Design and Development of a Software for the Estimation of the Vickers Hardness Measurement Uncertainty

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Abstract. Measurement uncertainty is a common concept. This concept gives us a certain degree of confidence in the results obtained from a specific measurement. However, its estimation is a very complex process, requiring knowledge of mathematics, but also a thorough knowledge of the method by which a certain type of measurement is performed. The uncertainty of the measurement result reflects the lack of knowledge of the measurand value. The result of a measurement after correction for recognized systematic effects is still only an estimated value of the measurand because of the uncertainty arising from random effects and from imperfect correction of the result for systematic effects. Scientists have created and developed tools to optimize their work in order to reduce the time wasted by making the mathematical calculations necessary to estimate uncertainty of measurement, regardless of the type of measurement. This paper aims to present the design and development of a software used to determine the Vickers hardness measurement uncertainty based on the mathematical model presented in the ISO 6507 standard. For the development of the software, a special program based on the C ++ programming language, program that allows graphical modelling of the interface, will be used.

1. Introduction
The concept of "uncertainty" is a relatively new concept and represents a parameter associated with the result of a measurement that characterizes the dispersion of values that can be reasonably attributed to the measurement [1,2].

The uncertainty of the result of a measurement reflects the lack of an accurate knowledge of the value of the measurement. The result of the measurement, after making the necessary corrections for the known systematic effects, is still estimated by the value of the measurement due to the random errors and the imperfection of the corrections made [2-4].

Each measurement has an associated uncertainty. The measuring devices and the calibration blocks are not perfect, also the environmental conditions, the processes, the procedures and the people are imperfect and variable [5,6].

In order to be able to compare two measurements of uncertainty, they must have the same reference. The method by which the measurement uncertainty is calculated depends on the nature of the test and can be simple or complex in order to meet the required requirements. Measuring uncertainty is not only important for calibration, but also in any test involving measurements [4-6].
Scientists have created and developed tools to optimize their work, to reduce the time wasted by performing the mathematical calculations necessary to estimate measurement uncertainty, regardless of the type of measurement [7].

2. Objective
The objective of this research is to develop a software application that will help to reduce the time spend to determine the Vickers hardness measurement uncertainty. The software to be developed is based on the mathematical model presented in the ISO 6507 standard.

3. Software design and development

3.1. Software Design
It is intended to develop a specific software for the determination of the measurement uncertainty in order to be used in the inspection laboratories form Faculty of Industrial Engineering and Robotics, University Politehnica of Bucharest. The proposed software will calculate the measurement uncertainty for determining the hardness in the Vickers scale and it will present two calculation modules: one based on ISO 6507 [8-9] and the second based on the simplified model proposed by one of the authors in the PhD Thesis [10], see the simplified mathematical model in figure 1.

![Figure 1. Schematic of the proposed mathematical model [adapted from 10].](image)

The software was created with the help of a specialized software that is based on the C ++ programming language.

The usage of the software does not require connection to the internet. The minimum requirements for the software to be used are: a computer, the software and all the measurements realized. The software does not need a specific computer configuration. It can work on any computer that have Windows installed as an operating system and it does not consider the configuration of the computer. The software was created using a background of knowledge regarding material properties, welding processes and hardness testing.

The software language is Romanian, because its main purpose is to be used in a Romanian university. An English version will be also developed.
3.2. Software interface
The software has a simple interface, consisting of three buttons, namely:
- ISO 6507 model (*Model ISO 6507 - in Romanian*) - by accessing it, the program will calculate the measurement uncertainty according to ISO 6507 standard.
- Proposed model (*Model propus - in Romanian*) - by accessing it, the program will calculate the measurement uncertainty according to the model proposed by the author.
- Contact - offers the possibility to contact the person in charge of the program in order to request additional information.

When accessing the software executable, a window will appear according to figure 2.

Figure 3 shows a measurement uncertainty calculation display based on the model given by the ISO 6507 standard.

After performing the calculations within the developed program, the program will display the results of all intermediate calculations, both for the standard and for the sample, as well as the standard measurement uncertainty, the extended uncertainty and the range in which it can take the average values of the experimentally determined values.

The following steps must be performed in order to obtain the display of the figure 3: access the software by double-clicking on the executable file, after activating the software menu, select the button named "Model ISO 6507", a command window will appear where the calculation data must be entered, the program will display in the command window what data to enter, after entering a date, press the "Enter" button, then the program will request the next one, after completing the data entry, by pressing the "Enter" button the program will display the image in figure 3.

4. Software test experiment
For the software test, a physical experiment was performed. The physical experiment consisted in determining the Vickers hardness uncertainty for a welding joint. For the physical experiment the following steels were chosen as basic materials: X2CrNiMo17-12-2 austenitic stainless steel and S235JR + AR carbon steel.

In order to calculate the measurement uncertainty in determining the hardness of the materials by the Vickers HV 0.2 method, the following steps were taken into account: description of the measurement, value of HV hardness; identifying the sources of uncertainty for measuring Vickers hardness and classifying them into Type A and Type B; the calculation of standard uncertainty; the calculation of the compound standard uncertainty; calculating the extended uncertainty; reporting the result. All the calculations were made using the prototype of the software.
Within a measurement, there are a variety of factors that can influence the value of the result. The most important factors and the sources of uncertainty they introduce, as well as the type of assessment used to analyse them are presented in table 1.

| Uncertainty source | The source of uncertainty and the type of assessment |
|--------------------|---------------------------------------------------|
| Sample used        | - sample preparation - Type B                     |
|                    | - shape, size and thickness - Type B              |
|                    | - parallelism - Type B                            |
|                    | - the appearance of the surface - TipB            |
|                    | - test force, F - Type B                          |
| Measurement tools  | - measuring the indentation diagonal, d - Type B  |
|                    | - indentation angle, α - Type B                   |
|                    | - duration of force application, T - Type B       |
| Environment        | - temperature - Type B                            |
| Operator           | - knowledge and experience                         |

All sources of uncertainty, presented in this case, are evaluated using the Type B evaluation, in which the standard uncertainty is evaluated by scientific reasoning based on all available information on the likely variation of the size in question.

The information may contain data from previous measurements, experience or general knowledge about the behaviour and properties of the relevant materials and instruments, the manufacturer's specifications, data provided in calibration certificates and other certificates or uncertainties attributed to the reference data taken from the manuals.

The sample used and the measurement directions for the experimental determination of the Vickers HV 0.2 is presented in figure 4.

![Figure 4](image.png)

**Figure 4.** The sample used and the measurement directions for Vickers micro-hardness.
A. General data:
- Samples coding: P1, P2, P3, P4.
- Micro-hardness test performed: HV 0.2.
- Equipment used: SHIMADZU HMV 2T, calibration certificate no. B-007-07-120 / 26.01.2009, with standard hardness measures: HV 0.2 (08-240 series) and calibration certificate: 3.28.215 / 2008.
- Linear repeatability: 0.06 μm.
- Indentation force: 1.961 N, tolerance ± 0.15 maintained for 10s.
- Resolution: 0.005 μm, tolerance ± 0.004.
- Indentation angle: 136°, tolerance ± 0.5°.

B. Measuring conditions:
- Temperature: 25ºC.
- Humidity: 54%.

C. Data on the specific measurement conditions:
- Measurements were made to determine the values of the micro-hardness of the test samples of austenitic stainless steel-carbon steel heterogeneous welded joints, in order to establish the value of the measurement uncertainty of hardness.
- 10 measurements were made with each value of the pressing force, the readings being carried out in line from the austenitic stainless steel to the carbon steel, with fixed displacements, on two parallel measuring directions.

The values of the measurement uncertainty calculated using the prototype of the software are presented in table 2. In table 3 the general measurement uncertainties for each sample are presented. Because the welded joint used in the experiments it is made of two materials with different properties, the measurement uncertainty was calculated for each area. The calculation made with the software was the same with the ones obtained by hand calculation.

| Sample no. | $u_e$ | $u_{CMR}$ | $u_H$ | $a$ [HV 0.2] | $W$ |
|------------|-------|-----------|-------|--------------|-----|
| Sample 1   | 1.62  | 1.39      | 1.82  | 200.1 ±16.34 | 159.3 ±16.85 |
|            |       |           |       | 187.7 ±9.003 | 201.7 ±8.528 |
|            |       |           |       | 169.3 ±8.703 | 199.6 ±8.394 |
|            |       |           |       | 161.8 ±16.34 |               |
| Sample 2   | 1.62  | 1.39      | 1.82  | 187.8 ±9.536 | 200.2 ±7.744 |
|            |       |           |       | 171.2 ±9.265 | 199.8 ±8.686 |
|            |       |           |       | 159.6 ±16.10 |               |
| Sample 3   | 1.62  | 1.39      | 1.82  | 187.4 ±8.380 | 199.6 ±7.031 |
|            |       |           |       | 170.6 ±8.325 | 199.4 ±6.918 |
|            |       |           |       | 161 ±15.94  |               |
| Sample 4   | 1.62  | 1.39      | 1.82  | 189.2 ±9.799 | 198 ±6.995   |
|            |       |           |       | 170.7 ±13.34 |               |

$u_e$ - the standard uncertainty according to the maximum deviation allowed
$u_{CMR}$ - standard uncertainty and mean hardness value of CRM
$u_H$ - standard uncertainty of the hardness tester
$a$ - mean value
$W$ - extended uncertainty
Table 3. The values of the measurement uncertainty on each sample.

| Sample   | \( u_x \) | \( u_{CMR} \) | \( u_H \) | \( a \) [HV 0.2] | W    |
|----------|-----------|--------------|----------|-----------------|------|
| Sample 1 | 1.62      | 1.39         | 1.82     | 186.16 ±16.340  | ±16.340 |
| Sample 2 | 1.62      | 1.39         | 1.82     | 183.40 ±15.577  | ±15.577 |
| Sample 3 | 1.62      | 1.39         | 1.82     | 186.28 ±16.026  | ±16.026 |
| Sample 4 | 1.62      | 1.39         | 1.82     | 185.28 ±16.912  | ±16.912 |

5. Conclusions
Based on this paper content, the following conclusions can be drawn.

The developed software application is very easy to use, the result of the determination being displayed instantly, thus reducing the computation time.

Data entry can be done either from the keyboard, one by one, or through a .txt file from where the program can retrieve the necessary data.

The software displays the results of all intermediate calculations, both for the standard and for the sample, as well as the standard measurement uncertainty, the extended uncertainty and the range in which it can take the average values of the experimentally determined values.

Using the developed software, the time for calculating the measurement uncertainty of hardness can be significantly reduced.

6. References
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