Automatic Image Inspection Method for Detection of Superficial Defects on Circular Top Sides of Cylindrical Ceramic Rods

C. Nava, member IEEE  
Back End Staff Engineer  
Skyworks Solutions Inc.  
CarlosFabian.Nava@skyworksinc.com

M. Bravo, M. Felix, member IEEE  
Engineering Faculty  
Autonomous University of Baja California  
Mexicali, Baja California, Mexico

Abstract—In the last decades, new computer vision technologies and image processing techniques have been very important in the improvement and automation of manual processes in many technical areas, e.g., in the semiconductor industry. In this paper, we propose an automation method for a currently deployed manual inspection procedure by using image processing techniques, in order to detect and measure superficial defects in the circular surface of circular cylinder RF ceramic rods. In the first step of this method, a color image is acquired from a proposed CCD camera setup, then preprocessing and image processing techniques are applied in order to find curvatures and areas over the circular surface of a cylindrical ceramic rod. Then a features comparison is computed to detect defects in the ceramic rod material. Finally, our results show that the proposed automatic vision method reduces more than ~90% the manual inspection time, as well as reduces in ~75% the number of required factory operators related with the manual inspection.

Keywords—machine vision; ceramic rods; defects detection; image processing.

I. INTRODUCTION

A ceramic dielectric rod used for wireless applications has been an important component for years [1, 2], and is being manufactured in high volume each year for commercial and military markets. A common ceramic rod device for wireless communications networks can be used in several wireless network blocks as a combiner, filter or resonator, depending on the manufactured ceramic material and geometry [3]. The designed geometrical parameters of the ceramic rods determine the frequency tuning of the RF electronic product to be manufactured. A typical quality assurance of this ceramic rod, involves a manual rod inspection procedure that requires four technicians per shift (a total of twelve) with an accuracy capability of 85%, resulting in an unacceptable high failure detection annual cost. The visual manual inspections include perception of surface curvature and tarnish, and detection of defects in the cylindrical structures for cracks, scratches or voids. Several cylindrical rod inspection systems and methods have been previously reported [4-11]. Some methods are pointed to solve image processing issues like sorting and grading fruit superficial features [7], surface mount devices inspections for AOI systems [8], a method to detect faults of patterns on PCBs [9], image detection flow for the dimension and appearance of multilayer ceramic capacitors [10] and an optical measurement system to inspect automotive part surface [11]. Our proposal for an automatic rod inspection system tries to reduce inspection time and improve accuracy, as an alternative to the manual process. The contribution of this work is focused in an inspection process automation that meets manufacturing quality requirements. Our presented work is a machine vision based inspection system that measures geometrical parameters of the ceramic rod and identifies currently addressed manufacturing defects.

II. CERAMIC ROD INSPECTION

There could be many types of defects on the surface of the ceramic rods. Many of them are distributed along the curvature of the circular edges, others over the surface creating geometrical roughness and irregularities. For this presented work, we are focusing in two types of defects. One is called chips, which is a ceramic rod cutting spots over the curvature, as shown in Fig. 1.

Fig. 1. Chip defects on ceramic rods shown in the red boxes.
Fig. 2. Other types of defects on ceramic rods. a) Metallization, b) Voids, c) Holes, d) Blemishes, e) Cracks.

III. EXPERIMENTAL SETUP

The proposed method starts with a comparison of different available vision systems in our lab, as shown in Table I.

<table>
<thead>
<tr>
<th>System</th>
<th>Manufacturer</th>
<th>Interface</th>
<th>Resolution</th>
<th>Sensor Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mako G-125C</td>
<td>Allied Vision</td>
<td>GigE IEEE 802.3</td>
<td>1292 x 964</td>
<td>CCD Progressive</td>
</tr>
<tr>
<td>Guppy Pro F-503C</td>
<td>Allied Vision</td>
<td>FireWire IEEE 1394b</td>
<td>2588 x 1940</td>
<td>CMOS Progressive</td>
</tr>
<tr>
<td>Stingray F-504C</td>
<td>Allied Vision</td>
<td>FireWire IEEE 1394b</td>
<td>2452 x 2056</td>
<td>CCD Progressive</td>
</tr>
<tr>
<td>NI 1754 Smart Camera</td>
<td>National Instruments</td>
<td>GigE IEEE 802.3</td>
<td>1280 x 1024</td>
<td>CCD Progressive</td>
</tr>
</tbody>
</table>

We chose the camera with greater resolution and higher quality images with low noise, in this case the AVT Stingray F-504C CCD Camera. In tests, we could prove that the Stingray image quality is better than the Guppy Pro Camera. The chosen camera is used to acquire an image of ceramic rods inside a tray. It uses the IEEE-1394b interface at a maximum data transfer speed at 9 fps with full camera resolution of 2452x2056 pixels. The selected resolution and data transfer speed parameters meet the factory production schedule of inspected ceramic rods. The camera was set with a RGB output image type, making easy to differentiate background from our ceramic rods.

The camera was connected to the computer using a reconfigurable DIO IEEE-1394 NI PCIe-8255R interface from National Instruments™, integrated with a Vision Acquisition Module used to acquire, display and save images from the Camera through the NI PCIe-8255R board. This Vision Development Module uses LabVIEW™ for image processing at the computer. Two spherical fluorescent lamps were used to provide illumination at both sides of the ceramic rod material tray. These lamps were installed in order to show surface structure defects and enhance object topography. A sharp angle of incidence close to 20 degrees with respect to the material plane was used to reduce the possibility of detection errors due to shadows generated by topography changes over the ceramic rod’s surface. Light intensity was controlled manually to not create glare or hot spots, but enough lighting to spread out an even illumination over the ceramic rods. Our light intensity was not affected by the environmental light. We did some test in a black room with the same results. The principal components of the proposed setup are shown in Fig. 3.

A color CCD image showing a section of the ceramic rods inside the tray is shown in Fig. 4. This distribution has a constant distribution of 20 rods, 5 rows of 4 rods each. This 20-rod distribution is chosen to have the best resolution image with fewer movements that a motion system can do to inspect a complete tray of 20 rows and 16 columns. Ceramic rods touching the image boundary will be rejected. Two types of ceramics rods are shown in Fig. 4. Our method is capable to inspect any ceramic rod color, but proper color characterization has to be done. For this developed inspection method, due for production status, only brown ceramic rods where inspected.

IV. INSPECTION PROCEDURE

Our method is mainly composed of the processing steps shown in Fig. 5.
A. **Ceramic rod tray background removal procedure.**

The color of the ceramic rod tray is in the green levels with RGB background target of (95,95,35). Any decimal color code below our ceramic rod tray background target has to be removed from the entire color image. We applied a subtract arithmetic operator in the entire image to reduce by the (95,95,35) constant the RGB value of every pixel. The background removal procedure is shown in Fig. 6.

B. **Gray scale to binarization procedure.**

The background removed images are converted from 32-bit Color Image to 8-bit grayscale images, composed of a single 8-bit unsigned integer represented by values from 0 to 255 for each pixel in the image. Then the grayscale image was converted to a binary image, with pixel values of 0 or 1. Fig. 7 shows the binarization procedure.

C. **Small particle detection and removal procedure.**

After having the binarization procedure, some ceramic rods lose some superficial structure information due to the same superficial defects, and because a global threshold range has been applied. Also, the binarized image is not clean all time, it depends if the ceramic rod material tray surface was smooth plane with excellent topography conditions. In order to solve this issue, a removal function that searches for any particle with erroneous pixels is applied. When non-ceramic rod surface pixels are found, these pixels are converted to the Boolean value of zero, as the background. Fig. 8 shows the particle removal procedure.
D. Ceramic rod identification procedure.

After the clean process of all residual background noise, we need to look for possible ceramic rod patterns. The number of identified ceramic rods is obtained by means of computing a function that detects groups of nonzero pixels values. Besides the rod count, this function also obtains each rod positioning center of mass, perimeter and area parameters that will be useful in the following steps, as shown in Fig. 9 and Table II.

![Fig. 8. Particle removal procedure for noisy particles shown at the left side. The processed clean image is shown at the right side.](image)

![Fig. 9. Possible ceramic rods. Useful parameters will be obtained in the identification procedure.](image)

<table>
<thead>
<tr>
<th>Ceramic Rod</th>
<th>Center of Mass X (Pixels)</th>
<th>Center of Mass Y (Pixels)</th>
<th>Perimeter (Pixels)</th>
<th>Area (Pixels²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>562.56</td>
<td>378.50</td>
<td>1045.56</td>
<td>84228</td>
</tr>
<tr>
<td>2</td>
<td>1108.67</td>
<td>378.55</td>
<td>1033.31</td>
<td>83824</td>
</tr>
<tr>
<td>3</td>
<td>1658.39</td>
<td>385.51</td>
<td>1041.33</td>
<td>83951</td>
</tr>
<tr>
<td>4</td>
<td>843.06</td>
<td>717.53</td>
<td>1032.85</td>
<td>83552</td>
</tr>
<tr>
<td>5</td>
<td>1393.09</td>
<td>720.17</td>
<td>1030.19</td>
<td>83523</td>
</tr>
</tbody>
</table>

E. Circle edge finding and final ceramic rod positioning procedure.

The circle edge finding procedure uses the center of mass \((x, y)\) and area parameters for each rod. A search band is constructed with the particle center of mass \((x, y)\), inner radius of 90 pixels and an outer radius of 200 pixels, as shown in Fig. 10. This area is selected in order to find edge curvature changes between pixels 0 values from the background and 1 for particle surface pixels. Several analyzed rods from a tray are shown in Fig. 11.

![Fig. 10. The circle edge finding and search band drawing procedures.](image)

![Fig. 11. Image from several analyzed rods from a tray.](image)

F. Acquired Image Spatial Calibration.

Before this part of the paper, all measurements units were in pixels. Calibrating our imaging setup is important in order to have accurate measurements. Our camera axis is perpendicular to the plane and our 35 mm lens compact...
fixed focal length distortion is less than 0.3% of the image at a working distance of 300 mm (manufacturer specs). We use a simple calibration process where the pixel rectangular coordinate system is scaled by a factor calculated in the readings of a ceramic golden unit with a diameter size of 11.887 mm. Minimum image distortion in the rectangular coordinate system is shown in Fig. 12.

\[ G. \quad \text{Chips radial size and damaged surface area analysis.} \]

In this part of the method, we start extracting a mask of every ceramic rod to compute a histogram showing the distribution of the pixels at each greyscale level. After this, a local threshold is applied to indicate where the chips and damaged area are over the ceramic rod, as shown in Fig. 13.

After having the extraction and local threshold applied, in order to calculate how deep radially a chip is from the curvature, we need to extract the actual curvature and simulate a circle with a radius from previous stages. Then we calculate and compare those differences radially to check if this ceramic rod is in good or bad condition according to specifications. The maximum permitted difference is 0.508 mm. First we start extracting the best contour from the ceramic rod image, and then a simulated circle is created using previous radios fitting, as shown in Fig. 14. The mentioned calculated difference is shown in Fig. 15.

For the damaged area over the ceramic rod surface, we compared the simulated ceramic rod circle with the real ceramic rod, computing the difference and comparing this result with the maximum permitted area for defects, which is 3.87 mm². With any value greater than that, the ceramic rod is considered bad material.
V. RESULTS

The results of an inspection procedure using our proposed method are shown in Table III. Images of the developed inspection system front panel are shown in Fig. 16 and 17.

<table>
<thead>
<tr>
<th>System Process</th>
<th>Optical Inspection Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ceramic Rod Top Surface Inspection (sec)</td>
</tr>
<tr>
<td>Manual</td>
<td>1.62</td>
</tr>
<tr>
<td>Automated</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Fig. 16. Front panel of the developed ceramic rod inspection system.

Fig. 17. Inspection of ceramic rods in tray.

VI. CONCLUSIONS

The developed automatic image inspection method presented in this paper, demonstrates improvement for detection of superficial defects on circular top sides of ceramic rods, as can be seen in the results. The required time for inspecting the surface of a ceramic rod with the developed method reduces from 1.62 to 0.16 sec, compared with the manual method. Also the automation process reduces the required factory operators required for manual inspection from 12 to 3 inspectors.

REFERENCES