Vickers hardness measurement by using convolutional neural network

Y Tanaka¹, Y Seino¹ and K Hattori¹

¹ National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology (NMIJ-AIST), Tsukuba, Japan

E-mail: yukimi.tanaka@aist.go.jp

Abstract. Vickers hardness is still measured by human operators for accurate measurement, because automatic measurement sometimes shows poor accuracy due to the slight difference in contrast and shape of the indentation. In this study, for more accurate Vickers hardness automatic measurement, we propose a novel technique by using convolutional neural network (CNN). We examine the usefulness of our novel technique, compared with manual measurement and image processing measurement. The hardness values measured by the CNN method suggest being close to the values measured manually, and more accurate than the image processing method.

1. Introduction

Hardness testing is often used to evaluate the material strength. Vickers hardness is one of the most useful hardness value in many areas. In the Vickers hardness testing [1], a diamond pyramidal indenter is forced into the surface of a test piece, and the hardness value is calculated from the diagonal length of the indentation. For many years, the diagonal length has been measured by human operators through microscopes. To reduce the time and effort of these operators, image processing techniques have been proposed to measure the diagonal length automatically [2, 3]. However, the diagonal length is still measured by human operators for accurate measurement, because automatic measurement sometimes shows poor accuracy. One probable reason for the poor accuracy is that the binarization and segmentation in image processing do not work well, because of the slight difference in intensity, contrast and shape of the indentation image. Therefore, the image processing sometimes fails to recognize the correct indentation-corners, even though human eyes can recognize the corners properly. In image processing, it is difficult to extract all feature quantity for recognition of the indentation-corner in the same way as human eyes. In recent years, deep learning has been developed to extract necessary feature quantity automatically for object recognition. Convolutional neural network (CNN) that is a kind of deep learning, is often used for the image analysis to classify many objects or detect the region of objects [4]. This study proposes more accurate automatic measurement of Vickers hardness by using CNN. We examined the usefulness of our novel method by comparing with the measurement of human operator and the method of image processing.

2. Methods

The diagonal length of the indentation was measured by three ways, the measurement by a human operator, image processing (IP) method and CNN method. We measured the indentation of steel Vickers standard blocks (nominal values are 200 HV, 600 HV and 900 HV) that were applied 9.807 N, 98.07 N and 294.2 N force. All measurement was performed through the CCD camera connected to the
microscope with movable stage. The camera connected to the microscope captures the whole image of indentation with resolution of 1280 × 960 pixels. The manual measurement was performed with measuring the travel of the microscope stage.

Both IP method and CNN method were programmed in Python. In the IP method, OpenCV library was used to find the indentation-corner. First, the images were binarized by using Otsu threshold method [5]. Second, some areas and contours were automatically detected, however, that including small areas due to the noise of the image. Hence, we chose the area with maximum size as the indentation. Third, the corners of the contour were detected by using min- and max-function as the corners of the indentation, and the difference of them was calculated.

Figure 1 indicates the schematic diagram showing CNN method. First, CNN was trained. We detected the corner of the indentation roughly, and captured 50 × 50 pixels grayscale images around the corner by using IP. The images were rotated so that the corners are in the same direction. Inputs were the 50 × 50 pixels images, and output was the distance (pixel) from the left end of the image to the corner of the indentation. CNN was trained 200 epochs by the dataset that contained 1920 images and the distance corresponding to each image measured by a human operator. Training images contained the indentation of standard blocks (nominal values are 200, 600 and 900 HV) that were applied 9.807 N, 98.07 N and 294.2 N force. To improve the accuracy of the model, the dataset also included the images that are varied the intensity and the position of the corner intentionally. Figure 2 shows the architecture of CNN in this study. Convolutional layers extract the feature by the convolution of the input images with the 5 × 5 filter that varied with training. For example, first convolutional layers indicate the convolution of the input image with 16 different filters. Pooling layers reduce the amount of information and leave the essential feature. Free connected layers are connected data of the last pooling layer and output the distance from the left end to the corner. Through the training, the weighting values of the filters and the neural networks are optimized. After the CNN training, the diagonal length of indentation

![Figure 1. Schematic diagram showing the measurement of indentation size by using CNN](image1)

![Figure 2. Architecture of CNN](image2)
was predicted from the output of CNN and the position of the input image. The developed method is also applicable if the whole indentation does not fit into a single image.

3. Result and discussion

Figure 3 shows the example of the recognition of the indentation-corner by using IP method and CNN method. As shown in these images, the CNN method was seemed to be better than the IP method. The difference between IP and CNN is 4 pixels only for single corner. That is about 0.6 \( \mu m \) in this case and is greater than 1.0 \( \mu m \) when we measure the diagonal length. This value seems to be a considerably large error to measure the Vickers hardness with the small size of indentation.

Table 1 shows the diagonal length (d1 and d2) and Vickers hardness that were measured by three ways. Figure 4 shows the mean of the relative error of IP method and CNN method with respect to the manual measurement, assuming the value of manual measurement is correct. The relative error is calculated by following equation:

\[
\text{Relative error} (%) = \left| \frac{x_{\text{auto}} - x_{\text{manual}}}{x_{\text{manual}}} \right| \times 100
\]

where \( x \) indicates the comparing value such as the diagonal length and hardness. The relative error of CNN method was lower than that of IP method. Therefore, the hardness values that were measured by the CNN method were close to manual measurement and suggested being more accurate than IP method. In IP method, the processing such as binarization and segmentation precludes the information that is indifferent to detect the indentation-corner. If these processing does not work well due to the slight difference in contrast or shape of the indentation, the necessary information for detecting the indentation-corner is also precluded. Consequently, it is assumed that IP method sometimes fails to recognize the correct indentation-corners. Conversely, CNN method automatically extracts the necessary feature to detect the indentation-corner by using the whole of information of the image. It is

![Figure 3. Example of the recognition of the indentation-corner (200HV30)](image-url)

Table 1. The Vickers hardness values measured by three ways

| Nominal | IP | Automatic measurement | Manual | CNN | Manual |
|---------|----|-----------------------|--------|-----|--------|
| d1 (\( \mu m \)) | d2 (\( \mu m \)) | Hardness | d1 (\( \mu m \)) | d2 (\( \mu m \)) | Hardness |
| 900HV | 247.99 | 247.74 | 905.49 | 248.85 | 248.33 | 900.20 |
| 247.62 | 247.21 | 908.80 | 248.37 | 247.80 | 903.88 |
| 142.79 | 142.32 | 912.55 | 143.48 | 143.02 | 903.66 |
| 142.84 | 142.53 | 910.83 | 143.48 | 143.18 | 902.64 |
| 44.49 | 44.12 | 944.72 | 44.87 | 44.49 | 928.84 |
| 44.33 | 44.06 | 949.34 | 44.76 | 44.49 | 931.09 |
| 301.27 | 300.58 | 614.34 | 302.13 | 301.39 | 610.95 |
| 301.63 | 300.84 | 613.08 | 302.10 | 301.43 | 610.92 |
| 172.96 | 172.46 | 621.69 | 173.71 | 173.10 | 616.69 |
| 172.80 | 172.67 | 621.50 | 173.55 | 173.37 | 616.30 |
| 54.28 | 55.11 | 619.87 | 54.55 | 55.27 | 615.02 |
| 54.10 | 54.46 | 629.75 | 54.23 | 54.62 | 626.02 |
| 200HV | 509.06 | 507.18 | 215.47 | 510.09 | 508.15 | 214.62 |
| 509.66 | 508.19 | 214.37 | 510.90 | 510.48 | 213.31 |
| 293.95 | 293.30 | 215.08 | 295.24 | 293.46 | 214.03 |
| 294.48 | 292.48 | 215.30 | 294.85 | 292.97 | 214.67 |
| 92.32 | 92.48 | 217.17 | 92.75 | 93.30 | 214.29 |
| 92.81 | 92.92 | 215.04 | 92.86 | 93.19 | 214.29 |

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considered that this technique is similar to the measurement by human operators. For these reasons, CNN method suggests being more accurate measurement than IP method.

Generally, the experienced and skilled operators are required to measure Vickers hardness more accurately, because it is difficult to fit the marked line with the corner of the indentation. Additionally, there are variance and deviation of the measurement even in the experienced operators each other [6]. It is undesirable that the measurement is depended on the skills of the operator. The novel technique we proposed is useful to measure Vickers hardness more accurately and automatically. However, if CNN is trained by the only one operator, it is not clear whether the result of CNN is correct or not, because the measurement for training contains the operator biases. Training of CNN by many experienced operators is more desirable.

It would be possible that the hardness measurement with CNN can solve several problems in the measurement of the indentation size. It was reported that the apparent diagonal length is varied with the focal position and the brightness of microscopes [6]. The method with CNN may be applicable to measure the diagonal length accurately even if the focus and brightness are varied a little. Additionally, this method can be also applied to actual products that is difficult to recognize the indentation due to their rough surface. It is expected that the method with CNN enables to reduce the time and effort of human operators as well as the error of the hardness measurement.

4. Conclusion

In this study, we proposed a novel method with CNN to measure the diagonal length of the indentation more accurately. We considered the usefulness of our novel technique by comparing with manual measurement and automatic measurement of image processing. The Vickers hardness measured by the method with CNN were close to the values by the measurement with the human operator, and showed being more accurate than image processing method. The method with CNN is suggested to be useful to measure the Vickers hardness more accurately and automatically.

References

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