition into singular values is applied to each of the matrixes representing the patterns.
5. The decomposition into singular values is applied to each of the matrix representing the pieces.
6. Using Frobenius's norm, the distance between a given piece and each pattern is determined.
7. According to the distance values, it is determined whether the piece has, in relation to each pattern, total, great, reasonable or little adequacy or whether it is not adequate to any of the patterns available.

7.1. In this last case, since the piece does not have any basic defect as shown by the test, the user shall decide if the piece will be regarded as a new pattern.

The text below shows the respective computer program related to operations described above.

1 - BASIC INDEFINITE DEFECTS

Input 1.1.A matrix (with variable size) whose inputs are integer numbers which lie between two specific values.

Input 1.2. Reference values for decomposing the matrix which represents the image of the piece.

Process 1.1. Each matrix represents a piece which will be decomposed into three other matrixes in such a way that the product of these three can reproduce the original matrix. The central matrix of the product will be that whose main diagonal lists in a decreasing order the singular values related to the original matrix;

Process 1.2. The evaluation of the image will be carried out by contrasting the singular values related to the piece representation matrix with the reference values. Such values fix intervals within which the singular values must lie; thus, if this is not the case, a situation of presence of defects on the original image will have been characterized.

Output 1.1. Singular values related to the image representation matrix.

Output 1.2. Diagnosis of the image as a whole.

2 - MATCHING WITH PATTERNS

Input 2.1. A set of matrixes – called pattern-matrixes – each perfectly identified by a code and a second set of matrixes – called piece-matrixes – also identified by a code. Both sets of matrixes have the same characteristics of the matrix in phase 1

Input 2.2. A set of parameters consisting of integer numbers which will be identified as the basic parameters for comparison between the pieces and the patterns. These parameters can be considered to be reference values.

Process 2.1. The processing refers to matching the matrixes which represent the pieces with each pattern stored. The procedure is as follows: a given piece-matrix is considered and contrasted with the pattern-matrix available from the system records. A test determines the need (or not) of comparing the same piece-matrix with the next pattern-matrix. The procedure is repeated until the last pattern-matrix is analyzed, if necessary.

Operation 2.1. The singular values of the matrix representing the first piece are determined.

Operation 2.2. The singular values of the matrix representing the first pattern are determined.

Operation 2.3. Using Frobenius's norm, the distance between the singular values of both matrixes is calculated.

Operation 2.4. If this distance is less than the reference values specified for the norm in question, the piece is considered to be adequate for the pattern and a specific message is issued (*'Piece XX fits pattern YY'*). In this case, no basic indefinite defect was detected;

Operation 2.5. Otherwise, the operation is repeated for the same piece and the next pattern.

Operation 2.6. If the piece does not fit any of the patterns listed, it is necessary to decide whether this piece will from then on be accepted as a new pattern. If not, the process restarts with the next piece. If so, a code is given to the piece which from then on will be regarded as a pattern and the process begins again with the next piece. In case there is no new piece to examine, the process stops at this point.

Output 2.1. Singular values related to each matrix representing the pieces under inspection and the patterns considered

Output 2.2. Most adequate piece and pattern (or no adequacy in relation to all of the patterns recorded and, if applicable, the new pattern created). In this case, there is no basic indefinite defect.

VI. Application

In order to test the program, several intervals of production process have been considered during 30 days of work. The average production level (daily) for this piece is around 2,000 units. Representative samples have been considered to each day of work, with 150 pieces each.

Considering 60,000 pieces, a representative set of samples totalizes 4.500 pieces. Taking into account particularities of the production process, the 30 samples have been divided into 12 groups (375 each). Table 2 shows the results. These variables were considered:

NS : Number of the sample

SS: Sample size.

PP: Perfect pieces classified by the quality inspection structure.

PI: Perfect pieces classified by the quality inspector.

PI is considered as the correct number of defective pieces.

It is defined as error [PI – PP]. The analysis of perceptual of error indicates error/ PI.

The most important number is not in table 2. It describes the total error of the quality valuation made by the system. Considering 4.500 pieces, the system makes correct evaluation to 4.477 pieces. It means 99.48% of correct decisions. The most common error: Defective pieces that the systems did not detect as so and considered as perfect (95.6%). Only one perfect piece was considered as defective (4.4%)

Let us consider a small example. The first piece in group 1 has the following gray levels: 73 67 72 75 65 62 70 72 71. The average for these values is 69.667 and the singular values are: 209.1513; 7.9096 e 3.7647. Therefore, W(1) = 0.1503. Since this value is lower than 83.66, the piece does not have basic defects. The program considered that the piece had no basic defects and more adequate to pattern 4, highlighting the fact that there was a great conformity between the piece and the pattern. It is important to point out that pattern 4 would be chosen (a difference of only 0.333).

VII. Conclusions

The quality inspection described here is used whenever there are no guarantees that the resolution of the image captured is of good quality and there is interference on the image representation structure. This is caused by the lack of well defined borders delimiting the defect.

The hardware and software devices are not installed for normal operations of the factory where the study was done. They were experimentally assembled and tested, only to obtain and process the images required by the inspection structure.

The greatest difficulty in inserting the inspection structure into the production process is to ensure the perfect synchronization between the capture and the analysis of the images of each piece and its removal from the process in case of defects detection in this piece.

It should also be noted that the inspection structure works very well in case of detection of basic defects. The adjustments to be made refer to the matching between the values defined by the pieces (in the matrix representation of them) and the values defined by the patterns (in their matrix representation).

Table 2: Results of quality evaluations.

NS	SS	PP	PP (%)	PI	PI (%)	Error	Error (%)
1	375	5	1.3	5	1.3	0	0
2	375	7	1.9	8	2.1	-1	12.5
3	375	9	2.4	9	2.4	0	0
4	375	14	3.7	14	3.7	0	0
5	375	15	4.0	14	3.7	+1	7.1
6	375	11	2.9	15	4.0	-4	26.7
7	375	10	2.8	10	2.8	0	0
8	375	5	1.3	9	2.4	-4	44.4
9	375	10	2.7	14	3.7	-4	28.5
10	375	12	3.2	12	3.2	0	0
11	375	15	4.0	15	4.0	0	0
12	375	7	1.9	16	4.3	-9	56.3
	4.500	120	2.7	141	3.1	23	16.3

In the experimental evaluations made, the values of the standards were not rigidly defined, but, instead, larger intervals were used, precisely to avoid errors in case of very strict and tight limits.

This is yet another adjustment to be made in the future: using standards with smaller ranges of specifications, although the ranges used here, in this study, are very close to those used in the factories studied today.

But to ensure better quality of the pieces in the future, the factories we have studied intend to reduce specification ranges to evaluate the gray levels of parts (in the case of monochromatic evaluations) and several parameters of the polychromatic analysis.

Experimental results show that the quality inspection structure proposed here works well, both in terms of hardware devices and hardware programs (mathematical model). The theoretical support that supports the model worked well in the same way.

The next steps of this research involve the improvement of the devices of capture and analysis of the images and their proper insertion in the productive process. This part of the research will involve professionals from various areas of Engineering and Information Systems.

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