A Distributed Industrial Application for Quality Control of Clinched Boards based on Computer Vision

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ABSTRACT
In the last years, a system for joining metal sheets by using a cold press joining technique has been invented and called clinching. This technique has been adopted in the production of metal boards for civil construction. The quality of joint points is a critical aspect and the current approach for quality control is based on the capabilities of an expert to understand the nature of the defect by observing the shape of each clinched button. VISICON IST Research and Development project proposes a solution for realizing a distributed quality control system for the production of clinched metal boards. The solution integrates aspects of software engineering, process modeling, knowledge representation and computer vision.

Keywords
Artificial Vision, Quality Control, Vision Systems, Distributed Systems.

1. INTRODUCTION
Most of factories which produces metal boards for scaffoldings use the weld system to join different parts of the boards. In the last years, an alternative system for joining metal sheets by using a cold press joining technique has been invented and called *clinching*. The joint points are a sort of buttons and the quality is a critical aspect to be maintained under control during the production process. The typical approach for quality control is based on the measurement of joint button size, the evaluation of its thickness and the observation by an expert of its shape from both sides. The adoption of a throughout manual control is very expensive since the defects in the production process occur sporadically, but also the adoption of a simple quality control based on random verification has relevant costs since boards produced with poor quality joint buttons are rejected for safety reasons. In this paper, VISICON IST Research and Development project partially funded by the European Commission is presented [1], [2]. VISICON proposes a solution for realizing a distributed quality control system for the production of clinched metal boards, which are used by carpenters for civil constructions. VISICON architecture consists of a set of TV-cameras managed by industrial computers which in turn are controlled by a quality control supervisor. The images analysis and *a-priori*-knowledge about the joint buttons structure and their position on the board allow both deciding if the joints are defected or not and estimating the defect relevance. In this way the production efficiency is improved by reducing the number of faulty boards. The solution integrates aspects of software engineering, process modeling, knowledge representation and computer vision.

2. VISICON SYSTEM ARCHITECTURE
In this section, an overview of the hardware (Figure 1) and software (Figure 2) architectures of VISICON solution is presented.

2.1 Hardware Architecture
The hardware architecture presents the following three main subsystems:

The Quality Control Area (QCA) is the area where TV cameras and lights of the quality control system are physically positioned and in which the fully clinched boards, coming from the clinching machine by means of a conveyor belt, are controlled.

The Quality Control Server (QCS) implements the main user interface of the whole VISICON system and the decisional center for the activity of quality control and production process management. The QCS communicates with Local Inspectors by sending commands and receiving results and images. It also controls the position and lighting of the boards by using a CANbus interface to motors of a conveyor belt and digital I/O ports. Finally, the QCS produces WWW pages for monitoring the whole activity by means of any computer connected to the factory LAN.

The Local Inspector (LI) consists of an industrial peripheral computer, IPC, which includes an image acquisition board for frame-grabbing by means of one of more TV-cameras. Each LI interprets the commands coming from the QCS, grabs the image(s), executes the image analysis for quality control, communicates the results to the QCS and provides the current images when requested.

2.2 Software Architecture
In the VISICON software architecture, five main subsystems are present:

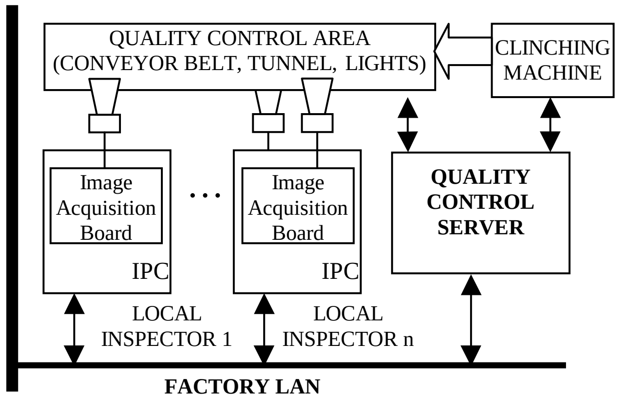

Figure 1. VISICON Hardware Architecture

The Quality Control Manager (QCM) is located on the QCS and manages the synchronization between the IPIs and the MC (see below). The whole decisional process of quality control is performed by QCM by commanding actions and analyzing the results provided by IPIs to establish the acceptance of the current board on the basis of the expected board model, the measured position and quality of each joint-button and the selected acceptance threshold.

The Image Processing Inspector (IPI) is the core of the image acquisition and analysis. For each TV-camera connected to some LI, one instance of this subsystem is present on that LI. Its aim is to allow the distribution of the frame capture and image processing costs on the basis of the amount of available LIs. The acquired joint-button images are analyzed to detect the position of joint buttons and to extract their features. Such results are communicated to the QCM.

The Machine Controller (MC) is located on the QCS and controls the synchronization between the clinching machine and the QCA. It manages the positioning of the boards under the TV-cameras by controlling the conveyor belt, lights and sensors placed in the QCA. When the board reaches the position requested by the QCM, a synchronization signal is sent by the MC to start the image acquisition phase.

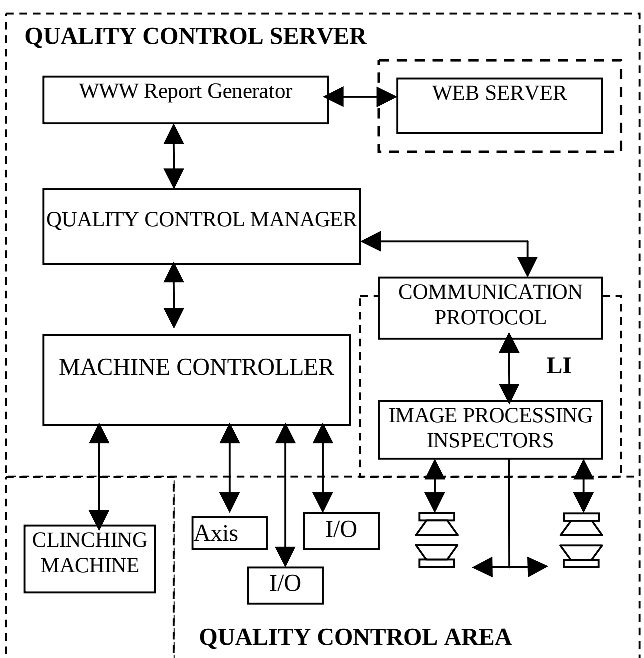

Figure 2. VISICON Software Architecture

Communication Protocol is used for the communication between the QCM and the IPIs. The communication protocol is based on TCP/IP sockets and it is used to delivery commands, parameters, results, errors and images.

The WWW Report Generator produces a report about the status of the whole process by using the information provided by the QCM. A standard Web server running on the QCS publishes the produced HTML pages on the factory LAN.

3. OBJECT ORIENTED MODELING

The software architecture has been designed according to the object oriented paradigm so as to implement a general framework which can be used for building other quality control systems for industrial machines. The analysis has highlighted the needs of classes reported in Figure 3.

Class Manager controls the whole quality control process and it implements the QCM. It includes an array of detectable Items, an array of all possible board Views, an array of all available Inspectors and the Controller.

The class Item represents a visual entity which has to be recognized in the image (good, defected or missing joint). It is modeled by a set of attributes (size, range for G-transform values, quality score) used during the recognition and quality assessment process.

The class View represents a board detail, the image of which can be acquired by some TV-camera when the board is placed in some valid position inside the QCA. Each view has its proper value of relevance, in accord with the mechanical relevance of different clinched parts of the board with respect to the overall board robustness.

A Target represents a feature to be searched in the acquired image and contains both its presumed position/size and an array of symbolic references to Items corresponding to all possible search results for that feature.

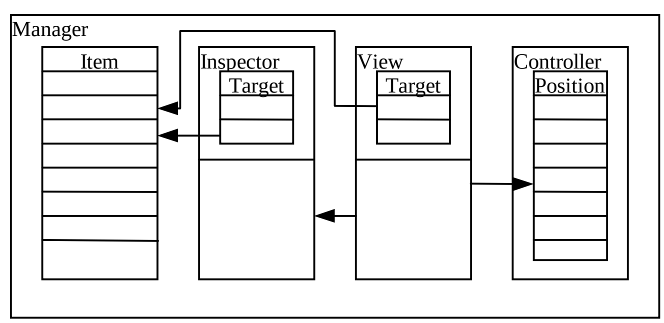

Figure 3. Object Diagram of main classes

Class Inspector represents both the logic reference to a physical TV-camera from the side of the QCS and the IPI software subsystem from the side of the LI. For each instance of the Inspector running on a remote LI there is a corresponding instance of the same class in the QCS. The class Controller implements the software entity responsible to manage board positioning along the conveyor belt, lights and clinching machine interface. It hides all the CANbus management details to the Manager and contains a vector of all possible Positions.

Class Position represents a valid board positioning along the conveyor belt and contains both the control parameters required to drive the board until the Position is reached and the proper lighting configuration for image acquisition.

3.1 Quality Control Process

The process used to assess the general quality of a board is driven by the knowledge associated with its structure, expressed by position and relevance of each joint button of the board.

The overall quality, *OQ*, of a board has a range from 0 to 1 and it is estimated by using a weighted sum according to:

$$OQ = \frac{\sum_{p}^{P}\sum_{v}^{V_p} W_{pv} \sum_{t}^{T_{pv}} S_t}{\sum_{p}^{P}\sum_{v}^{V_P} W_{pv} \left|T_{pv}\right|}$$

where:

- P is the set of Positions of the board for getting all the image corresponding to the joint buttons;
- V_p is the set of Views of board Position p;
- W_{pv} are the weights of View v of Position p;
- T_{pv} is the set of Targets of View v of Position p;
- S_t is the score assigned to the Target t from the recognition process which has identified the most probable Item for the Target t;
- $|T_{pv}|$ is the number of Targets in the View v of Position p.

The *OQ* assumes the value of 1 when a score of 1 is computed for each Target, or each joint-button is recognized as good. Its value is compared to defined thresholds in order to determine the category of acceptance of the board or for its eventual rejection and production stop.

In order to help the understanding of the operational relationships between the classes, the typical operations performed by VISICON during the quality control process are detailed in the following.

- For each Position:
  - Impose the Position of the board via the Control Manager according to the list of positions;
  - Identify the set of Views related to the reached position;
  - For each View:
    - Upload the View parameters and detectable Item attributes on the remote Inspector;
    - Upload the Targets of the View on the remote Inspector;
    - Acquire the image from the TV-camera;
    - Compute the image gradient;
    - Start the search for a Target (see the next section) by using the Target initial conditions: position, size, etc.;
    - Confirm the presence of the searched Target;
    - For each confirmed Target:
      - Estimate the corresponding set of metrics which allows Target classification in terms of Items;
      - Compute the assigned model by giving a score for each possible Item, which expresses the confidence to which a given target is recognized as a possible Item;
      - Assign the quality value of the winner to the Target;
      - Sum the quality value to that of all the other Targets of the same View;
    - Multiply the quality value estimated for the Targets of the view for the View weight to compute its quality score;
  - Sum the quality score of the View with those of the other Views in the same Position to estimate the quality score of the Position;
- Sum the Position quality score with those of the other Positions in order to estimate the general quality score of the board;
- When the last Position has been reached, the Manager:
  - Compare the board quality score with the threshold and determines the status of fault or not;
  - In the case of acceptable quality starts the control of another board.

4. COMPUTER VISION OVERVIEW

Clinched button images are acquired by a set of industrial greyscale TV-cameras. Each camera is connected to a frame grabber, which acquires images (384x288 with 8 bit/pixel) of buttons groups. The image resolution has been defined as a compromise between processing time and analysis precision.

4.1 Detection Process

Joint button detection is accomplished by maximising a specifically designed mathematical operator, the so-called G transform [4]. This operator transforms the image so that at each peak of the transform corresponds the centre of a circular region on the original image, presenting a high degree of radial symmetry and a relevant radial gradient, such as the annular shape of a joint button (see Figure 4a-b). G transform has been defined as the ratio between two surface integrals, according to:

$$\gamma(\xi,\eta) = \frac{\iint_{C_R} \left|\nabla_{x,y}\left[\boldsymbol{f}(\xi+\boldsymbol{x}(\boldsymbol{S}),\eta+\boldsymbol{y}(\boldsymbol{S}))\right]\cdot \underline{\boldsymbol{i}}_r(\theta(\boldsymbol{S}))\right| \boldsymbol{dS}}{\iint_{C_R} \left|\nabla_{x,y}\left[\boldsymbol{f}(\xi+\boldsymbol{x}(\boldsymbol{S}),\eta+\boldsymbol{y}(\boldsymbol{S}))\right]\cdot \underline{\boldsymbol{i}}_\theta(\theta(\boldsymbol{S}))\right| \boldsymbol{dS}}$$

where C_R is the circle with radius R centered in the origin and scanned by the surface unit dS, $\underline{i}_r$ and $\underline{i}_\theta$ are respectively the radial and tangent versors and θ is the angle comprised between the radial versor and the positive semi-axis of abscissas.

The search for the transform peaks is performed only in the image segments in which the Targets are supposed to be, in order to reduce the computation complexity of the process. If the value of the found maximum is above an assigned threshold, a button or some other circular shape has been detected and its position is that of the maximum with an error of few pixels. Moreover, the G transform produces higher values if the button radius is close to R and the button shape is round [4], that are two of the criteria usually adopted when evaluating joint button quality.

G transform is invariant with respect to the luminance and contrast changes, commutative with respect to reflections, translations and rotations and robust with respect to errors on estimation of R [4].

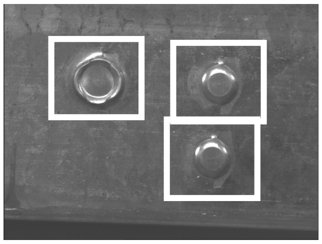

Figure 4a. A good and two defected buttons with Target image segments.

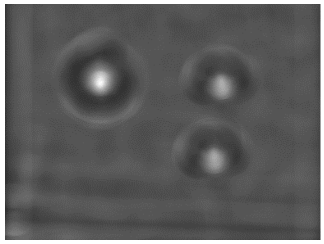

Figure 4b. The G trasform on the whole image.

4.2 Single Button Quality Assessment

The quality evaluation of each button is performed by interpreting maxima values of G transform as a quality index of the corresponding buttons. In fact, most of high quality buttons present maxima values between 3 and 4, so that by assuming these numbers as quality thresholds for button classification it is possible to distinguish defected buttons from good ones with an overall confidence which is over 90%.

The method performance has been improved by using other metrics together with G transform, such as image difference, etc. In this case, the quality of the button is computed as a weighted sum of the indexes produced by these metrics:

$$Q = \beta_1 M_1 + \beta_2 M_2 + ... + \beta_m M_m$$

where β_i are the weights and M_i are the adopted metrics. The estimated quality could be scaled and directly used as score, but for flexibility purposes it has been chosen to use this value for assigning to each Target an Item amongst those which are possibly expected. The weights have been estimated by using a multilinear regression method on a reasonable amount of test cases and the obtained model resulted to be statistically significant, with an overall confidence which is over 95%.

5. AN EXAMPLE

To show an example of the discussed process, a simplified model with respect to real production models has been adopted.

```
<Item     Type = "MISSING"
          Score = "0.00"
          Attributes = "0.00, 2.00, ……"/>
          ……
<Item     Type = "GOOD"
          Score = "1.00"
          Attributes = "3.00, 4.00, ……"/>
          ……
<View     Name = "LEFTFRONT"
          Weight = "0.067"
          Parameters = "384, 288, 256, ……"
          PositionName = "FRONT"
          InspectorName = "LEFT">
          <Target    Size = "60"
                     Center = "115, 95"
                     ItemsNames = "MISSING,
                              STRONGLY_DEFECTIVE,
                              SLIGHTLY_DEFECTIVE,
                              ALMOST_GOOD, GOOD"/>
          ……
</View>
```

Figure 5. An excerpt from the Manager configuration file

Excerpts of the XML Manager configuration file is shown in Figure 5: a score between 0 (missing) and 1 (good) is associated to each Item and the corresponding attributes are the thresholds used during detection and classification. Each Target in the View contains also the presumed size and position of the Items to be searched, expressed in pixels. Once the Inspector has performed detection on the image acquired for “LEFTFRONT” View (Figure 6a), three maxima for the G transform have been found and used both for button detection and for classification.

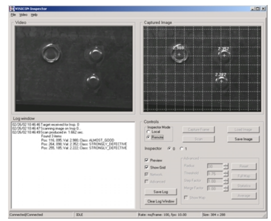

Figure 6a. The Local Inspector user interface.

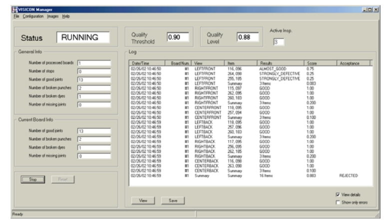

Figure 6b. The Quality Control Manager user interface.

The classification results of this View, together with the results of all the other Views, are sent to the Manager which computes the overall board quality according to *OQ* Equation. In Figure 6b, the snapshot of the QCM at the end of the board evaluation is shown. On the right side, the trace of the performed quality assessment process for each View and for each Target of the View.

6. CONCLUSIONS

To perform quality control on clinched metal boards, a general-purpose distributed quality control system based on computer vision has been developed. The adopted architecture allowed the real-time evaluation of a complex structure, such as a board with multiple clinched areas, by delegating to a variable number of industrial PCs the image processing aspects, together with the corresponding computational cost. This also allowed to scale the system on the basis of the production line speed and end-user’s quality requirements. The developed architecture is strongly modular and easily customizable to other industrial applications.

7. ACKNOWLEDGEMENTS

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