Implementation of Brinell hardness measurement device using Hough transform in Raspberry Pi 3

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Abstract

In Brinell hardness measurement, the diameter measurement of the indentation is an important process related to the measurement accuracy.

In this paper, a special image input device was designed to input the magnified image of the indentation to increase the accuracy of hardness measurement.

Then, a method for determining Brinell hardness according to the indentation diameter obtained by Hough transform on the input image was established and implemented as a device using a single-board computer Raspberry Pi 3.

The experimental results demonstrate that the designed measurement device can be used to provide the high accuracy and convenient measurement.

Keywords: Brinell, Hough transform, Image processing, Raspberry pi

1. Introduction

Brinell hardness measurement is a hardness test method based on the principle that when a steel ball of diameter **D** is placed on the test piece and pressed under a constant force, the depth of the indentation on the test piece surface is inversely proportional to the hardness.

In practice, a lever or hydraulic device is used to measure the indentation diameter (**d**) of a steel ball on a test piece by applying the force (**F**) required for the measurement for a certain time on a steel ball of diameter **D**, and on the basis of this result, the hardness of a test piece to be measured is determined [3, 4].

In the Fig.1, **p** represents the depth at which the steel ball was introduced.

From the figure, the Brinell hardness number is calculated by the following equation:

$$HB = \frac{2F}{\pi D\left(D-\sqrt{D^2-d^2}\right)} \qquad (1)$$

HB-Hardness of Brinell

F-force pressing the ball (kgf)

D- diameter of steel ball (mm)

d-Average diameter of indentation (mm) $d=\frac{d_1+d_2}{2}$

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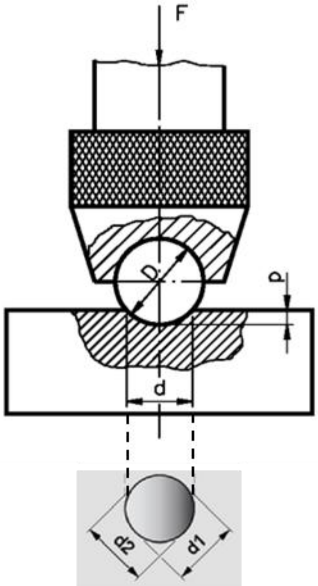

Fig. 1 Brinell hardness measurement schematic

Brinell hardness measurements can be used to measure hardness of various materials, such as metals and wood, and the measurement values are given as the ratio of the pressing force to the dented area of a closed curve type.

The diameter of the steel ball is usually 2.5, 5, and 10 mm, and the magnitude of pressing force on it is also varied according to the diameter of the ball. The indentation diameter is in the range of 0.24**D** to 0.6**D** (mm).

In this paper, we investigated a 10 mm steel ball, which is widely used for hardness measurement of metals.

The pressing force varies with the measured test piece when the diameter of the steel ball is 10 mm, but the measured force is set to 3000 kgf for normal steel and 1000 kgf or 500 kgf for copper and aluminum alloys.

At that time, the indentation diameter of steel ball on the test piece shall be in the range of 2.4~6 mm.

The kernel in Brinell hardness test is to measure precisely the indentation diameter produced by the steel ball, and the accuracy of Brinell hardness number is determined according to this.

The general Brinell hardness test procedure is shown in Fig2.

In the past, the indentation diameter of the steel ball on the test piece was estimated by the degree of agreement between the scale and the edge of the indentation with one eye using a calibrated microscope at an interval of 0.05 mm.

This method can reduce measurement accuracy depending on the external light conditions, the visual status and the functional level of a measuring man, and it is not possible to improve the objectivity of the measurement or the measurement speed.

From this, the several methods for increasing the accuracy of Brinell hardness measurement have presented, and there are two types of fully computerized and automated hardness measurement devices and semi-automated hardness measurement devices that only update indentation diameter measurement of existing equipment.

Fully computerized and automated Brinell hardness measurement devices offer high levels of measurement convenience and accuracy, but they are very expensive [19].

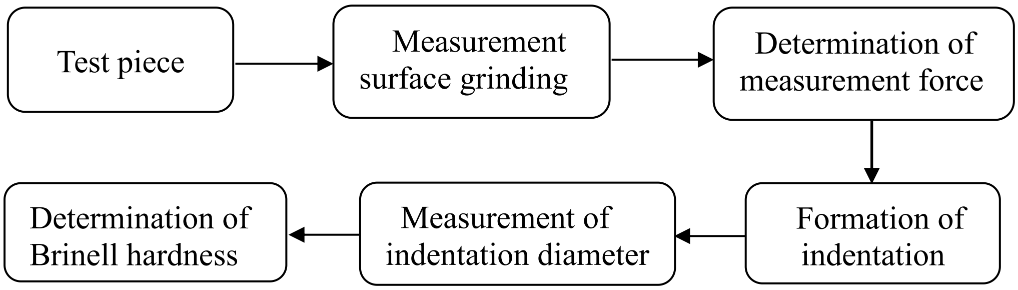

Fig. 2 General Brinell hardness measurement procedure

Semi-automated hardness measurement devices are proposed to improve measurement accuracy at low cost and determine the hardness number based on diameter that is measured by image processing about the indentation image of a steel ball inputting through a camera [18].

The main idea is to increase the accuracy of image processing and to reduce the cost of the processing unit used for measurement.

Currently, various methods have been proposed to improve the accuracy of image processing using desktop or laptop computers.

The methods based on the region segmentation are difficult to improve the accuracy of diameter measurement if the edge is non-uniform [5-11].

The convolutional neural network or DNN approach requires high-performance processor and large number of test data [12,13].

The method of estimating the diameter by using only circular detection using Hough transform will result in low measurement accuracy in the case of the elliptical indentation [21].

In this paper we designed a special image input device using USB camera, established a method to increase the accuracy of indentation measurement by computing the minimum distance between points on a detected circumference by Hough transform and detected edge points by Canny operator, and implemented a measurement device using Raspberry Pi 3.

2. Design of Brinell hardness measurement device using Hough transform

1) Special image input device design

(1) Determination of design parameters of optical system to improve measurement accuracy

We input the indentation image on the test piece and measure the indentation diameter by image processing and display the corresponding hardness numbers in Brinell hardness measurement using image processing.

In image processing, all parameters are extracted from the input image, so the processing accuracy depends on the quality of the input image.

Furthermore, since the object to be processed in the input image is a small circle with a diameter of 2-6 mm, the quality of the image inputted through the camera must be high to increase the measurement accuracy.

We designed a lens with a magnification of 18 and a focal length of 60 mm to represent 720 pixels with a maximum diameter of 6 mm to be measured using a USB camera with a resolution of 1024 x 768 pixel.

Thus, 0.01 mm appears as 1.2 pixels, increasing the measurement accuracy.

The LED is also built-in to provide self-illumination, which improves image quality and overcomes the disadvantages of low measurement accuracy due to external conditions.

(2) Tube making with self-lighting

If the distance between the lens and the measuring surface is not always constant, the indentation images with the same diameter are inputted at different magnifications so that the measurement accuracy decreases.

Also, the influence of external light and the light reflected from the measurement surface will cause a lot of noise in the image, which will negatively affect the measurement accuracy.

To prevent this drawback, a self-illuminated tube was designed and fabricated to reduce th e influence of external light and to maintain a constant distance between the lens and the meas uring surface.

The structure of the tube designed to input the indentation image is shown in Fig. 3.

As shown in Fig. 3, the tube keeps always the constant distance between the lens and the measuring surface so that the indentation image is magnified at the same magnification.

The height of the tube was 120 mm, the diameter was 60 mm, the diameter of the portion that an indentation image was inputted was 12 mm, twice the maximum diameter, and the height from the measuring surface to the lens was designed to be 60 mm.

Also, self-illumination was installed to reduce the influence of external light and the noise reflected from the surfaces around the indentation.

Two LEDs were used as the self-illumination.

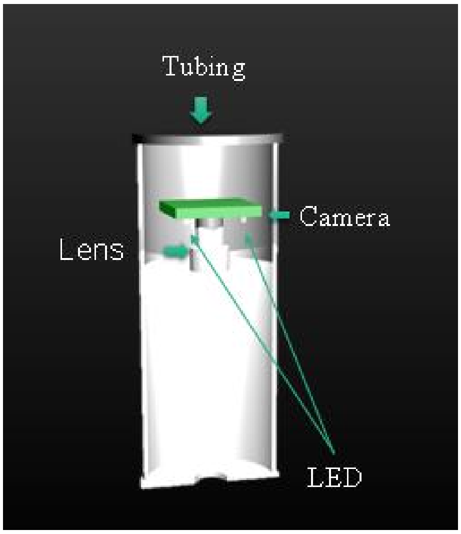

Fig. 3 Internal structure of the designed tube

2) Brinell hardness measurement method using Hough transform

We used the Hough transform to measure the diameter of the indentation appearing as a ci rcle. The Hough transform is a practical transform that detects a set of pixels that can be consi dered to form a particular pattern (line, circle, or general pattern) in the image space by mappi ng them to a parameter feature (voting) space [1,2,15].

The Hough transform uses the global property of the image and is a method that connects t he edge pixels to form the closed edge of the region.

Given the known shape of the region, using the Hough transform, we can easily obtain a edge curve and connect the discontinuous edge pixel points.

The method of detecting circles using Hough transform is as follows [14-16].

In general, the equation of the circle is given by Eq. 2.

$$(x-a)^2+(y-b)^2=r^2 \tag{2}$$

where **(x, y)** is the position of the pixel, **r** is the radius of the circle, and **(a, b)** is the center coordinate of the circle.

There are three parameters **a, b** and **r** in a circle, so there must be a three-dimensional cum ulative set **C** in the parameter space, and the element can be written as **C (a, b, r)**.

By Eq.2, we can calculate **r** by changing **a** and **b** in order and calculate the cumulative **C (a, b, r) = C (a, b, r) + 1** for **C**.

In general, if we detect a circle in given image, we can convert the problem into two-dime nsional parameter space because the radius **r** is given.

In the parameter space, we define the range of **A** and **B** (usually chosen as the size of the i mage) and set the accumulator **C (a, b) = 0**.

By changing **a** to the point **(x, y)** on the circle of the image space, and computing **b** satisfy ing Eq. 3, we will draw a circle in the parameter space.

$$b = y \pm sqrt\,(r^2 - (x-a)^2) \qquad (3)$$

In the same way, for all points on a circle of the image space, if we map them to the param eter space, all circles intersect at a point (the largest cumulative value at this point), and the va lue **a** and **b** of this point are the central coordinates of the existent circle in the image space.

The real indentation in image inputted through the camera is only one from measurement r equirements. Therefore, among the several candidate circles detected by the Hough transform, according to the size of the position and diameter, we are the pseudo circles and find a circle corresponding to the real indentation.

In general, the indentations are obtained as ellipses, although they are often found in the right circles. So, we found the nearest edge pixel points of the indentation from the points on a detected circumference by the Hough transform, and then found a minimum circumscribed quadrangle to them.

Then, we found a ellipse responding to transversal and longitudinal length of a minimum circumscribed quadrangle, and extracted a real edge of the indentation.

The steps for measuring the diameter of the indentation and calculating the Brinell hardnes s number using the Hough transform are as follows:

Step 1: Select the force used for forming the indentation in the Brinell hardness measurem ent.

Step 2: Input the indentation using the designed special image input device.

Step 3: Gaussian smoothing filtering of the input image is performed to remove noise.

Step 4: Then, we extract the edge of the indentation using the Canny operator, perform the morphological opening and closing operation to connect the broken edge and re move the isolated noise [1,2].

Step 5: The Hough transform on the edge image is performed to determine the closest circl e to the indentation by using the center position and the size of diameter among th e circles detected.

Step 6: We find a minimum circumscribed quadrangle by finding the edge pixels of the ne arest indentation from the detected circumferential points, then calculate its transv ersal and longitudinal diameters and average diameter.

Step 7: Calculate and display the Brinell hardness number corresponding to the average di ameter of the measured indentation.

In this way, we measured the diameter of the indentation on the test piece and calculated a nd displayed automatically Brinell hardness numbers corresponding to it.

3. Results

To perform Brinell hardness measurement, we developed a program by installing Qt 5.7 and OpenCV 4.1 on a single-board computer Raspberry Pi 3 B+ [2, 19].

A 3.5-inch touch LCD was used to display the images and four 3.7V Li-batteries were connected in series to provide self-powering [20].

The special image input device was designed using an 18-fold magnification lens and two LEDs, a tube, an USB camera with a resolution of 1024 x 768 pixel.

For the experiments, 10 test pieces with indentations in range of 2.5 to 5.8 mm were used.

Brinell hardness measurement device used in experiment and the measured results for 4.16 mm and 3.38mm indentation obtained by a force of 500 kgf are shown in Fig. 4.

a) Brinell hardness measurement device

b) 4.16mm indentation measurement results

c) 3.38mm indentation measurement results

Fig. 4 Brinell hardness measurement device and measurement results

In the Fig. 4, the red line is a circle detected by the Hough transform and the green line is the ellipse responding to a minimum circumscribed quadrangle found by computing the minim um distance between points on a detected circumference by Hough transform and detected ed ge pixel points. From the figure, we can know that the method of paper can detect the indentat ion accurately even if some edges are cut and the Brinell hardness number for the indentation diameter is accurate too. As shown in Fig. 4.c), we can also know that if only the Hough trans form is performed, the false detection results can be obtained in some cases, but if the method of paper is used, the indentation can accurately be detected.

The measurement results of test pieces with 10 different diameters are shown in Table 1. As shown in Table 1, we can know that the average measurement error of the proposed metho d is small compared to other methods.

The use of the Brinell hardness measurement device designed in proposed method allows f or the accuracy and objectivity of the measurement.

Table 1 Measuring analysis table

No	Diameter to be measured	Diameter measured by proposed method (mm)	Macroscopically measured diameter	Method by region segmentation
1	2.55	2.55	2.6	2.52
2	2.67	2.66	2.7	2.7
3	2.73	2.75	2.7	2.75
4	2.83	2.85	2.85	2.81
5	3.38	3.38	3.4	3.39
6	3.53	3.52	3.5	3.55
7	4.16	4.16	4.2	4.18
8	4.27	4.25	4.25	4.28
9	5.02	5.03	5	5
10	5.85	5.85	5.9	5.86
Average error		0.01	0.03	0.02

4. Conclusion

We solved the following problems by developing a Brinell hardness measurement device using the proposed method in the paper.

First, the accuracy and objectivity of Brinell hardness measurement was improved.

Second, we designed a portable device using a single-board computer Raspberry Pi 3, so t hat we provided the convenience of the measurement.

Experimental results show that the proposed method can accurately measure Brinell hardn ess.

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