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BRINELL AND VICKERS HARDNESS MEASUREMENT USING IMAGE PROCESSING AND ANALYSIS TECHNIQUES

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ABSTRACT

Mechanical hardness testing is fundamental in the evaluation of the mechanical properties of metallic materials due to the fact that the hardness values allow one to determine the wear resistance of the material involved, as well as the approximate values of its ductility, flow tension, among a number of other key characteristics. As a result, the main objective of the present work has been the development and analysis of a computational methodology capable of determining the Brinell and Vickers hardness value from hardness indentation images, which is based on image processing and analysis algorithms . In order to validate the methodology which has been developed, comparisons of the results resulting from the consideration of ten indentation image samples obtained through the conventional manual hardness measurement approach and a computational methodology have been carried out. This analysis allows one to conclude that the semi-automatic measurement of Vickers and Brinell hardness by the computational approach is easier, faster and less depended on the operator's subjectivity.

KEYWORDS: Testing and evaluation, Computational Vision, Image segmentation, Histogram binarization, Region growing, Indentation images, Manual hardness measurement, Computational system.

1 Introduction

Mechanical hardness testing is commonly used to evaluate some of the key mechanical properties of materials. For example, the hardness value of a metallic material enables the estimation of its wear resistance, ductility, flow and cut tension.

Hardness is defined as the material's resistance to the indentation of an object; that is, to the impression that the object causes on the materials' surface. Moreover, in Material Science hardness is defined as representing the materials' capacity of resisting permanent deformations, which is proportional to the bonding strength of its atoms, [1].

Brinell and Vickers hardness testing are the hardness testing techniques involving metallic materials which are most commonly used, [2-4]. These techniques will be presented in the following two sections.

Throughout this study the hardness testing machine Vebwerkstoffprüfmaschinen Leipzig ZD-20 has been used to carry out all experimental work, Figure 1. Its display follows the specifications suggested by the ASTM standard E140-05e1, [5], and it permits the full and appropriate focused visualization of the indentation region involved that is obtained by its internal microscope. In addition to these visual requirements, one must determine the correct value of the load applied on the material to be tested, which should be in accordance with its mechanical properties.

In hardness testing, the conventional manual measurement is a very interpretive and subjective process, since the reading of the values required for the hardness calculus from the indentation on the surface of the materials depends on the operators' viewpoint (the parallax effect) and as well as on his experience. In addition, it should be noted that the operators' fatigue or tiredness due to, for example, a high number of tests performed, may also result in the reading of incorrect values and consequently, in obtaining the incorrect hardness values.

In Computational Vision, when one aims to extract high level information from the input images, as in the case of obtaining robust and reliable descriptors and measurements, tasks of image analysis are considered. However, for the success of the desired image analysis, the segmentation step, that is the identification of the regions presented in the input images, is extremely important as it can severely comprise the required analysis, [6]. Generally, the image segmentation is driven by the application in cause, [6-8], and nowadays there are several methods to accomplish this, such as those based on deformable models, statistical modeling, physical modeling, deformable templates, variational and watershed approaches, and neural networks, see, for example, [9-13].

In this context, this work's main objective has been to develop and analyze a semi-automatic methodology, capable of determining the Vickers and Brinell hardness testing values from indentation images. To accomplish this goal, techniques of image processing and analysis have been used, such as histogram binarization and region growing. These computational techniques can be successfully applied to several image segmentation tasks and, contrary to those used by Yao and Fang in [14], they are easy to implement and have reduced computational requirements. In fact, very often simple techniques of image processing and analysis can successfully solve important tasks. For example, in [15] the Vickers hardness testing from indentation images case is suitably accomplished by using image binarization by threshold value. Despite its simplicity, this approach is sensitive to the noise commonly presented in the indentation images. This drawback is overcome by the proposed methodology by using the region growing technique.

The results obtained from the developed methodology were compared with those obtained by the conventional Vickers and Brinell hardness manual measurement approach, thereby making it possible to evaluate its efficiency and effectiveness.

This paper is structured as follows: in next two sections, the Vickers and Brinell hardness testing techniques are introduced; in the fourth section, the techniques of image processing and analysis such as histogram binarization and region growing, are presented; the experimental results which have been obtained are presented in the fifth section; finally, in sixth and final section, the conclusions and future work perspectives are addressed.

2 Vickers hardness testing

In 1925, the Vickers hardness testing technique was proposed by Smith and Sandland. It received this designation due to the fact that they were working in a company called Vickers-Armstrong. Like other hardness measurement methods, it also uses an indenter that leaves an impression on the material test sample, usually referred to as indentation.

The Vickers hardness value depends directly on the load applied and the region formed by the indentation built on the material's testing surface. This hardness testing can be applied to any type of material because a diamond indenter is used, which is therefore extremely hard and resistant. Thus, it can be used with materials which have a different hardness and dimensions, in addition to being applied to irregular materials, ceramics and other types of materials, [16].

To perform the Vickers hardness testing, the material sample must present a testing surface which has no oxidation, roughness, lubricants and other contaminations. In addition, the testing surface must be flat and well finished so the operator can be completely certain as to the obtained measures. Furthermore, one must ensure that the sample does not have deformations on the opposite side of the one that is going to be tested and one must guarantee that the testing equipment does not suffer vibrations or impacts, [3].

Usually, the Vickers hardness testing technique must be accomplished with the application of loads that vary from 5 to 120 kgf, and the actuation time of the indenter onto the material sample must be between 10 and 15 seconds. As has been previously referred to, these parameters must be defined according to the mechanical properties of the material that is to be tested. The Vickers hardness is expressed in HV (Hardness Vickers) units, [17, 18].

The indenter used in the Vickers hardness testing process has the geometrical configuration of a square pyramid made of a diamond with an angle of 136^{o} between opposing faces. After the indenter actuation, the material sample presents an indentation region with the approximate shape of a regular lozenge, Figure 2. Then, in the conventional manual measurement approach, the diagonals of the indentation lozenge are measured through the testing machine's display which adopts a millesimal scale. Subsequently, the values d_1 and d_2, of the diagonals, Figure 2, are used in the determination of the mean diagonal value (D_{mean}) that enables the calculus of the hardness value by using the following equation:

$$HV = \frac{1.8544F}{D_{mean}^2}, \quad (1)$$

where F is the applied load in kgf and D_{mean} is in mm.

Besides using Equation (1), the ASTM E140-05e1 standard table, [5], can also be used in order to obtain the associated Vickers hardness value from the values of the mean indentation diagonal and from the load applied.

3 Brinell hardness testing

The Brinell hardness testing method was the first hardness testing method to be used in the industry. Usually, this testing process takes between 10 to 30 seconds and is accomplished by pressing a spherical indenter of a certain diameter against the testing surface of the material sample. The load applied is not superior to 3000 kgf and the hardness value is provided in HB (Hardness Brinell) units.

The Brinell hardness testing uses indenters made of steel to test materials with hardness values of up to 350 HB, or of hard metal (tungsten) to test materials with hardness values from 350 to 650 HB. The choice of the indenter to be used is directly related to the mechanical properties of the material to be analyzed.

Generally, the Brinell hardness testing uses spheres with diameters of 2.5 (the most common value that corresponds to a load of 187.5 kgf), 5 and 10 mm.

To carry out Brinell testing, the material which is to be analyzed must present a testing surface which is free from oxidation, roughness, lubricants and other contaminations. This surface must also be flat and well finished so the operator can be certain of the quality of the obtained values. One should also ensure that deformations are not made on the opposite surface and therefore, the sample to be tested must possess a thickness eight times superior to the indentation diameter, [1]. In addition, vibrations and impacts on the testing equipment must be avoided at all costs.

In manual Brinell hardness testing, the diameters of the indenters' impression on the material test sample must be measured in the testing machine's display and the obtained values must be converted into the associated Brinell hardness using the ASTM E92-82(2003)e2 standard table, [17, 18, 19]. For this conversion, the mean diameter required, D_{mean}, is the average of the diameters obtained from the impression involved, d_1 and d_2, Figure 3. Using the value of D_{mean} the associated Brinell hardness value can also be obtained by using the equation:

$$HB = \frac{2F}{\pi D\left(D - \sqrt{D^2 - D_{mean}^2}\right)}, \quad (2)$$

where F is the force applied in kgf and D the diameter in mm of the spherical indenter used.

4 Image Processing and Analysis

In this section the techniques considered by the developed computational methodology to obtain the Vickers and Brinell hardness values from indentation images are briefly presented: namely, image binarization and histogram, and region growing.

4.1 Image binarization and histogram

The main objective of an image binarization task is to transform the input image, which is originally in grey or in color levels, into the correspondent binary image, that only has two levels: black and white, [19].

The histogram of an image represents its grey or color level distribution, and can provide useful information so as to obtain several image processing operations, such as image enhancement, contrasting and segmentation, [19]. For a common height bits greyscale image, the histogram is usually represented by a bar graph that shows the possible grey levels, varying from 0 (zero) to 255, in the abscissa axis and the amount of pixels associated with each grey level in the ordinate axis.

As has been previously referred to, some problems related to image processing and analysis are often solved by using the image histogram, which is justified by the fact that homogeneous objects frequently have similar grey levels in all of their image regions. For example, the segmentation of objects represented in greyscale images can easily be performed by image binarization if the suitable threshold value can be obtained from the involved image's histogram through the identification of the grey level that separates the two most distinct peaks presented in the associated histogram, [19, 20]. Frequently, that threshold value can be identified automatically by using, for example, the Otsu threshold method, [20], or the threshold method proposed by Johannsen, [21], which has been used throughout this work.

In Figure 4, a Brinell hardness indentation image and the associated histogram are presented. By observing that histogram, one can see that there are two peak concentration areas, one located on the left-hand side and the other on the right-hand side, which represents two different image areas: the indentation region and the image background, respectively.

In this work, following the image segmentation phase, the region growing technique which is used to obtain an indentation region free of noise and imperfections that are often acquired in the image acquisition and preparation of the samples process is then applied.

4.2 Region growing

Region growing is a technique which is applied in image processing so as to associate pixels of interesting regions presented in images. This association is initiated through the identification of seeds in the desired regions, which are then spread throughout the image considering for that the properties that the neighbor pixels must present, [22].

The expansion of the regions presented in an input image can be obtained by using local criteria and a seed in the desired region, or by considering global criteria and seeds distributed in different regions. Additionally, in the merge-split technique, regions may be split or merged, using structured graphs, among a number of other approaches, [23, 24].

For the application of the region growing technique, a region of interest (*ROI*) is initially defined that may be subdivided into a number of *n* sub-regions ROI_1, ROI_2,..., ROI_n, [19, 23, 24]. The equation to be considered in the application of the region growing technique is:

$$ROI = \bigcup_{i=1}^{n} R_i \ , \qquad (3)$$

where *ROI* indicates that the desired region must be complete, R_i is a region connected to $i = 1, 2, \ldots, n$, in which $R_i \cap R_{OI} = \varnothing$ for all i.

In this work, the region growing technique has been applied to the hardness indentation region and when this has been done, Figure 5, the indentation diagonals which are required are then calculated, Figures 2 and 3. As is shown in those figures, in order to calculate the diagonal values, it is necessary to identify the diagonal endpoints: A, B, C and D. Point A is determined by performing a scanning of the indentation region through the pixel that has the highest coordinated value along the *yy* axis, while point B is considered to be the pixel that has the lowest value along the same axis. In the same scanning process, point C is identified as being the pixel that has the lowest coordinate value along the *xx* axis, while point D is considered to be the pixel that has the highest coordinate value along the same axis.

5 Experimental results

The adopted computational methodology was implemented in C^{++} programming language in order to build a dedicated computational system capable of obtaining the Vickers/Brinell hardness testing values from indentation images in an easy, rapid and objective manner.

To perform the Vickers/Brinell hardness testing technique, one must first metallographically prepare the involved material sample and assure that the testing surface is completely polished. In order to use the developed computational system, the associated indentation image should be obtained through the use of an optical microscope. Subsequently, the integrated techniques of image processing and analysis should be applied.

To use the developed system in hardness testing, one must open the indentation image and then click on the indentation region, Figure 4. Next, the original image is automatically binarized after which the region growing technique is applied. Finally, the required diagonal values are calculated. To obtain the associated hardness testing value, the value of the load applied must be inputted into the system, as well as the scale value used to obtain the indentation image. Finally, the desired type of hardness testing, Vickers or Brinell, must be selected and introduced into the system's interface so the corresponding hardness value can be presented.

An example of the use of the computational system to obtain the Vickers hardness testing value from an indentation image is shown in Figure 6. In this Figure, one can see an original indentation image, the identified indentation area (in red) and the hardness value found. Similarly, Figure 7 shows an original Brinell hardness indentation image and the result obtained by using the developed system.

In the experimental work that has been carried out, in the case of the Vickers hardness testing process a diamond indenter and a load of 100 kgf were applied, whereas in the case of the Brinell hardness testing process a sphere indenter with a diameter of 2.5 mm and a load of 50 kgf were used.

As testing samples standard steel blocks of known and certified hardness values were considered. Thus, in the Vickers hardness testing process a block with a hardness value equal to 436 HV was used while the Brinell hardness testing process employed a block of 173 HB. For each block, ten indentations were performed and the associated hardness values were obtained through the use of the conventional manual approach and the computational system, Tables 1 and 2.

When analyzing the experimental results, it is possible to notice that the difference between the average values obtained using the manual measurement approach and the computational system for the Vickers hardness testing technique was equal to 5.97 HV, whereas in the case of the Brinell hardness testing it corresponded to 0.26 HB. Considering that the hardness testing values were obtained using standard blocks with certified hardness values equal to 436 HV and 173 HB respectively as samples, one may verify that the average values obtained using the computational system are closer to the real values than those obtained through the conventional manual approach.

6 Conclusions and future work

The manual measurement in the Vickers/Brinell material hardness testing technique is a very wearisome process, and very dependent on the operator’s subjectivity, more specifically on the reading of the indentation diagonals, which is consequently highly prone to errors.

In order to make material hardness testing possible in a more accurate, rapid and less subjective manner, this work has developed a computational methodology, based on techniques of image processing and analysis, more particularly on techniques of histogram binarization and region growing. These techniques have been implemented and integrated in a new semi-automatical computational system dedicated to obtaining the Vickers/Brinell hardness testing values from indentation images.

Currently, this novel system has been integrated in a former model of a hardness testing machine in which a digital camera has been installed, in order to enable the online acquisition, processing and analysis of indentation images.
The Vickers/Brinell hardness testing process which applies the computational system which has been developed, obtains satisfactory results and is very quick. Furthermore, the system considerably reduces the operator's subjectivity.
In the experiments that have been carried out, the mean hardness values obtained by the developed system were superior to the associated values obtained through the manual measurement approach. Despite the fact that the system accuracy for the Brinell hardness testing may already be considered as being good and superior to the accuracy resulting from a manual approach (standard deviation of 1.88 against 2.97, respectively), the system accuracy for the Vickers hardness testing process did not measure up to the accuracy resulting from the manual procedure (standard deviation of 11.32 against 5.04, respectively). Thus, in the near future, the accuracy of the system which has been developed will be improved; mainly, by ameliorating the measurement process of the required diagonals. As such, the interpolation of the indentation region borders' pixels will be carried out, thereby improving the robustness of the system to noisy and outsider pixels.

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FIGURE CAPTIONS

Figure 1: The hardness testing machine used (on the left) and its display (on the right).

Figure 2: Considered diagonals, d_1 and d_2, in the calculus of the Vickers hardness values.

Figure 3: Considered diameters, d_1 and d_2, in the calculus of the Brinell hardness values.

Figure 4: An original image of a Brinell hardness indentation a) and its histogram b).

Figure 5: Processing of a Vickers hardness indentation image: a) original image, b) binarized resultant image and c) resultant image after region growing.

Figure 6: An original image of a Vickers hardness indentation a) and the resulting image and hardness value b) using the developed computational system.

Figure 7: An original image of a Brinell hardness indentation a) and the resultant image and hardness value b) using the developed computational system.

TABLE CAPTIONS

Table 1: The Vickers hardness values and associated errors obtained, in relation to the standard steel block of 436 HV which has been used, using the manual approach and the computational system.

Table 2: The Brinell hardness values and associated errors obtained, in relation to the standard steel block of 172 HB used, using the manual approach and the computational system.

FIGURES

Figure 1

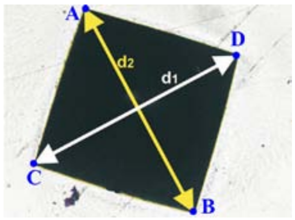

Figure 2

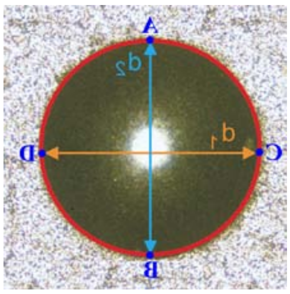

Figure 3

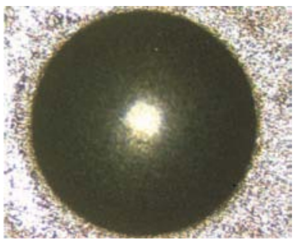

Figure 4a

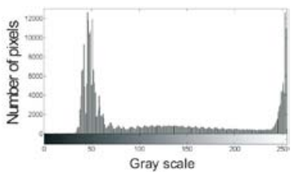

Figure 4b

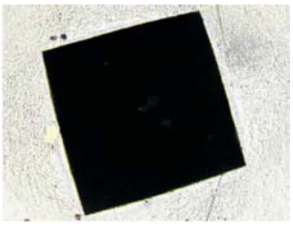

Figure 5a

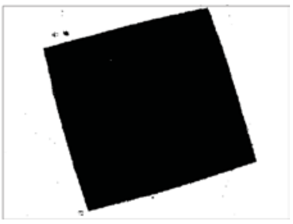

Figure 5b

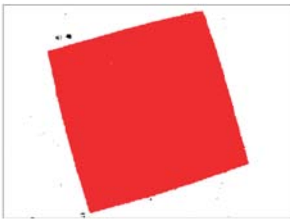

Figure 5c

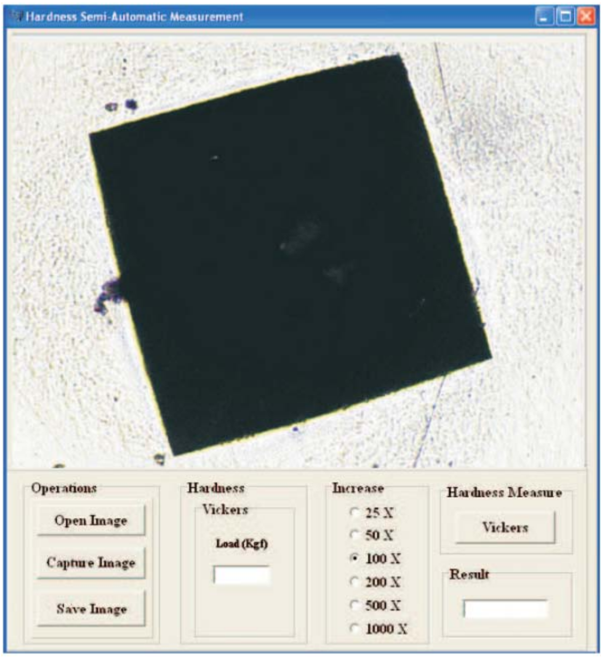

Figure 6a

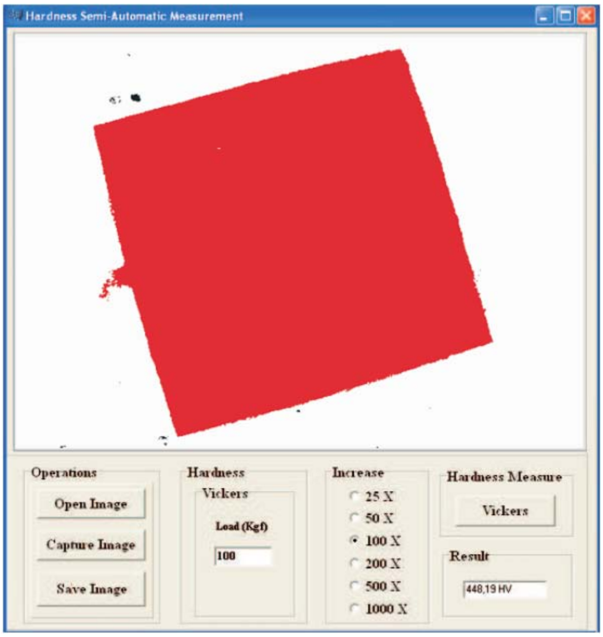

Figure 6b

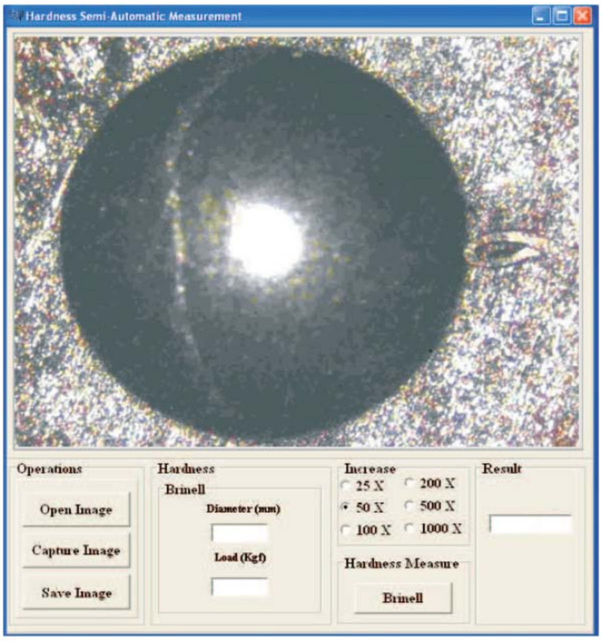

Figure 7a

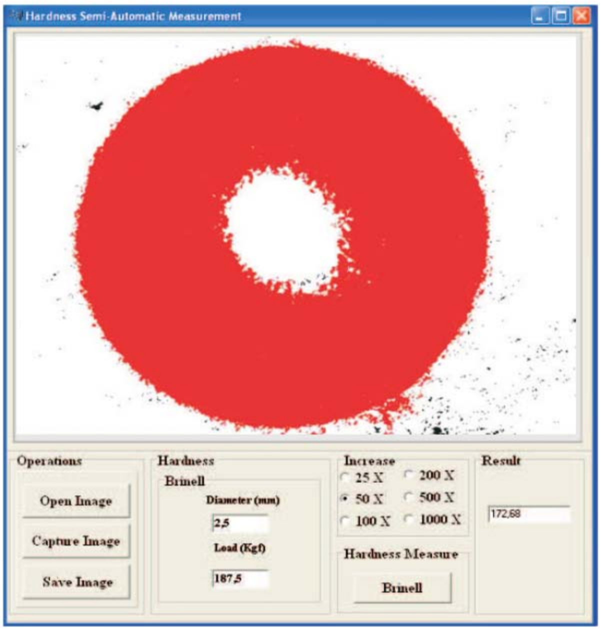
Hardness Semi-Automatic Measurement
Operations
Open Image
Capture Image
Save Image
Hardness
Brinell
Diameter (mm)
2,5
Load (Kgf)
187,5
Increase
25 X
200 X
50 X
500 X
100 X
1000 X
Hardness Measure
Brinell
Result
172,68

Figure 7b

TABLES

Table 1

	Manual method		Computational system	
Sample #	Hardness value [HV]	Associated error [HV]	Hardness value [HV]	Associated error [HV]
1	447.72	11.72	445.74	9.74
2	444.95	8.95	460.59	24.59
3	441.52	5.52	440.97	4.97
4	442.89	6.89	435.11	-0.89
5	447.72	11.72	442.51	6.51
6	443.58	7.58	425.12	-10.88
7	436.79	0.79	420.08	-15.92
8	445.64	9.64	436.35	0.35
9	447.03	11.03	442.16	6.16
10	456.19	20.19	445.73	9.73
Average	445.40	9.40	439.43	8.97

Table 2

	Manual method		Computational system	
Sample #	Hardness value [HB]	Associated error [HB]	Hardness value [HB]	Associated error [HB]
1	170.45	2.55	172.68	0.32
2	176.21	3.21	172.29	0.71
3	172.30	0.70	171.90	1.10
4	168.21	4.79	170.72	2.28
5	167.91	5.09	171.50	1.50
6	174.24	1.24	174.67	1.67
7	173.59	0.59	173.08	0.08
8	167.90	5.10	172.29	0.71
9	173.59	0.59	167.65	5.35
10	173.27	0.27	173.49	0.49
Average	171.77	2.41	172.03	1.42