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Integrating Fuzzy Inference System, Image Processing, and Quality Control to Detect Defects and Classify Quality Level of Copper Rods

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KEYWORDS

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Image processing;
Fuzzy inference system;
Copper rods.

ABSTRACT

Human-based quality control can be of low accuracy and, in most cases, may reduce the speed of decision-making. Therefore, various automated quality control systems have been developed. In this paper, the design of an expert system for automatic quality control is investigated to increase the accuracy of a control system. The knowledge used in this system is gathered thanks to experts, and the data are obtained by a camera. However, since knowledge is implicit and data are uncertain, fuzzy logic is utilized for this system. The captured images of the product are inputs of the system, and the state of the process (in control or out of the control) is output. The input images may be noisy; therefore, the pre-processing method is applied; then, a fuzzy rule-based system along with FAST (Features from Accelerated Segment Test) is developed and applied to extract the specific features needed for controlling the process. Then, the control chart is applied to identify whether the process is in "in control" state or not. An empirical case study is also presented to show the capabilities of the proposed approach.

1. Introduction

With the advent of the industrial revolution in the middle of the 18th century, machines have gradually become a replacement for the tools and individual skill of the people. By the genesis of the novel and complex production methods, the desire to produce has increased and, accordingly, the need for controlling the quality of products has shown new dimensions. Nowadays, statistical quality control has a key role and, when applied, can guarantee a certain standard for quality of services and products. A control chart is a tool for providing a visual schema of the statistical process control. The prevalent application of these charts is to protect and control the processes during the production operations by showing a qualified characteristic based on the samples or time, measured or calculated according to the sample information [1].

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Whenever a process is more complex or needs higher accuracy, the human fault will increase. Therefore, using an automated and smart system is necessary to reduce human faults. In addition, since visual inspection is one of the most used methods in quality control systems, image processing techniques are necessary to use for automated systems. This not only helps to reduce the identification time but also facilitates the coordination in the classification of defects and causes more monotony in the quality evaluations. Several researchers have studied these automated systems.

lin [2] investigated the quality of light-emitting diodes (LEDs) using an automated visual surface detection system. Brosnan and Sun [3] used an image processing approach for controlling the quality of food. In this research, important components of image processing and quality control, as well as recent developments in the food industry, have been studied. Ranjan et al. [4] investigated the friction stir welding (FSW) levels with the image processing approach. The purpose of this exploratory task is to identify and cluster different kinds of surface faults during the production process. Hosenski and Vasili [5] used an image processing approach to identify the defects of tiles. Zhang et al. [6] presented an approach to fault detection and diagnosis based on measurements of multiple sensor groups. Schmitt et al. [7] used image processing to identify and measure the cracks and bumps on the surface of a brick. Zermane and Mouss [8] developed a fuzzy control system for an industrial process to ensure remote running and controlling of a cement factory.

In this study, an intelligent system is developed to increase the accuracy of quality control. Thus, the knowledge of specialists is stored, and the images of the product are used. After acquiring the images, the first step is to enhance the quality of the images. Then, the needed features should be extracted from the images. To do so, fuzzy rule-based system along with FAST (Features from Accelerated Segment Test) is developed. Finally, an inference system is designed to determine the in-control or out-of-control state in the production process. In sum, developing an automated system for controlling the quality of production is the main innovation of this study. This system is also applied in the copper industry to identify the quality of copper rods via images captured by a camera.

The paper is structured as follows: in Section 2, the background of research methodology, including the introduction of quality control and image processing, is investigated. In Section 3, the proposed approach is presented. Section 4 introduces the case study and related results. Finally, Section 5 presents conclusions and suggestions for the future researches.

2. Preliminaries

2-1. Statistical process control

By using the control chart, qualified characteristics are calculated according to the sample information and are plotted in a chart based on sample or time (Figure 1). In this chart, the two upper and lower limits are selected such that, if the process is under control, then the whole points almost calculated according to the sample information are in this limit. When the points are in this limit, it is assumed that the process is under control and there is no need for corrective measures. If the point is traced out of the specification limits, then it can be assumed that the process is in the out-of-control state. It is common for the traced points on the control chart to be connected to each other with a direct line, simplifying the tracking [1].

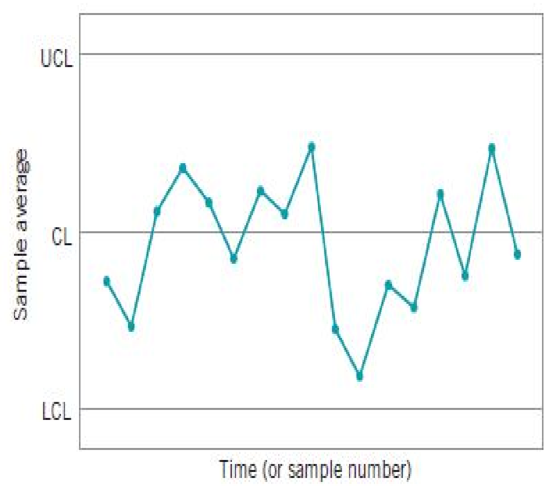

Fig. 1. An example of a control chart

2-2. Image processing

The image processing methods receive an image as an input and produce a modified image, measures or descriptions as outputs. Various algorithms have been developed for this purpose (for more information, see [10, 11]). Generally, the processing is categorized into three levels: low-level, mid-level, and high-level (see Figure 2). Low-level processing includes the methods for reducing the noises, improving the contrast, and sharpening the image. In this level, the input and output of the process are both images. The mid-level processing includes image segmentation, feature extraction, image classification, and object identification. In this level, the input of the process is an image, and the output represents the extracted parameters of the image. Finally, the high-level includes "sense development", which uses the features extracted from the mid-level [12].

	Low-level	Intermediate-level	High-level	
Image	Pre-processing	Segmentation Representation Description	Analysis Interpretation Recognition	Result

Fig. 2. A general schema from three levels of image processing

In the above three categories and in general, in the field of image processing, there are many uncertainties such as uncertainties of digitizing analog images, uncertain of boundaries, and non-homogeneous regions [13]. In order to handle these uncertainties, fuzzy logic has been successfully applied to many areas, such as pattern recognition and computer vision. It has also been applied to edge detection, image enhancement, image segmentation, image classification, and thresholding value selection [14]. Fuzzy sets offer a problem-solving tool between the precision of classical mathematics and the inherent imprecision of the real-world problem [14] such as image processing, understanding, and representing [15].

In many image processing applications, expert knowledge is used to overcome the difficulties in object recognition, scene analysis, etc. Fuzzy set theory and fuzzy logic offer powerful tools to represent and process human knowledge in the form of fuzzy IF-THEN rules [12]. In addition to this method, other methods are used such as FAST (Features from Accelerated Segment Test) feature detector [16]. A test is performed for a feature at a pixel p by examining a circle of 16 pixels (in [17], a circle of radius 3) surrounding p. A feature is detected at p if the intensities of at least 12 contiguous pixels are all above or all below the intensity of p by some threshold t. (see Figure 3). The test of this condition may be optimized by examining pixels 1, 9, 5, and 13 to reject candidate pixels more quickly, since a feature can only exist if three of these test points are all above or below the intensity of p by the threshold [16]. Using this method, the intensity of the brightness of the pixels in a region could be specified.

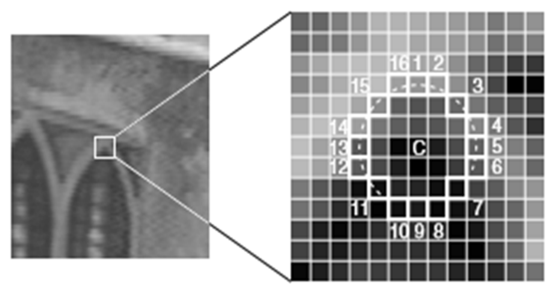

Fig. 3. FAST feature detection in an image patch

In this paper, an integrated method based on fuzzy image processing and FAST feature detector are proposed to identify the features used in the quality control process. This is discussed in the next section.

3. Proposed Approach

As mentioned above, the main purpose of this research is to design an expert system for quality control using a control chart. Since the inputs of this system are images, the image processing approach is used to extract the required features in the controlling process. Designing an expert system for this purpose includes four main steps: (1) image acquisition, (2) image preprocessing, (3) feature extraction, and (4) approximate reasoning (whether the process is in control state or not), as shown in Figure 3.

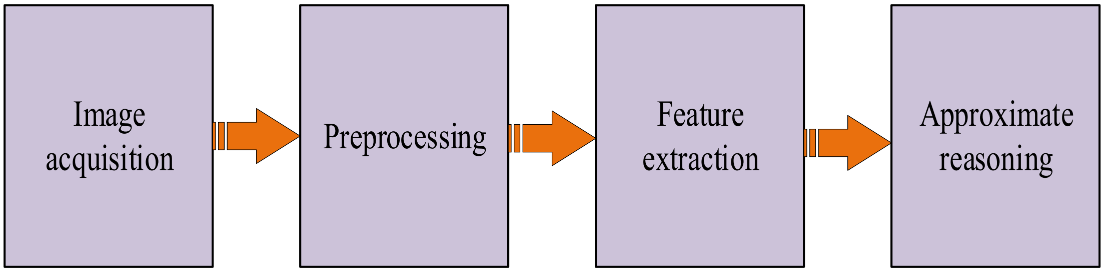

Fig. 4. Proposed expert system

Image acquisition is a highly important step for the automatic quality control because it provides the input data for the whole process [18]. In this step, in order to acquire images with needed specifications, a camera or any other devices are used to take digital images. After acquiring the images, the next step is pre-processing. There are many pre-processing techniques, each one is applicable in different circumstances (see [19-21]). Removing noises and smoothing the image are done in this step.

Features are extracted from the images in the next step. The extracted values (features) intend to be informative and non-redundant and, in some cases, lead to better human interpretations. Feature extraction is related to dimensionality reduction [22]. Various methods have been developed for this purpose. Edge detection methods are a group of methods used to obtain physical properties of edges within the image using the changes in intensity levels. Methods of Canny [23] and Sobel [24] are the two most well-known edge detection methods. One of the other approaches to finding the edge is to use fuzzy logic. This approach to edge detection uses membership functions for determining the degree of belonging a pixel to an edge region. There are some general features extraction methods that are not related to a specific field and apply to natural images such as corner detection, SIFT, SURF, FAST, etc. Herein, the FAST feature detector is used as described in the research methodology.

The definition of appropriate rules for the detection of a fault and determination of control or out-of-control state in the production process is one of the most important steps. The power of an inference engine is based on the accuracy of input data and the predefined rules. For this purpose, according to the control chart, appropriate rules for an expert system are defined.

This system is developed and is applied in the copper industry for controlling the quality of copper rods. The following section describes the developed system in detail.

4. Case Study and Results Analysis

Controlling the quality of copper rods is a major concern in copper industries and usually consists of the following steps. First, samples are selected; then, the testing machine twists these samples with the speed of 15 round per meter to determine the surface defects of rods [25]. Based on the type and amount of defections, the sample and, as consequence, produced rods are classified into "reject (C)", "average quality (B)", and "high quality (A)" groups.

These steps for the developed automatic quality control expert system are as follows:

Step 1: Image Acquisition

In the first step and in order to acquire images with needed specifications, Canon SX510 is used to take 300*400 JPEG digital images. All images are captured at a constant distance from the rod surface. Figures 5 to 7 demonstrate samples of A, B, and C classes, respectively.

Fig. 5. Samples of a copper rod with class A quality

Fig. 6. Samples of a copper rod with class B quality

Fig. 7. Samples of a copper rod with class C quality

Step 2: Pre-processing

Input images have the red-green-blue (RGB) color model, which is very common. However, based on experiments, they are required to be converted to hue-saturation-value (HSV) color model for the better results. HSV is one of the most common representations of points in an RGB color model, in which the geometry of RGB is rearranged; more intuitive and perceptually relevant representation is obtained [26]. After converting the image into the HSV, space S is used, because there is the slightest reflection of light on the surface of the rod. The transformed image in S channel using MATLAB (2016b) is shown in Figure 8.

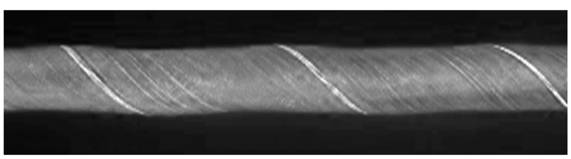

Fig. 8. S channel from HSV color space

After converting the input images, the noises and roughness of the image are reduced by using filters. However, in the case of inappropriate usage, the noises may be increased, or small details may be eliminated [14]. In addition, as there is no sufficient information about the noises in images, the Gaussian filter is used for this purpose. Bad lighting, a defect of dynamic scope in imaging sensors, or wrong settings may cause low-contrast images. Therefore, the contrast stretching method is also applied, which is one of the methods used to increase the contrast of an image and extends the range of intensity of the image.

Step 3: Feature extraction

In this step, the required feature of the copper rods, i.e., the status of rode after the twist test or the amount of defection, should be extracted. Therefore, in order to have a better result, the first Canny edge detection method is applied (Figure 9). Then, the Fuzzy logic is utilized to have better results. That is, if the gradient value for a pixel is 0, then it belongs to the edge with a degree of 1. Thus, both the edge and the defect can be indicated (See Figure 10)

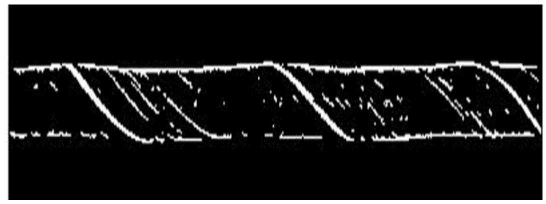

Fig. 9. Canny edge detection using MATLAB

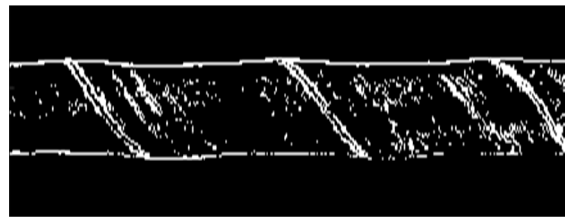

Fig. 10. Fuzzy edge detection using MATLAB

Then, Fuzzy Inference System (FIS) and FAST feature detector are used to measure the status of the rod after a twist test. Herein, the main goal is not to consider the edges, but to identify the defects on the surface of the copper rods. This goal can be achieved by defining an appropriate fuzzy inference system as well as logical rules. For this purpose, inputs and outputs are defined as three membership functions. Figure 11 shows defined characteristics of inputs, outputs, and their rules.

1. *If (gradient-of-every-pixel-in-the-x-direction is Uniform-intensity-pixels) and (gradient-of-every-pixel-in-the-y-direction is Uniform-intensity-pixels), then (output1 is black)*
2. *If (gradient-of-every-pixel-in-the-x-direction is Low-intensity-pixels) and (gradient-of-every-pixel-in-the-y-direction is Low-intensity-pixels), then (output1 is white)*
3. *If (gradient-of-every-pixel-in-the-x-direction is Low-intensity-pixels) and (gradient-of-every-pixel-in-the-y-direction is High-intensity-pixels), then (output1 is white)*
4. *If (gradient-of-every-pixel-in-the-x-direction is High-intensity-pixels) and (gradient-of-every-pixel-in-the-y-direction is Low-intensity-pixels), then (output1 is white)*
5. *If (gradient-of-every-pixel-in-the-x-direction is Uniform-intensity-pixels) and (gradient-of-every-pixel-in-the-y-direction is Uniform-intensity-pixels), then (output1 is gray)*

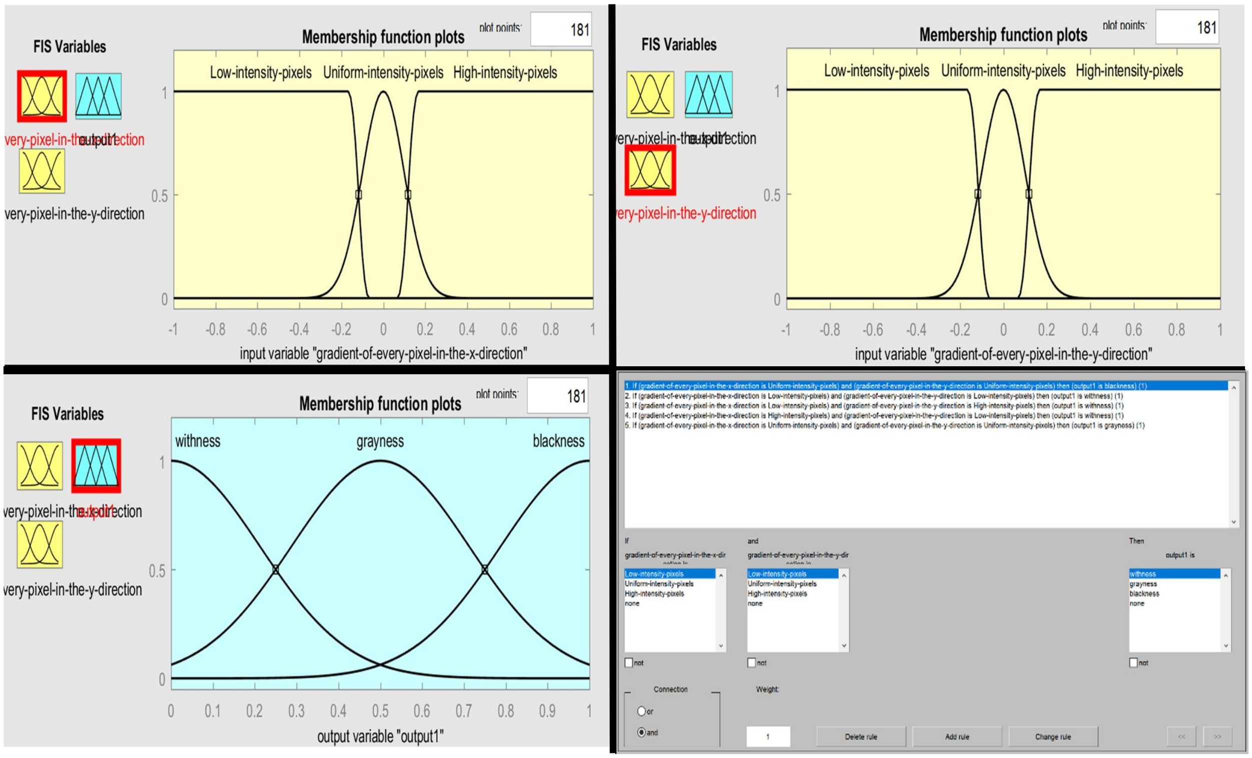

Fig. 11. (a) Input1, the gradient of every pixel in x directions. (b) Input2, the gradient of every pixel in y directions, (c) Output1, (d) Rules.

Now, using the developed fuzzy system and applying it to the images, the outcome is obtained according to Figure 12 (a). As is observed, the available defects are identified in the rod. Now, by giving a threshold for removing the points with the lowest mass, the failure level is improved (Figure 12 (b)).

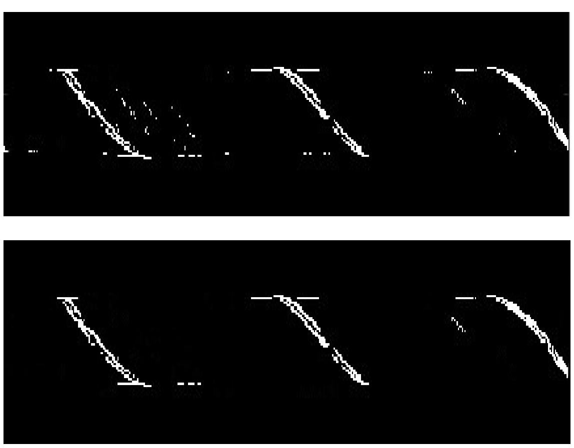

Fig. 12. (a) The output image is fuzzy systems; (b) Threshold is applied to remove spots with the lowest defect

By counting the white pixels in the image, the defects are extracted and are going to be used for the control chart (next step). In order to improve the accuracy of copper rods classification, FAST feature detector, provided in the proposed method, is used for investigating the pixel's neighbors. The result of using this method can be observed in Figure 13. Like the previous method, by counting the identified point numbers, the defects are extracted and are going to be used for the control chart (next step).

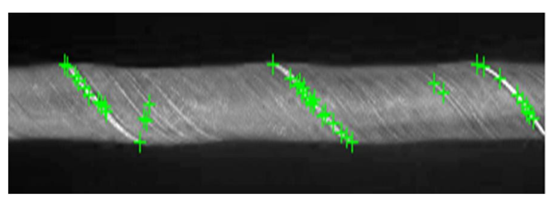

Fig. 13. Results of FAST feature detection

Step 4: Approximate reasoning

In the previous step, for each image, two features have been extracted, as reported in Table 1. In this table, the first column demonstrates image number, the second column is dedicated to the number of the pixels of the rod failure obtained by FIS method, and the number of extracted features of the FAST method is reported in the third column.

Tab. 1. Extracted data for failures in the copper rod

Sample	No. defect points	No. corner points
1	26	0
2	57	1
3	14	0
4	290	3
5	753	16
6	597	46
7	26	0
8	22	2
9	68	5
10	128	0
11	571	41
12	613	9
13	256	17
14	375	13
15	442	40
16	355	24
17	267	24
18	363	15
19	677	33
20	68	9
21	68	11
22	454	29
23	737	24
24	184	27
25	96	1
26	74	2

For each feature, a control chart is drawn and demonstrated (Figures 14(a) and 14(b), respectively).

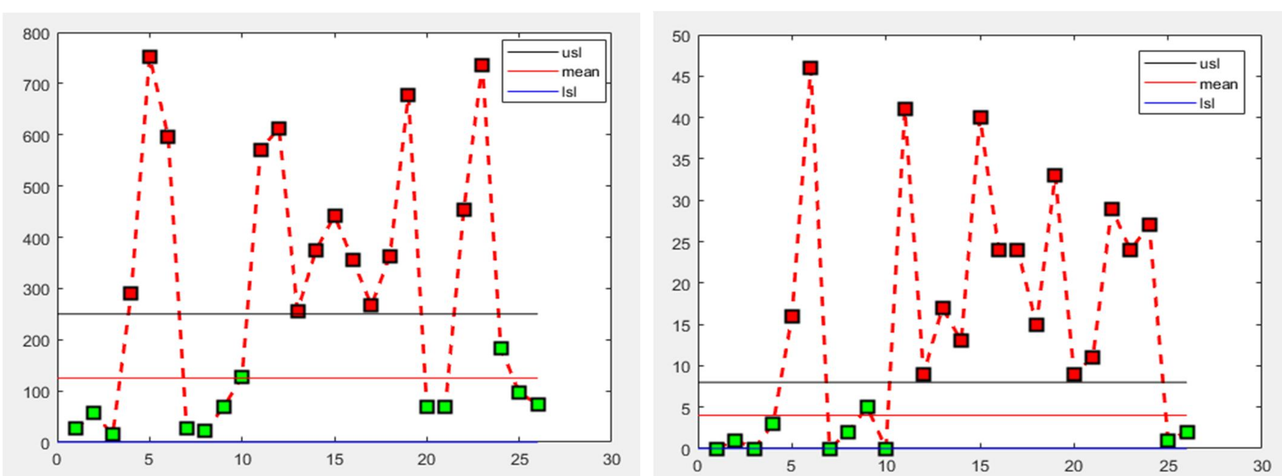

Fig. 14. (a) The first control chart data. (b) The second control chart data.

Now, the rules based on the knowledge of the expert and these control charts are used to classify the rods. The defined rules are as follows:

1. *If a sample is in "in control" state in both control charts, then the sample has A quality*
2. *If a sample is in "out of the control" state in both control charts, then the sample has C quality.*
3. *If a sample is in "in control" state in one control chart and in "out of the control" state in the other chart, then the sample has B quality.*

As an example, Samples 1 and 2 are both in the specification limits; therefore, by considering the above rules, these samples have the A-quality level. Samples 20 and 21 both are in a control state in one of the control charts in out of control in the other chart; hence, they have the B-quality level. Samples 15 and 16 are both in out of control state in both of the control charts; therefore, they have the C-quality level.

5. Conclusion

In human-based quality control, human fault affects the results. For handling this problem and increasing the accuracy in the control process, an automated system is developed. The Captured images of the product are inputs of the system, and the state of the process (in control or out of the control) is output. This system has four steps: image acquisition, pre-processing, feature extraction, and approximate reasoning. In the first step and to provide images with needed specifications, 300*400 JPEG digital images were taken by a Canon camera. In the second step, input images were converted to HSV color space and improved. In the third step, the required features of the copper rods were extracted by FIS and FAST feature detectors. In the fourth step, according to extracted features from the previous steps, the control charts were drawn, and the state of the production process was determined. An empirical case study in the copper industry was also presented to show the capabilities of the proposed approach in classifying the copper rods into three levels. Using deep learning approaches could be the future researches in this field.

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