Applications of the Image Processing Technology in Casting Surface Roughness Detection Technology

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Abstract. The casting performance and life is directly affected by the degree of casting surface roughness. In this thesis, the image processing technology was used to establish an automatic detection system of casting surface roughness and to realize the median filtering, image edge enhancement, and binaryzation processing during the image pretreatment process. Moreover, the casting surface roughness parameters were analyzed. By combining with examples, effectiveness and practicability of the computer image processing technology in the casting surface roughness detection technology were verified. The findings in this thesis laid a foundation on developing the digital images’ 3D evaluation technology for the casting surface roughness.

1. Introduction

The casting surface roughness is one of important indexes to measure the casting surface quality, which causes an impact on the casting performance and life. There are all kinds of instruments and methods detecting the casting surface roughness. Traditional methods include the comparative sampling method and contact contour graph. In fact, the computer image processing technology is a measurement technology burgeoned in the measurement field recently. It is featured with low costs, abundant amount of information, large dynamic range, fast speed, and non-contact type. In this thesis, the computer image processing technology was introduced to detect the casting surface roughness, realizing the non-contact automatic detection of roughness.

2. The automatic detection system framework of the casting surface roughness

The automatic detection system of the casting surface roughness based on the computer image processing technology is composed of the roughness management system, computer vision unit, parallel light source, and output device in Figure 1. Controlled by a computer, the parallel light source can project the parallel light to the casting surface from the any angle. The computer vision unit includes the computer, image capture card, black-white CCD camera, and optical microscope. The software management system of the casting surface roughness is composed of the light source switch, incident angle regulation module, roughness parameter calculation module, characteristic parameter extraction module, and image processing unit. The output device contains a printer and display linked with a computer. The workflow of the automatic detection system is stated as follows: a computer adjusts the parallel light source position according to the projected light source angle and then opens the light source. The casting to be detected is placed under the optical microscope with the fixed casting surface and lens distance. The casting surface remains vertical with the axis of the microscope. The black-white CCD camera is used to shoot the casting surface image to be detected, which is stored...
in the computer seized by the image capture card. The roughness image processing software in the computer deals with images and completes parameter calculation and characteristic extraction. Then, results are outputted to the output device for printing. Next, the parallel light source turns off.

![Figure 1. The Automatic Detection System Structure of the Casting Surface Roughness.](image)

In this system, the key of finishing automatic detection of the casting surface roughness parameters is the computer image process, so it is very important to select the image processing technology. The casting surface images are featured with the complicated direction, poor texture regularity, irregularity, and poor uniformity. Characteristic extraction and recognition, image binaryzation processing, image enhancement, and median filtering are applied in the casting surface image processing. The software part of this system has been developed by combining with advantages of Matlab and VC++ for image processing.

3. Realization of the casting surface image pretreatment

3.1. Median filtering

Since noise jamming exists in any image that is not processed, it affects image quality or even results in flooding and vagueness of image characteristics, causing great convenience for analysis. Therefore, the first step of the image processing is the image denoising filtering processing. The median filtering is a very good non-linear filtering technology, especially for the excellent performance as dealing with image scanning noise and impulse interference. The mobile window length is set up as the odd number \( m \). And median filtering is used to deal with the 1D sequence \( f_1, f_2, \ldots, f_n \) with the mathematical expression as follow:

\[
y_i = \text{Med} \{ f_{i-v}, \ldots, f_i, f_{i+v} \} \quad i \in N, v = \frac{1}{2}(m - 1)
\]

After getting the median filtering concept of the 1D sequence, the above formula is deduced to obtain the median filtering expression of the 2D sequence as:

\[
y_{ij} = \text{Med} \{ f_{ij} \}
\]

Where, the mobile window is \( A \).

In the 2D median filtering, the filtering effect is greatly affected by the mobile window sizes and shapes. Hence, different mobile window sizes and shapes should be applied to different images. The common window sizes include \( 3 \times 3, 5 \times 5 \) or larger. This is determined by users’ demands for the image filtering. In this thesis, \( 3 \times 3 \) window size was used. The common mobile window shapes contain the ring-shaped, cross, roundness, and square. The filtering effect is shown in Figure 2.
3.2. Image edge enhancement

Image edge enhancement is also called edge sharpening processing. The purpose of using this technology is to avoid image blurring caused by ray diffraction and image quality reduction caused by image format conversion or transmission or even subsequent troubles for binaryzation processing. The common image enhancement method is the Laplace’s operation, which can effectively increase image definition. According to the casting surface blurred image of this thesis, the Laplace’s operation was:

\[ \nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} \]  

(3)

The image processed by edge sharpening was:

\[ g = f - k \cdot \nabla^2 f \]  

(4)

k in formula couldn’t be oversized or undersized, relating to the diffusing effect. If it is undersized, it can’t sharpen. If it is oversized, it will result in image edge overshoot.

For computer images, formula (5) can be used to represent Laplace operator of dot (i, j), showing the sharpening image as formula (6). Therefore, it can be observed that dot (i, j) grey level minus the dot’s average grey value within the region to solve the Laplace operator of this dot. After testing for many times, the author determined to identify k as 1.

\[ \nabla^2 f = -5 \left\{ f(i,j) - \frac{1}{5} \left[ f(i+1, j) + f(i-1, j) + f(i, j+1) + f(i, j-1) + f(i,j) \right] \right\} \]  

(5)

\[ g(i, j) = 5 f(i, j) - f(i+1, j) - f(i-1, j) - f(i, j+1) - f(i, j-1) \]  

(6)

The above method was used to do edge sharpening for Figure 2(b) through median filtering to get Figure 3.
3.3. Binaryzation processing

Binaryzation processing is also called image segmentation, which divides image space into several areas and selects the useful part according to different application purposes. The threshold segmentation method is the most common and simplest image segmentation method, which divides images into some grades in accordance with different grey levels. The best threshold is utilized to set up the binaryzation images, ultimately obtaining the valuable region. The threshold segmentation method first sets up the segmented threshold. Then, the image pixel value is compared with the established threshold and also pixels are divided.

To set up the suitable segmentation threshold is the key issue of this method. Generally speaking, T is set up as the segmented threshold. The original image f(x, y) is defined as:

\[
\begin{align*}
h(x, y) &= \begin{cases} 
1 & f(x, y) \geq T \\
0 & f(x, y) < T 
\end{cases}
\end{align*}
\] (7)

through the image segmented by the threshold. Under the circumstance with the even ray of the casting surface roughness image, the following method can be used to automatically search for the suitable segmented threshold: determine the termination condition e and randomly select the segmented threshold T, calculate the mean pixel grey level u1 less than the random threshold and mean pixel grey level u2 more than the random threshold, and calculate T'= (u1+ u2). If there is |T' - T|<e, T' is the ultimate segmented threshold. Otherwise, T' is used as the measurement threshold for recalculation until it meets |T' - T|<e. According to the actual situation in this case, the ultimate segmented threshold was identified as 97. Moreover, Figure 3 was conducted binaryzation processing to get Figure 4.

4. Roughness characteristic parameter extraction

4.1. Mean and variance of the histogram

The image through the above technical processing has the special correspondence with the histogram with certain probability distribution. Hence, it is necessary to establish the roughness and texture element relationship through the casting surface image window texture analysis and element calculation. The histogram is a parameter to represent the casting surface texture thickness. The parameters, including the texture element and element permutation in the histogram, are used to represent the casting surface texture thickness. They are also key factors of constituting in texture characteristics and can be gained by observing surface images of different samples. The mathematical calculation formula for the mean and variance of the histogram is stated as follow:

\[
m = \frac{\sum z \cdot h(z)}{\sum h(z)} \] (8)

\[
\sigma^2 = \frac{\sum (z - m)^2 \cdot h(z)}{\sum h(z)} \] (9)

The larger mean of the histogram is, the rougher of the casting surface profile will be, vice versa. The larger variance of the histogram is, the larger change of casting surface texture result will be, vice versa.

4.2. The peak area of the unit surface

For the casting surface area with the same size, the number of peak valleys is inversely proportional to the mean area of the single peak. In other words, the more number of peak valleys is, the more exquisite of the casting surface profile will be, vice versa. Hence, as measuring the casting surface roughness, it can be represented by the unit peak area. In this thesis, the peak area of the unit surface
was defined as follows: the pixel number of the single peak with the grey level of 1 in the binaryzation image. The mathematical expression is:

\[ S = \frac{N}{A} \]  

(10)

Where, \( A \) is the characteristic region area of the standard sampling image. \( N \) is the number of the single peak.

4.3. Steepness

During the casting surface roughness image acquisition process, if the parallel light source is vertically radiated to the casting surface, images captured by a computer will have the higher grey level. The grey value in most areas of preprocessed images is 1, but the grey value at the connection of peak valleys will be 0. Hence, by combining with the casting surface acquisition image, the author in this thesis proposed the steepness concept of the casting surface. Steepness describes the inclination degree of casting surface peak valleys, but it can represent the casting surface roughness in the horizontal and vertical directions, showing some significance on studying the casting surface roughness. The mathematical expression of steepness is:

\[ \Delta = K \sum \frac{S_0}{S_1} \]  

(11)

5. Examples of the casting surface roughness image processing

In this thesis, 11 standard casting samples in the Table 1 were conducted the surface image acquisition by virtue of the devices as follows: the industrial personal computer, TY-800 image capture card, 1280*24bit black-white CCD camera, 100 times of optical microscope, and stable parallel light source, obtaining the roughness characteristic parameters in Table 1.

| Detected samples | Parameter Ra | Parameter Rz | m     | \( \delta^2 \) | S       | \( \Delta \) |
|------------------|--------------|--------------|-------|---------------|---------|-------------|
| TSz12.5          | -            | 12.5         | 103.8861 | 2501.6627    | 605.8473| 2.0001      |
| TSz25            | -            | 25.0         | 99.7023 | 2402.8839    | 2098.5237| 2.3911      |
| TSz50            | -            | 50           | 101.8256 | 2254.7941    | 11002.0793| 2.6704      |
| GPa6.3           | 6.3          | -            | 104.9801 | 2001.2139    | 301.4501| 4.5622      |
| GPa12.5          | 12.5         | -            | 104.5011 | 1398.5674    | 409.6697| 4.6011      |
| GPa25            | 25           | -            | 101.2019 | 1198.6354    | 1502.3563| 5.5371      |
| GPa50            | 50           | -            | 100.9987 | 852.4791     | 7506.9991| 5.5999      |
| TJa6.3           | 6.3          | -            | 108.3679 | 2100.3261    | 6.3010 | 0.8407      |
| TJa12.5          | 12.5         | -            | 104.3325 | 1796.2591    | 25.3610 | 1.9256      |
| TJa25            | 25           | -            | 103.8919 | 1501.8634    | 140.5551| 2.0994      |
| TJa50            | 50           | -            | 101.2560 | 1305.4484    | 560.1790| 3.4006      |

6. Conclusions

It could be observed from the analytical results that with the increase of two parameters, the variance and mean of the histogram were also increased, but as a whole, the variance and mean showed the trend change of reduction. For different materials with the same surface roughness, the variance of the histogram had more advantages than the mean as representing the roughness. With the increase of two parameters, steepness and the peak area of the unit surface showed the increase trend as a whole. For different materials with the same surface roughness, calculation of steepness had a great difference with the peak area of the unit surface, but these two characteristic parameters showed the increase trend. Such an analytical result conformed to the actual industrial detection data of surface roughness.
in 11 castings, verifying the application value of using the computer image processing technology in the casting surface roughness detection.

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