

Online Machine Vision Inspection System for Detecting Coating Defects in Metal Lids

Ismail Al Kamal, *Student Member, IEEE*, Mohamad Adnan Al-Alaoui, *Senior Member, IEEE*

Abstract— Experts forecast that globalization and open economy will be the characteristic of the 21st century. Industry in developing countries must be well prepared and competitive in order to have a vital role. These countries will not be able to access global markets unless they procure the needed technology to manufacture high quality, up to the standard products. Automated visual inspection is one of these emerging technologies. Higher production speeds require higher inspection speeds which can be implemented best by replacing human visual inspection procedures by machine vision inspection systems. This paper presents an online machine vision system design that is capable of detecting defects in rubber coating of metal lids during manufacturing. The system is simple and low cost consisting of a CCD camera mounted on a conveyer belt and connected to a PC through FireWire (IEEE 1394). Image acquisition, analysis, and inspection are implemented using National Instrument's (NI) Vision Builder tool. The inspection algorithm is realized through a four stage process: starting with acquisition to enhancement, thresholding and finally object matching.

Index Terms— automated visual inspection, machine vision, NI vision builder, coating defect, object matching.

I. INTRODUCTION

Machine vision systems have been implemented in hundreds of applications worldwide especially in visual inspection. Reliability, versatility, speed, integration of production processes, and cost saving are the key factors that motivate the use of these systems [1]. Higher manufacturing speeds and increased customer demands for quality give automated visual inspection an upper hand over manual visual inspection. Although the human visual system is most complex and best in making judgments, it fails in completing complex quantitative tasks that require very fast repetitive decision making along very long working periods which is quite impossible for a human [2].

Certain factors were considered in our implementation of a visual inspection system [3]:

- The impact of the vision system on the speed of production.

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Ismail Al Kamal, is a graduate student with the Department of Electrical and Computer Engineering, the American University of Beirut, Beirut 1107 2020, Lebanon (e-mail: ima16@aub.edu.lb).

Mohamad Adnan Al-Alaoui, is with the Department of Electrical and Computer Engineering, the American University of Beirut, Beirut 1107 2020, Lebanon (e-mail: adnan@aub.edu.lb).

- Accommodation of the production process to the vision system.
- Determination of a service schedule for the vision system in light of the overall production schedule.
- Reliability and reconfigurability of the vision system.
- Justification of the vision system on economic grounds.

Machine vision systems are usually divided into two types. One that uses smart cameras and another that uses a PC [4]. In our application, A PC based system was chosen due to its flexibility and expandable functionality and performance as well as to its alignment with the five factors presented above. A CCD color camera mounted on a conveyer belt is connected to a PC through FireWire (IEEE 1394) which boasts speeds up to 800 Mbps and is suitable for real-time applications. Pictures are taken repetitively in predefined time frames and are then analyzed using a script written in NI's vision builder application. Simplicity was the main consideration in the design of the inspection algorithm. It passes through four stages starting from image acquisition to image enhancement with a Gaussian filter, thresholding and then pattern matching using a predefined pattern for detection. When a defective sample is detected, it is immediately pushed out of the conveyer belt without disturbing the production process.

The industrial problem is defined in section II, then a detailed description of the hardware and software setups follow in section III and IV. The inspection process and algorithm is presented in section V. Further considerations are noted in section VI and finally a conclusion is made stating the results of implementing the system and any future developments.

II. PROBLEM DEFINITION

The research work was done on one of the processes of a metal can production line. The metal lids of these cans came in two colors (white and silver) and three sizes (6cm, 7cm and 8cm). The boundary of the lids was coated with a layer of isolation rubber. Due to the high speeds of production, several samples don't get coated properly resulting in a decrease of quality. The inspection was done manually and it regularly failed in detecting the defective lids moving on the conveyer belt. Three considerations have to be noted:

- The conveyer belt can have any combination of silver or white lids at any given time.
- Any lid size can be present on the conveyer belt during the production process meaning that different

kinds of lids can be manufactured on the same production line.

- The production operation is very fast and the vision system has to be capable of monitoring all lids.

III. HARDWARE SETUP

The CCD camera mounted on the conveyer belt is connected to the PC through a PCI FireWire Card.

A. CCD Camera

The camera used in the hardware setup is a Sony XCD-X710CR color digital camera. It is a 1/3 type 800,000 pixels CCD which offers XGA resolution images. The camera's output is in Bayer format and pixel color values are sent in 8bits to the PC. It also incorporates an external trigger to allow the clear capture of fast moving objects. A 6mm 1/2" fixed focal length NAVITAR lens was fitted to the camera for a clear magnified view of the lids on the conveyer belt. The camera and lens were mounted on a tripod at a height of 30 cm and an angle of 15° as shown in Fig. 1.

B. Light Source

Lighting the object that is to be captured is an essential step in detecting defects. Shadows and different reflections can degrade the image quality considerably affecting the overall detection process. Direct front illumination was chosen. A simple incandescent lamp is mounted on an arm at a height of 30cm with a 15° angle which provides a point-like bright field around the object. It has high intensity and boasts light efficiency. It is good for creating sharp image edges and accenting surface features. The main disadvantage is that some unwanted shadows are cast around the object which may affect the detection process.

C. PCI Firewire card and PC

The FireWire card is used to connect the camera to the PC which has NI vision assistant running. The main advantages of such a connection is hot plugging, scalable performance (current speeds up to 800 Mbps) and cable power which removes the need for powering the camera from an independent power source.

The PC used in the experimental setup was a Dell 3GHz P4 machine with 512 MB of Double Data Rate (DDR) memory.

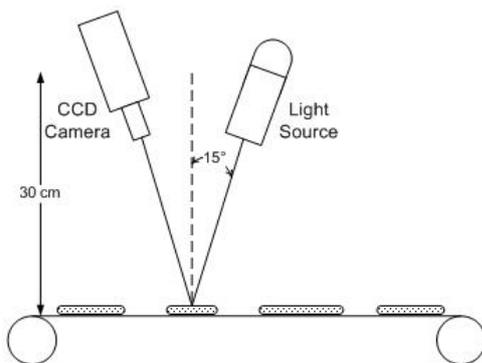


Fig.1. Visual inspection system setup measurements



Fig. 2. Visual inspection system experimental setup

D. Conveyer belt

During the experimental stage a 75cm x 15cm conveyer belt was used. A 12V DC motor controls the speed of the belt and is connected to the production process scheduler. The vision system controls an arm mounted on the belt which pushes the defective sample off the belt when a negative match is made. The lab setup is illustrated in Fig 2.

IV. SOFTWARE SETUP

NI vision builder for Automated Inspection (AI) was used as the software tool for acquiring and analyzing the images. It is very simple, powerful and provides an easy-to-navigate, interactive environment to configure, benchmark, and deploy machine vision applications. The software has a wealth of functions divided into five main areas: enhancing images, checking presence, locating features, measuring features and identifying parts [5].

The vision builder AI allows for configuration and inspection of complete automated inspection tasks, which can run as standalone software. Therefore, the NI vision builder AI provides two interfaces:

- The Configuration Interface: It is used to configure inspection tasks. The inspection application can be configured by adding inspection steps that contain the image functions applied to the image.
- The Inspection Interface: It shows the results and statistics of the inspection process. The script is then compiled to form a standalone application which can be run on site.

The GUI contains two windows, a main window with the analyzed image and another where inspection steps can be added. The inspection step can be immediately applied to the studied image as shown in fig. 3.



Fig. 3. NI Vision Builder GUI

V. INSPECTION PROCESS

The inspection process passes through four stages: image acquisition, image enhancement, thresholding and finally object matching.

A. Image Acquisition

Snapshots are sent to the PC in Bayer Format and so a Bayer to RGB transformation is necessary in software. We built a Virtual Instrument (VI) that takes care of the transformation using the IC Imaging tools provided by the camera’s driver and software packages. To convert an image from Bayer format to Red-Green-Blue (RGB) format, we need to interpolate the two missing color values in each pixel [6].

When interpolating the missing values of R and B on a green pixel, we take the average values of the two nearest neighbors of the same color. The value of the blue component in a shaded green pixel will be the average of the blue pixels above and below the green pixels. The value of the red component will be the average of the two red pixels to the left and right of the green pixel. The value of the green component is to be interpolated on a red pixel and is calculated from Fig. 4:

$$G(R) = \begin{cases} (G_1 + G_3)/2 & |R_1 - R_3| < |R_2 - R_4| \\ (G_2 + G_4)/2 & |R_1 - R_3| > |R_2 - R_4| \\ ((G_1 + G_2 + G_3 + G_4)/4) & |R_1 - R_3| = |R_2 - R_4| \end{cases} \quad (1)$$

The necessary steps to acquire a sample image are as follows:

- Retrieve the available video capture device from IC Imaging control and return its name in an array of strings.
- Open the specified device and retrieve the video norms, formats, input channels and frame rates provided by the device.
- Grab an image from the currently selected device and return it as an 8 bits Image Acquisition (IMAQ) image.

		R ₁		
	B	G ₁	B	
R ₄	G ₄	R	G ₂	R ₂
	B	G ₃	B	
		R ₃		

Fig. 4. Bayer format filter mask

- Decode a Bayer encoded image to produce an RGB representation of the images.
- The images are then transferred to the image enhancement stage.

B. Image Enhancement

The principal objective of enhancement is to process an image so that the result is more suitable than the original for a specific application. Enhancement techniques range from histogram equalization to applying logic operations, averaging and sharpening masks.

We chose to apply a smoothing Gaussian filter to reduce large differences in pixel intensities around the region of interest [7]. The size of the mask is 7x7 and has the following values:

$$\begin{bmatrix} 1 & 1 & 2 & 2 & 2 & 1 & 1 \\ 1 & 2 & 2 & 4 & 2 & 2 & 1 \\ 2 & 2 & 4 & 8 & 4 & 2 & 2 \\ 2 & 4 & 8 & 16 & 8 & 4 & 2 \\ 2 & 2 & 4 & 8 & 4 & 2 & 2 \\ 1 & 2 & 2 & 4 & 2 & 2 & 1 \\ 1 & 1 & 2 & 2 & 2 & 1 & 1 \end{bmatrix} \quad (2)$$

The choice of such a large mask is justified by the necessity to remove speckle noise and average out any shadows and reflections induced by the light source. A proper solution in our case is to change the lighting to diffused coaxial lighting which would remove any unwanted shadows and reflections on the studied samples. The increased computation time did not affect the performance of the system and was quite sufficient to move to the next stage of processing.

C. Thresholding

Thresholding is one of the most important applications of image segmentation. If thresholding is to be applied to an image f(x,y) then the thresholded image g(x,y) is defined as:

$$g(x, y) = \begin{cases} 1 & f(x, y) > T \\ 0 & f(x, y) \leq T \end{cases} \quad (3)$$

Where f(x,y) is the gray level of point (x,y) and T is the threshold. In this application and by applying the previous discussed lighting a threshold of T = 101 was chosen based on the histogram of the tested samples. A histogram of the tested samples is displayed in Fig. 5.

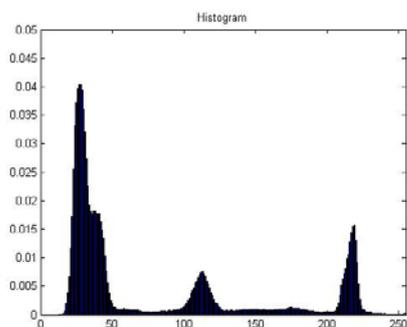


Fig. 5. Studied image sample histogram

D. Object Matching

The degree of similarity k between two shapes is defined as the largest order for which their shape numbers still coincide [8]. If a and b are two shape numbers of closed boundaries represented by 4 directional chain codes. These two shapes have a degree of similarity k if:

$$\begin{aligned} s_j(a) &= s_j(b) && \text{for } j = 4, 6, 8, \dots, k \\ s_j(a) &\neq s_j(b) && \text{for } j = k+2, k+4, \dots \end{aligned} \quad (4)$$

Where s indicates shape number and the subscript indicates order. The distance between two shapes a and b is the inverse of k .

$$D(a,b) = 1/k \quad (5)$$

This distance satisfies the following properties:

$$\begin{aligned} D(a,b) &\geq 0 \\ D(a,b) &= 0 \text{ if } a = b \\ D(a,c) &\leq \max[D(a,b), D(b,c)] \end{aligned} \quad (6)$$

When the distance is smaller or the degree of similarity larger, there is a better match between the studied shapes.

NI Vision Builder AI has an installed function that deals with shape matching. The inputs are a shape template which is a circle in our case and the degree of similarity which was set to 0.98. The kernel gives a positive match if the template circle can be matched with one in the image, in other words, a perfect non-defective metal lid. If a defective sample passes through, no match is made, thus meaning that a defective sample has been found and a command to the control unit is sent to remove that sample. The matching process is depicted in Fig. 6.

VI. FURTHER CONSIDERATIONS

In the real setup, the process of acquiring images has to be done in an isolated environment so that external light sources don't affect the primary light. Usually, the light source and camera are fixed inside a box in which the studied objects are photographed. To simulate this process in our experiment, we took all images in a dark room so that no other light source can affect the acquiring process.

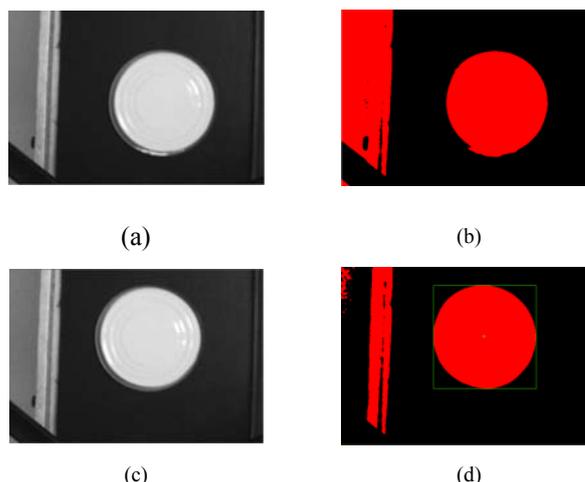


Fig. 6. (a) original defective sample, (b) no match -detected defect-, (c) original perfect sample, (d) positive match -sample is perfect-.

When applying the machine vision system to the actual production line, acquired images could get blurry due to the fast movement of the conveyer belt. The proposed solution is to replace the light source with a flasher that lights on regular intervals to ensure that images are sharp and clear.

VII. CONCLUSION

Some of the most important applications of machine vision systems in industry are systems that ensure quality control of manufactured products. Designing a low cost machine vision system with sophisticated software that enables automatic defect detection in metals accomplishes this goal and insures that local products can compete with other global products.

The complete project is simple, inexpensive and efficient. The main purpose of this paper is to recognize defects in the coating process of metal lids. The inspection procedure is automatic and straightforward and is effective with accuracy values higher than 99%.

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