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A COMPUTER VISION EXPERT SYSTEM APPLIED TO INDUSTRIAL QUALITY CONTROL

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Abstract : *A new terminology with technical terms closer to those used by engineers and technicians in industrial environments, is proposed which might contribute for acceptance and dissemination of Vision Systems in these environments. Concepts of Group Technology has been associated to Vision Systems and they might contribute for a greater integration of the industrial processes automation. A special data structure has been conceived for image data storage, allowing to reduce the processing time of algorithms of industrial parts features-extraction. Such structure associated to a set of production rules allows the use of expert systems that leads to a symbolic representation of the system. Such representation improves the system's performance in the knowledge acquirement and the system's intelligence.*

Keywords : *Expert Systems, Machine Vision, Inspection components, Inspection vector, Tolerance vector.*

1. INTRODUCTION

A typical artificial vision system includes a camera, a computer and a software. Such systems can handle many things. However, it cannot be claimed that computers or robots can really see, at least not in the usual sense of the word. Since that neither the biological visual system nor the artificial vision are completely mastered, or easily outlined, there is a trend in characterizing the artificial vision in terms of speed, accuracy and cost of its peripherals. Such attributes are important, but from the research standpoint, they are not central. The core of the problem is neither the camera nor the computer architecture, but the software. A large number of vision tasks has no solution nowadays because it is not known how to write their programs. More precisely, there is a lack of adequate algorithms, since the software can be implemented in special purposes electronic equipment (Hunter, 1995), (Granlund, 1994). The Knowledge

Engineer give us the Expert Systems that can be an approach in solving this problem. One of the main objectives of that kind of systems is to replicate the human knowledge and to provide learning of new facts and rules (Levine, 1988), (Rich, 1988).

The future development of artificial vision systems for industrial applications must consider improvements in the hardware efficiency and mainly in the development of software with well elaborated techniques of image processing for fast responses (Hunter, 1995), (Alves, 1991), (Gonçalves, 1988).

2. DEFINITIONS AND TERMINOLOGY

In this work, new concepts are conceived and introduced in the process of characteristic extraction, object classification and pattern recognition. The motivation in introducing those new concepts is based in the fact that the classic terminology used in image processing does not make use of an appropriate vocabulary used in industrial environments. Terms such as classes, regions and descriptors, for example, are replaced trying to make it easier to understand the activities of a computer vision system in these environments, to promote a change of mentality, and to help the spreading of the use of artificial vision in quality control applications. The use of Group Technology concepts in this work besides the tools of the computer vision is a contribution of this work. The way the vision system was constructed lead us to the use of Expert Systems because they are based in facts and rules. There are fourteen rules that are the core of the vision system.

Inspection Components: Consider a certain product p_k, in which inspection one is interested. Such inspection is done by investigating certain feature elements of the product referred as, for example, centroid, diameter and maximum radius. Elements like these are called Inspection Components, and are represented by C_j, $1 \leq j \leq L$, where L is the maximum number of these components.

Components Library: The set $B = \{C_1, C_2, ..., C_L\}$ made up of all L Inspection Components is given the name Component Library.

Inspection Vector: Every m-upla $x^* = (C_1, C_2, ..., C_m)$ where $C_i \in B$, $i = 1, 2, ..., m$ for $1 \leq m \leq L$ and $C_i \neq C_j$ for $i \neq j$, is given the name Inspection Vector. Inspection Vectors are represented internally by Binary Codes.

Parts Family: Those industrial products, the inspection of which is done through Components of the Vector x_j^*, form a set which is denoted by $w_{x_j^*}$ or simply w_j, and it is termed parts grouping. The ordinated pair $f_j = (x_j^*, w_j)$ is given the name Industrial Parts Family determined by x_j^*, or simply Parts Family.

Characteristic Vector: Consider a Parts Family $f_i = (x_i^*, w_i)$ and let the parts grouping be $w_i = \{p_1, p_2, ..., p_k, ...\}$. In this way, the inspection of the product p_k is done through components of the vector $x_i^* = (C_1, C_2, ..., C_m)$. So, each component C_j of x_i^* is associated to an a_j “value” termed characteristic, that corresponds to the result of the measurement in p_k of that Inspection Component C_j. Therefore, each $p_k \in w_i$, corresponds to a vector $V_k = (a_{k1}, a_{k2}, ..., a_{km})$ called Characteristic Vector of p_k.

Figure 1 illustrates the relationship among the parameters of a family of parts.

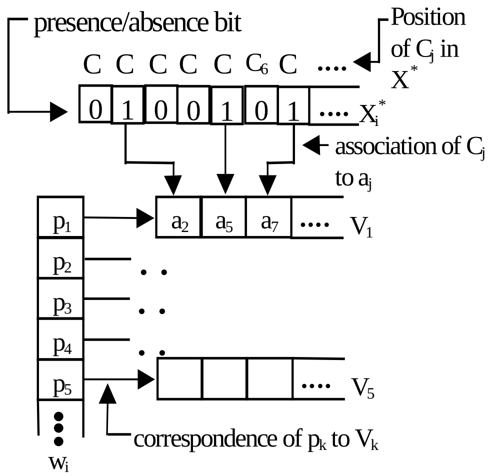

Fig. 1. Data structure showing parameters relationship in the family $f_i = (x_i^*, w_i)$.

During the inspection activities, it is useful to use tolerance measurements for acceptance or rejection of industrial parts. Therefore, it is necessary the Tolerance Vectors definition.

Tolerance Vector: Each industrial part $p_k \in w_i$, with Characteristic Vector $V_k = (a_{k1}, a_{k2}, ..., a_{km})$, is associated to a Vector $T_k = (T_{k1}, T_{k2}, ..., T_{km})$, termed Tolerance Vector of p_k or simply Tolerance Vector, whose components T_{kj}, $1 \leq j \leq m$, correspond to the maximum tolerances of the characteristics a_{kj}, $1 \leq j \leq m$, of V_k.

It is possible to create minor and dedicated versions of a vision system to be used in specific applications. In such cases, the system selects and works with only those components $C_j \in B$, for $1 \leq j \leq L$, necessary and sufficient for the performance of these applications. This leads to the necessity of a new definition, the Dedicated Libraries.

Dedicated Library: Let *A* be a specific industrial application, executable by the system. The larger Inspection Vector $b = (C_1, C_2, ..., C_r)$, associated to *A*, is given the name Dedicated Library to *A*, or simply Dedicated Library.

Only the definitions and terminology here established will be used from now on.

3 - ORGANIZATION OF A ROBOTIC VISION SYSTEM

This section intends to give a complete view of the operation of all modules of a vision system, detailing the activities of its main functions through rules. The definitions and terminology present in the item 2, such as *Inspection Components*, *Components Library*, *Inspection Vector*, *Parts Family*, *Characteristic Vector*, *Tolerance Vector* and *Dedicated Library* are represented as *lists*, powerful tools of the expert systems languages.

Inclusion of Components in B: This function obeys the rule R_1.

R_1 - Given an Inspection Component C_j, the system will add it to $B = \{C_1, C_2, ..., C_L\}$, if for $1 \leq s \leq L$, $C_s \neq C_j$.

Exclusion of Components of B: The exclusion of an Inspection Component obeys the rule R_2.

R_2 - Let $C_j \in B$ be an Inspection Component bound for exclusion. The system should perform the operation if, for all Dedicated Library *b*, C_j is not an Inspection Component of *b*.

Dedicated Library: It is allowed not only to create Dedicated Libraries, according to the definition established, but also to add new components to such libraries. In this case, two new rules, R_3 and R_4, should be considered.

R_3 - The system must create a Dedicated Library $b = (C_1, C_2, ..., C_r)$, by using Inspection Components of *B*, that is, $C_j \in B$, for $1 \leq j \leq r$, after being observed all the restrictions set in the definition of *b*.

R_4 - Let $b = (C_1, C_2, ..., C_r)$ be a Dedicated Library. An Inspection Component C_k being given, the system shall add it to *b*, if $C_k \in B$ and if for $1 \leq s \leq r$, $C_s \neq C_k$.

Once the Inspection Components are selected and the Dedicated Library *b* is constituted, the Programming Function performs other activities aiming to consolidate the utilization of the Inspection Components installed. Therefore, two new rules, R_5 and R_6 are imposed on the system. In the figure 2 it is shown an example how the rules R_3 and R_4 are used to select the inspection components in order to design a dedicated library.

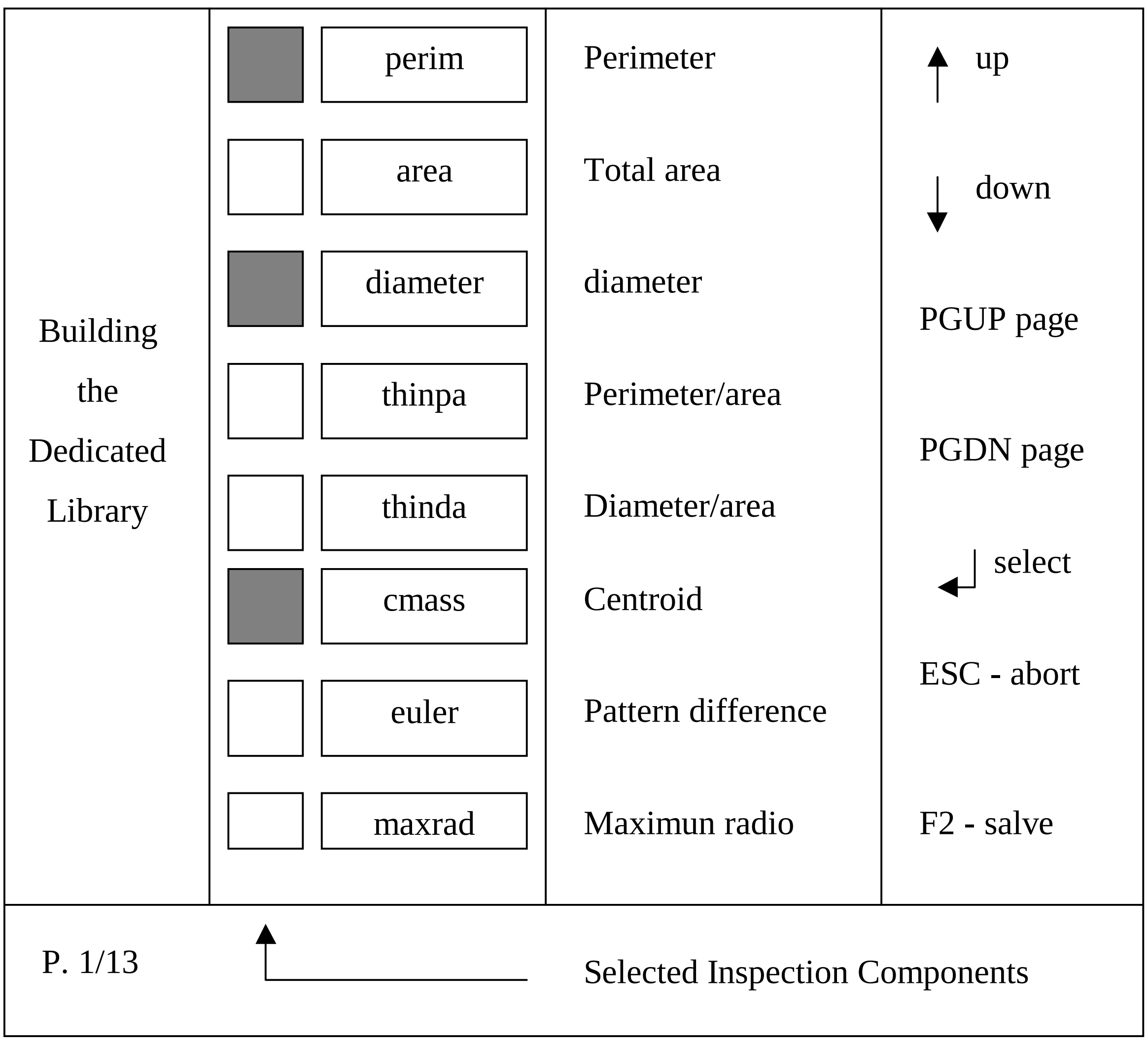

Figure 2 - Inspection Components Selection

R_5 - For each Dedicated Library *b* the system creates an executable subprogram, where each C_j component of *b* corresponds to an object module M_j that performs the operations defined for C_j.

R_6 - The set of object modules should be seen by the system as an Executable Inspection Vector $x_b = (M_1, M_2, ..., M_r)$.

Parts Grouping: Assuming *n* parts families $f_i = (x_i^*, w_i), 1 \leq i \leq n$, in the system. Three new rules R_7, R_8 and R_9, defining the set of activities for the function Parts Grouping, should be observed.

R_7 - Given a product p_k, the system should create a parts family $f_j = (x_j^*, w_j)$, if p_k cannot be inspected by $x_i^*, 1 \leq i \leq n$.

R_8 - The addition of a part p_k in the Parts Grouping w_i of a family $f_j = (x_j^*, w_j)$ is done by the system if $p_k \not\in w_i$, for $1 \leq i \leq n$, and if p_k can be inspected by x_i^*.

R_9 - For all $p_k \in w_i, 1 \leq i \leq n$, the system must calculate the corresponding Characteristic Vector V_k.

At least four important advantages are enhanced in the process of Parts Families formation:

1. Dozens of industrial products will certainly be capable to be well inspected by a same Inspection Vector and, as a consequence, will pertain to the parts Grouping of a same family, so causing large reduction in the amount of memory necessary for storage of data used in the inspection operations.
2. Grouping parts in Parts Families, according to pre-established criteria, means reducing the data amount handled by the system during the Inspection activities. The identification of a part p_k as pertaining to the parts Grouping w_i of $f_i = (x_i^*, w_i)$, in this way, becomes much more efficient, quickening the operations of retrieval of the Inspection Vector x_i^*, used in the determination of V_k, for the corresponding part p_k.
3. With the reduction of the data amount to be handled by the system, the requirements with respect to the hardware diminish. Besides, much more industrial parts can be inspected by unit of time, improving the system efficiency in real time operations.
4. If the Group Technology is being used in an industrial environment then it is possible to plan the inspection automatically, creating Inspection Vectors x_i^* of $f_i = (x_i^*, w_i), 1 \leq i \leq n$, using the identification p_k as an access key to a data base built as a consequence to the use of the Group Technology, in this environment.

The part p_k being included in a family, it is necessary to create the Characteristics Vector, the rule R_9 being observed.

The Characteristic Vector V_k being built for the part $p_k \in w_i$ of $f_i = (x_i^*, w_i)$ by user option, the system can perform the training function.

Training: The manufacturing cells must produce parts according to the engineering specifications. Therefore, the machines are pre-programmed for the production of parts within these specifications. During the image proposition operations, aiming the formation of families, a Tolerance Vector T_k is associated to the Characteristic Vector of the part p_k. Such information is stored together with the ones extracted from the part p_k during the training operations. In this way, the training procedure is justified by the following detail: the machines of a manufacturing cell can be so well adjusted, that the results obtained by the system, as tolerance margins T_k' for the values of the Characteristics Vector V_k, are lower than the ones calculated by engineering for T_k. With this procedure, the system introduces double benefit in the case of observing drop in the production quality.

1. The likely degradation of the machines components can be attested, that is, the benefit of a predictive/corrective maintenance diagnosis is obtained.
2. It serves as a guide for governing of the cell mechanisms, avoiding production losses.

Considering a family $f_i = (x_i^*, w_i)$ and an industrial part $p_k \in w_i$, whose characteristics vector is $V_k = (a_{k1}, a_{k2}, ..., a_{km})$.

Let $w_a = \{pa_1, pa_2, ..., pa_n\}$ be the set of n industrial parts with identification p_k, forming a Sample Grouping, for example, n iron nuts 5/16 inches. By using this Sample Grouping it is possible to train the system to calculate the tolerance $T_k' = (T_{k1}', T_{k2}', ..., T_{km}')$ for p_k, that helps the system in the Inspection Activities.

The training function requires the system to observe the rules R_{10} and R_{11}.

R_{10} - For all pa_j of w_a the system must determine a Characteristic Vector V_{aj}. So, the average μ_{k1} and the standard deviation σ_{k1}, for $1 \leq m$, are obtained from the distribution of the characteristics values, extracted for $V_{aj} = (a_{j1}, a_{j2}, ..., a_{jm})$, for $1 \leq j \leq n$. Therefore, the calculation of T_{k1}' is obtained for each characteristic a_{k1} of V_k, that corresponds to the industrial part $p_k \in w_i$.

R_{11} - The training ignores a part pa_j if the tolerance T_{k1}' determined by the system for the characteristic a_{j1} of V_{aj}, exceeds T_{k1}, where T_{k1} is the maximum tolerance defined by the engineering for the characteristic a_{k1} of V_k, that corresponds to the industrial part $p_k \in w_i$.

Inspection: This is an iterative form of inspection, when the parts are put in the camera vision field.

Identified the part p_k as pertaining to a family $f_i = (x_i^*, w_i)$, the system retrieves the Inspection Vector x_i^*, the Characteristics Vector $V_k = (a_{k1}, a_{k2}, ..., a_{km})$ of p_k and begins, iteratively, the inspection operations.

The inspection operations are applied to the elements of the Sample Grouping $w_a = \{pa_1, pa_2, ..., pa_n\}$ where each pa_1 has an identification p_k, $1 \leq 1 \leq n$, and n is the size of the sample. The system determines a V_{a1} for each pa_1 of w_a.

The acceptance of the part pa_1 is based on distance measures, and obeys the following rule:

R_{14} - Given the Characteristic Vector $V_k = (a_{k1}, a_{k2}, ..., a_{km})$, of p_k and the sample Characteristic Vector $V_{aj} = (a_{j1}, a_{j2}, ..., a_{jm})$ of a product pa_j of the sample grouping w_a one has:

a) If $|a_{ji} - a_{ki}| \leq T_{ki}$. for all i, pa_j is accepted.

b) If pa_j is accepted and if $\exists\ 1$ such that $|a_{jl} - a_{kl}| > T_{kl}'$, the system communicates..

c) If $\exists\ l$ such that $|a_{jl} - a_{kl}| > T_{kl}'$, pa_j is rejected.

3. CONCLUSIONS

This work will certainly help the process of development and dissemination of knowledge in the area of computer vision. Concepts, definitions and new terminology are presented, which should help in the understanding, acceptance and diffusion of knowledge in this area, and contribute significantly to the use of this new technology in industrial environments.

This work innovates on associating concepts of Group Technology to the computer vision applied to the activities of industrial inspection. The benefits of this association have been commented previously, and represent a contribution to vision systems. A set of expert system rules has been stipulated to guide the activities of the vision system, in the context presented. This fact makes it easy to understand the activities and functions performed by these systems. The prototype software developed by this paper authors uses all the concepts presented here. More than 100 inspection components were implemented and included in the Components Library. The system was validated by tests executed with a great number of industrial family parts. The choice of Inspection Components is made by user in direct interface with the system and provides easy inclusion of new components. The implementation concerning to the expert system was conceived to make use of the Prolog language.

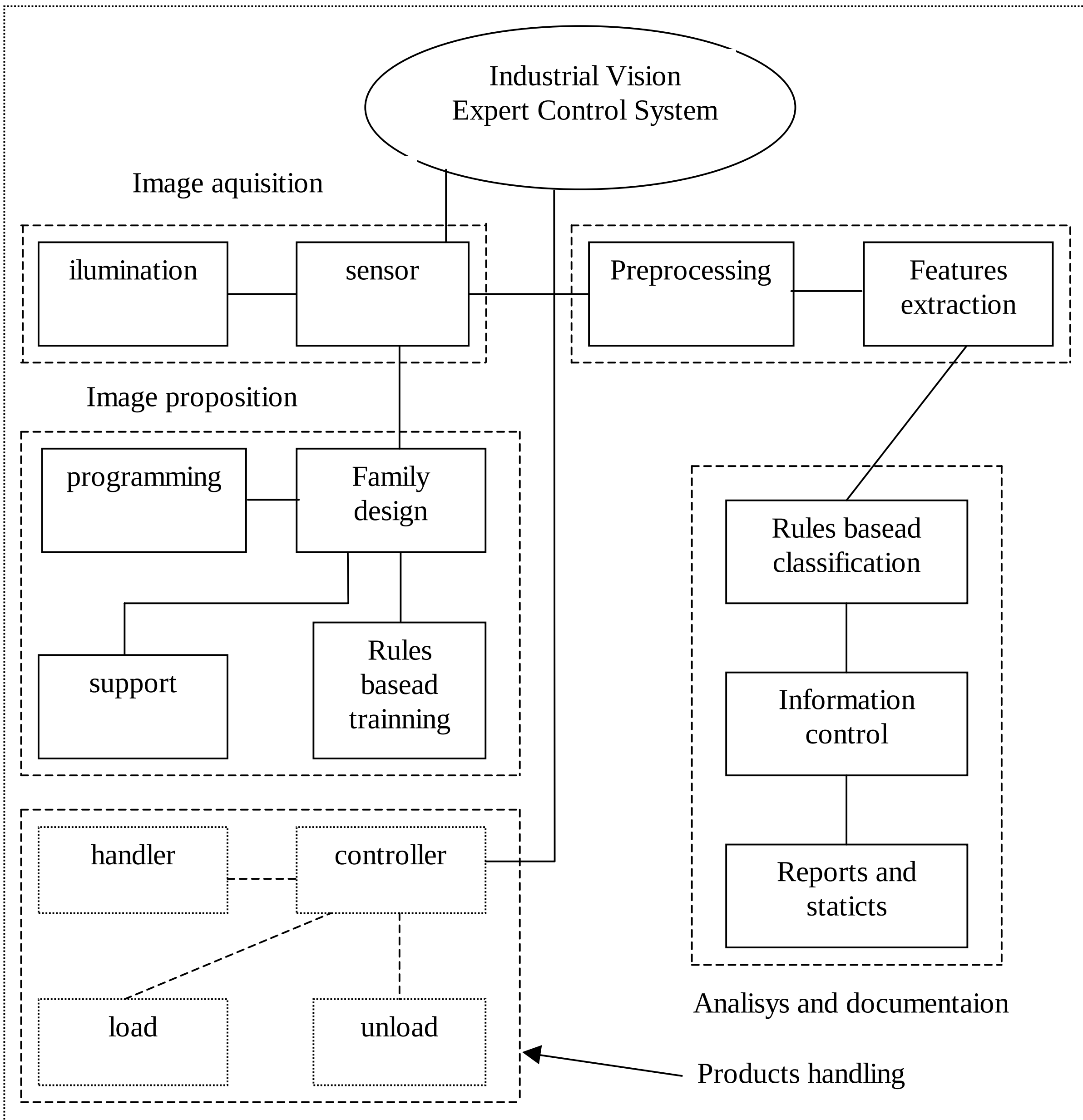

Figure 3 - Block diagram for the control system

Figure 3 shows the de basic modules of the developed system. Note that the control system coordinates all the activities at the system, establishing the natural sequence for the operation execution and exception handling. The system control language is quite simple, fundamental issue in assemble lines.

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