

COMPUTER-CONTROLLED EXPERIMENTS IN THE COURSE "MEASUREMENTS IN ELECTRICAL ENGINEERING"

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Abstract – Application of the computer-controlled methods of measurements in laboratory exercises within the course "Measurements in Electrical Engineering" (MUE) is presented. In the experiment, which accomplishes the basic statistical analysis of the measurement results, a computer is used for processing the data obtained by the digital multimeter (DMM) connected to the computer, as well as for necessary calculations. Another experiment is used to test the response of different types of DMMs in measuring ac voltages. Thus, the computer serves as an ac calibrator supplying the chosen waveform to the measuring instruments by means of the D/A card. Both experiments are examples of virtual instruments developed on the basis of an ordinary personal computer (PC), equipped with the necessary hardware and software.

Keywords: computer-controlled method, ac calibrator, statistical analysis, D/A conversion, virtual instrument

1. INTRODUCTION

Laboratory exercises are part of the subject MUE in the second study year at the Faculty of Electrical Engineering and Computing (FER), University of Zagreb. Application of the computer-controlled methods of measurements in the experiments is of great importance because these methods have a number of advantages over the traditional methods. The advantages include: data transfer between the measuring instruments and the computer through different types of interfaces, development of the graphical user interface (GUI), performing all the necessary mathematical analyses automatically, data saving, and many others. Following this approach, it is interesting to show the students that an ordinary PC can be used as a powerful measuring platform.

We have designed two types of experiments into which PC have been introduced. The purpose of the first experiment is a better understanding of the basic statistical terms and analyses, including calculation of the arithmetic mean, (experimental) standard deviation, (experimental) standard deviation of the mean, weighted arithmetic mean, and measurement uncertainty. Here, DMM is connected to the computer by means of the General Purpose Interface Bus (GPIB, also known as IEEE-488 interface) and measures the ac voltage. The data are processed into the computer and

many statistical analyses are performed using a few appropriate graphical user interfaces (GUIs).

On the other hand, in the second experiment the computer serves as the ac calibrator with selectable frequency, amplitude and higher harmonics. The generated waveform is available at the output of the D/A card and is measured by means of different types of DMMs, that is, with average and true rms responses. Therefore, their different readings can be easily surveyed in the case of non-sinusoidal voltages.

The first versions of these experiments were introduced some years ago [1], while the newest approaches will be presented here. Both experiments are well documented and a detailed guidance for students' performance is available [2]. Moreover, they are based on the available equipment, including software and hardware. Thus, a PC (66 MHz) working under the DOS operating system is used and the software was developed using the programming package LabWindows [3].

In this paper, both experiments will be explained in detail and almost all of the developed GUIs will be presented.

2. FIRST EXPERIMENT

The measuring system is shown in Fig. 1 and its parts are: PC, DMM and the transformer (TR), which decreases the power supply voltage to a level of approximately 26 V. The measured ac voltage is used as a substitution for the quantity that varies randomly and has a normal distribution. This presumption is rarely fulfilled in the real measurement conditions but, for students' exercises, this approximation is more than satisfactory.

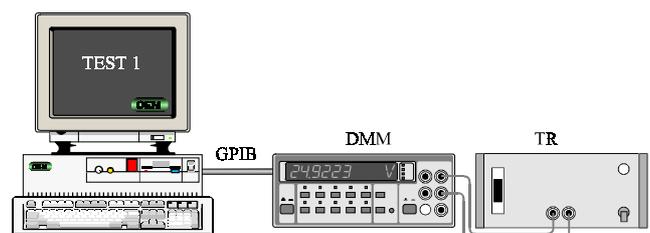


Fig. 1. Scheme of the computer-controlled experiment referring to the basic statistical terms

A GUI has been developed to control the DMM, as well as to display and acquire data (Fig. 2). The buttons "Start" and "Stop" are used to begin and to end data acquisition. The momentary measured values are presented in two ways: as (absolute) numerical values on the digital display and as the difference from the selectable reference value U_0 on the strip chart. During the initial part of the experiment, altogether five sets of data need to be saved, with 5, 20, 50, 100 and 200 samples (n), respectively.

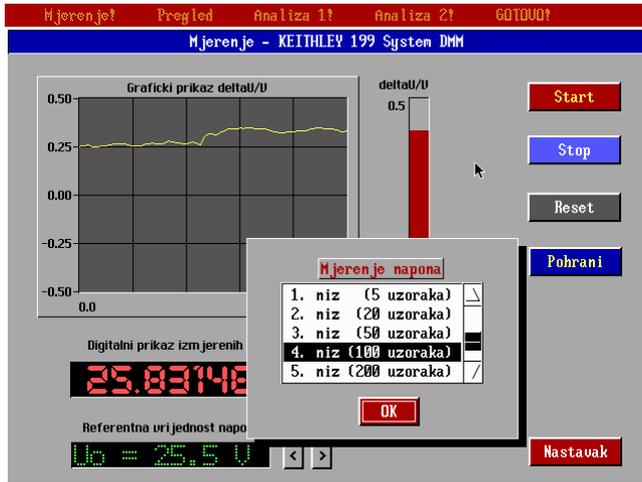


Fig. 2. The main GUI for the control of DMM (Keithley 199), and for acquiring, displaying and saving data

For all sets of data, the program calculates the arithmetic mean \bar{x} and the standard deviation s according to well-known equations [4]. The measured data and calculated values can be reviewed for each set of data using the commands in the Menu bar; an example is shown in Fig. 3, where the results for the fifth set of data with $n = 200$ are displayed (they are used as the input values for the calculation explained in section 2.2).

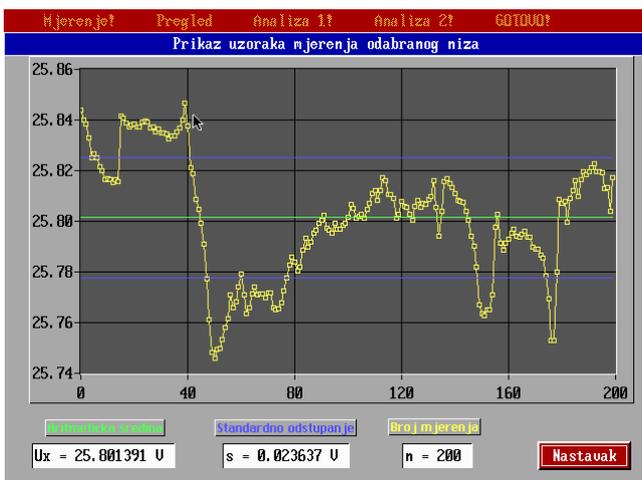


Fig. 3. Measured values for the 5th data set (yellow) with $n = 200$; calculated arithmetic mean and standard deviation ("Ux" and "s" on the GUI) are marked green and blue, respectively

It is also possible to check the frequency distribution of the measured values. In this case, five sets of data form one common set, with altogether 375 samples, while the distribution is graphically presented as a histogram (Fig. 4).

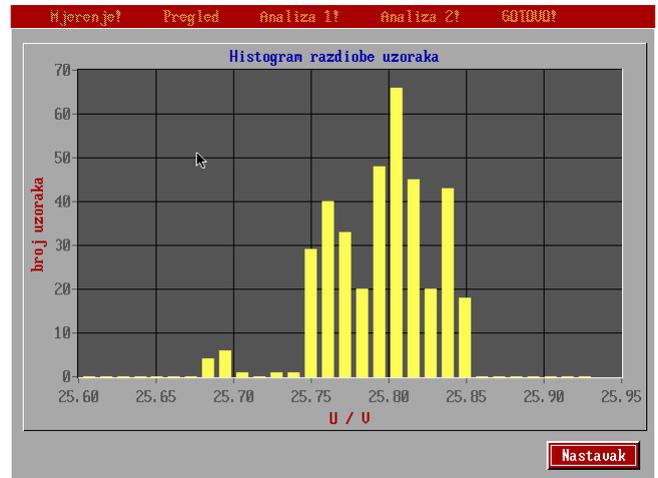


Fig. 4. Histogram representing the frequency distribution for all measured values (one set of data with altogether 375 samples)

2.1. Determination of the weighted arithmetic mean

In the second step of the first experiment, students have to calculate the (experimental) standard deviation of the mean for the first four data sets (with n equal to 5, 20, 50 and 100, respectively) as follows:

$$s_{\bar{x}} = t s / \sqrt{n} \quad (1)$$

where t is the variable of Student's distribution and is used as appropriate (for a 68,3% probability) [5], while s and n are the associated parameters for each set of data. The GUI used for this calculation is represented in Fig. 5, where the arithmetic mean \bar{x} and its standard deviation $s_{\bar{x}}$ are marked "Ux" and "sx", respectively.



Fig. 5. Calculation of the weighted arithmetic mean and its standard deviation for the sets of data with 5, 20, 50, and 100 samples; the GUI used is shown.

The weighted arithmetic mean ("Um" in Fig. 5) should be determined using the following equation:

$$\bar{x}_s = \frac{p_1\bar{x}_1 + p_2\bar{x}_2 + p_3\bar{x}_3 + p_4\bar{x}_4}{p_1 + p_2 + p_3 + p_4}, \quad (2)$$

where the weight $p_i = 1/s_{\bar{x}_i}^2$. The standard deviation of the weighted arithmetic mean ("sm" in Fig. 5) is calculated by the program as follows:

$$s_{\bar{x}_w} = \left(\sum_{i=1}^4 1/s_{\bar{x}_i}^2 \right)^{-1/2}. \quad (3)$$

2.2. Determination of uncertainty

The final step is the calculation of the combined standard uncertainty for the set of data with $n = 200$; the GUI used is shown in Fig. 6. As for the previous sets of data, the standard deviation of the mean ("sx") needs to be determined using (1), based on the known values of s and n (the whole set of samples for the presented example is shown in Fig. 3). Thus, this value is used as a type A evaluation of standard uncertainty (i.e., $s_{\bar{x}} = u_A$) when combined standard uncertainty is calculated as [6]

$$u_c = \sqrt{u_A^2 + u_B^2} \quad (4)$$

("u" in Fig. 6). Type B refers to the manufacturer's specifications of the DMM used [3], where the limits of errors are defined as $\pm(0,35\%$ of reading + 100 digits) for the 30 VAC range and resolution of $5\frac{1}{2}$ digits. Since this statement assigns the symmetric rectangular distribution of half-width a , the associate standard uncertainty is calculated as

$$u_B = a/\sqrt{3}. \quad (5)$$

The arithmetic mean ("Ux") is used as the reading in the calculation of the limits of errors, and the parameter a has a value of ≈ 100 mV; therefore type B of standard uncertainty is dominant in the calculation of u_c . Finally, when the student enters the correct value of u_c , the program writes a relative uncertainty, calculated as $u_r = (u_c/\bar{x}) \cdot 100\%$.

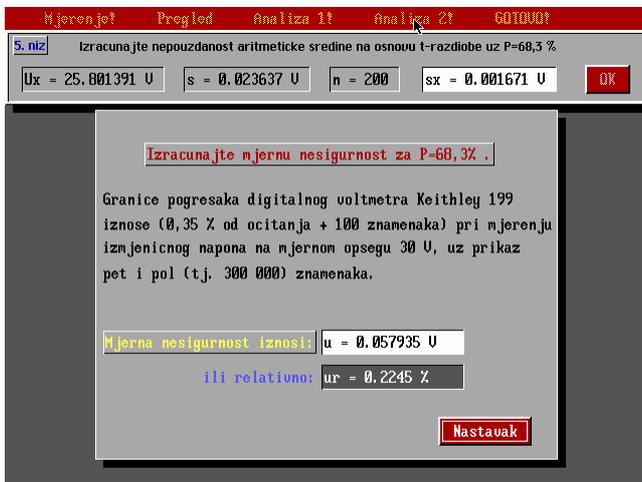


Fig. 6. Calculation of combined uncertainty

3. SECOND EXPERIMENT

The PC can be used as an ac calibrator when the program-generated waveform is transformed to the analog by means of the inserted D/A card. The block-scheme of the experiment is shown in Fig. 7.

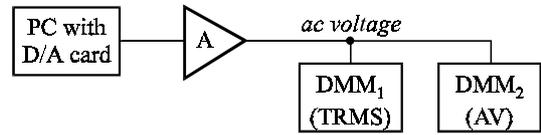


Fig. 7. Scheme of the computer-controlled experiment for testing the response of different types of DMMs in measuring ac voltages

Two DMMs are used to measure the generated ac voltage: the first (marked DMM₁ in Fig. 7) shows the true root mean square (TRMS) value, and the second (DMM₂) is an average responding instrument that shows the corresponding rms value only for the sinusoidal waveform with the form factor $\xi_0 = 1,111$. Signals other than sine waves (with form factor ξ) produce a relative error in the displayed value equal to:

$$p\% = \frac{\xi_0 - \xi}{\xi} \cdot 100\%. \quad (6)$$

The purpose of this experiment is to determine the relative error for the average responding instrument, according to (6), when it measures different non-sinusoidal waveforms.

The ac voltage is generated by means of the D/A conversion (Fig. 8). An analog waveform is approximated with a finite number of analog steps (marked k), where each step holds its value constant for the same time interval. In our experiment $k = 1000$ per each period of the generated waveform.

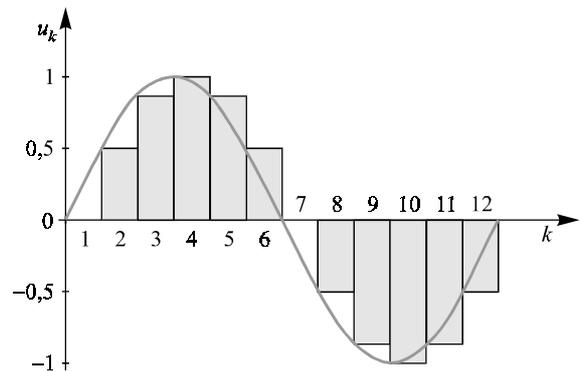


Fig. 8. An example of D/A conversion with a finite number of analog steps k per period of the generated waveform, with normalized amplitude

The amplitude of the so-formed ac calibrator can be as high as 10 V and higher (up to 7th harmonics can be introduced, including their amplitudes and phases. The program calculates the output values for each analog step within one period, as well as the rms value of a waveform using the following equation:

$$U = \sqrt{\frac{u_1^2 + u_2^2 + \dots + u_k^2}{k}} = \sqrt{\frac{1}{k} \sum_{i=1}^k u_i^2}. \quad (7)$$

Frequency of the generated waveforms can be chosen between 20 Hz, 50 Hz, 100 Hz and 200 Hz; at the moment, the exercise is run using only 50 Hz. The initial frequency is 200 Hz, and to generate the other mentioned frequencies (with longer periods), the duration of every step is multiplied by the ratio of the initial and chosen frequencies, as it follows from the computer set-up.

A special GUI was developed for the main part of the control program (Fig. 9). Default parameters include an amplitude of 5,000 V, a frequency of 50 Hz, a timer (time interval during which the generated ac voltage is disposable at the output after the "Start" button is pressed) of 10,000 s, and amplitudes of all harmonics equal to zero. Using the appropriate GUI controls, the student creates different waveforms (i.e., all the mentioned parameters are changeable). One period of the combined waveform is visible on the graph (yellow), and three boxes are placed beneath it on the screen, where the calculated rms value (U), average value (U_{av}) and the form factor (ξ) are displayed.

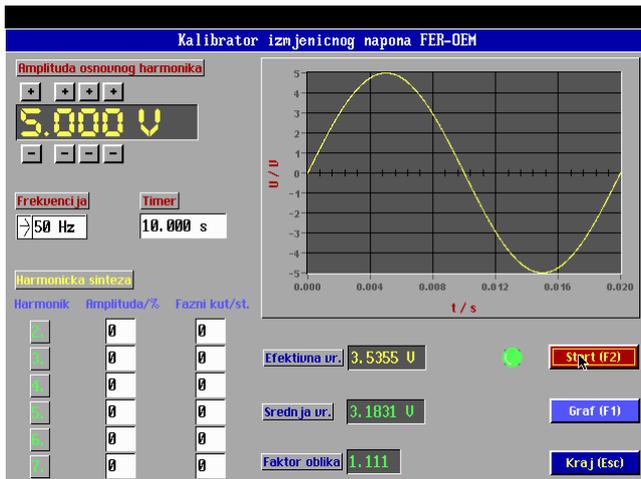


Fig. 9. GUI developed for the computer-based ac calibrator with selectable frequency, amplitude and higher harmonics; for the presented example with the function $u(t) = 5 \sin(100\pi t)$ $U = 3,535534$ V, $U_{av} = 3,183099$ V and $\xi_0 = 1,11072$

Fig. 10 displays an example of the combined waveform, described by the function

$$u(t) = 5 [\sin \omega t + 0,1 \sin 3 \omega t + 0,1 \sin 5 \omega t + 0,1 \sin 7 \omega t], \quad (8)$$

along with the calculated values of rms and average voltages, as well as the form factor. The relative error for the average responding DMM in this case, calculated by (6), is $p\% = 5,196\%$.

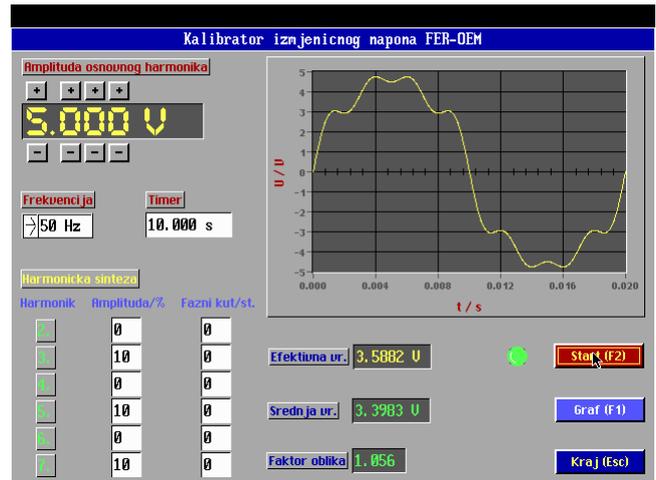


Fig. 10. Example of a non-sinusoidal waveform with amplitudes of the 3rd, 5th and 7th harmonics equal to 10 % of the main harmonic; $U = 3,588175$ V, $U_{av} = 3,398337$ V and $\xi = 1,05586$

4. CONCLUSIONS

Two types of experiments, based on the computer-controlled measurement methods, were set up. They enabled use of some new approaches in the laboratory exercises for students of the MUE course, and demonstrated the possibilities and usefulness of the PC-based virtual instruments.

In the first experiment, the emphasis is on data acquisition and their statistical treatments and analyses. The second experiment demonstrates the manner in which complex waveforms can be generated and analysed, as well as used to test the responses of the different types of DMMs.

The exercises were well accepted by the students and some new experiments will be designed in the future.

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