

# TRAINING OF COMPUTER-CONTROLLED MEASURING SYSTEMS

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*Abstract: The training of computer-controlled measuring systems is an important part of education activities in measurement technology for engineers. This paper shows in its first part essential preconditions and special possibilities to make training effective. The unity of theoretical and experimental works will be demonstrated by using a specially designed system. Standard measuring instruments completed by special software packages are used for an uncomplicated application. Different training courses, for example, signal and data processing, instruments programming, measurement of electrical quantities, and self-calibration of measuring systems, etc., can be realized in this experiment system. This system is very suitable for the demonstration of methodological view of measurement technology and for training different courses of teaching modern measurement technology.*

*Keywords: Education and training, Measuring system, Instruments programming*

## 1 INTRODUCTION

Most electronic measuring instruments and devices are computerized or computer-controllable nowadays [1,2]. Using the standard interfaces, e.g., IEEE-488 and RS-232, a measuring system composed of different standard instruments and devices can be easily controlled by a PC system. Furthermore, to analyze and process the measuring results immediately, a single measuring instrument is also connected by its interface to a PC system. On the other hand Virtual Instruments include intelligent components and software packages for independent running. The computer-controlled measuring systems play an important role in the measurement technology. Therefore the training of computer-controlled measuring systems is of increasing importance for the applications and development.

Training in measurement technology is a complex task including activities in the fields of:

- the problems analysis, involving basic information and scientific fundamentals
- the choice and development of suitable methods and tools (algorithms, instruments, etc.)
- knowledge and skills in measurement technology
- the evaluation of measuring results (errors, conclusions, comparison with other results, etc.).

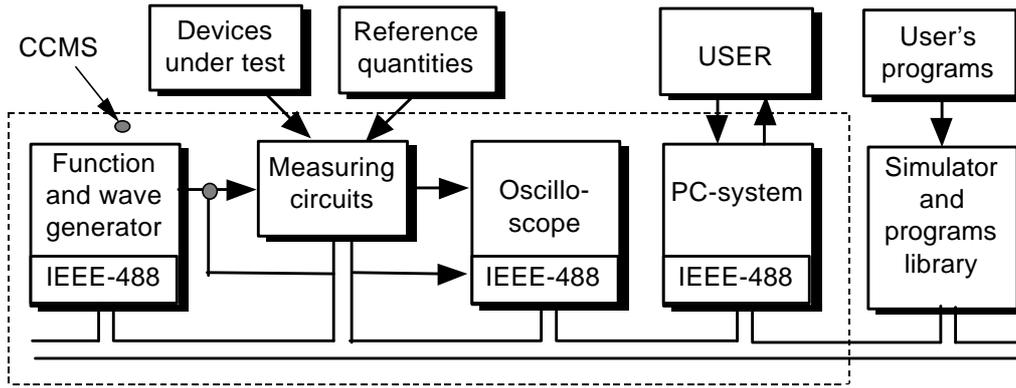
The interactions of these aspects will be demonstrated for special measuring tasks by using a developed experimental system in this paper. The training experiment system is developed with standard measuring instruments in order to be satisfied with the increasing requirements.

## 2 TRAINING EXPERIMENT SYSTEM

Figure 1 shows the training experiment system [3]. The system consists of a computer-controlled measuring system (CCMS), simulator and programs library, devices under test, and reference quantities and elements, etc. The CCMS is composed of a PC-system, a function and wave generator (hp 33120 A), an oscilloscope (hp 54601 A), and different measuring circuits, etc. They are connected each other with the standard interface IEEE-488.

Different signals can be generated by the function and wave generator. They are connected with the measuring circuits and the oscilloscope. The output signal of the measuring circuits is also inputted in the oscilloscope. These two signals are measured or sampled by the oscilloscope. The measuring results or sampling data are transferred into the PC-system. Further data processing and signal analysis can be made in the PC-system using corresponding programs from the programs library.

Reference quantities and elements are used to self-calibrate the measuring system according to the Self-Calibrated Measuring Methods [3,5,6]. This enables the USER to be trained by the new measuring



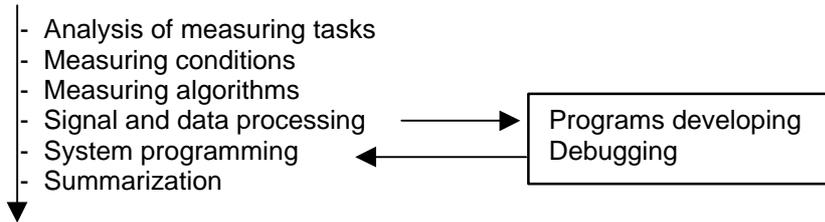
**Figure 1.** Scheme of the training experiment system (CCMS: computer-controlled measuring system)

methods. User's programs as DLL (Dynamic Link-Library) file can be integrated in the data and programs library of the training system, so that a programming training for system controlling and measurement can be realized.

The software package of this system is programmed with object orientated computer language Delphi. A comfortable user interface is constructed for the training programs. The sampled signals and processed data can be displayed as graphics and data list on the windows. A help program enables the training experiment system easily to be used.

Analog circuits and impedance measuring circuits are integrated in this system. Special training on measurements of electrical quantities (transfer function and impedance etc.) can be easily realized by using these circuits.

In this way the students have to use the knowledge and experiences shown in Figure 2.



**Figure 2.** Knowledge and experiences used in the training programs

### 3 TRAINING PROGRAMS

Taking in account of the above discussed problems the training programs focus mainly on the following tasks:

- Signal analysis and data processing by the DFT, averaging, smoothing, interpolation and correlation, etc.
- Instruments and measurement programming using instruments language and computer languages (Basic, Pascal, C, C++, Delphi, etc.)
- Measurement of electrical quantities using the oscilloscope and data processing
- Self-calibration of measuring systems using the principles of the self-calibrated measuring methods [3,5,6], etc.

#### 3.1 Signal Analysis and Data Processing

Using the signal sampling data from the oscilloscope and simulator the USER can be trained in signal and data processing, e.g. averaging, smoothing, correlation functions, and interpolation, etc., and in signal analysis, e.g., spectrum analysis using DFT and statistics analysis, etc.

Taking the averaging and DFT of periodic signals as examples the standard algorithms can be introduced in primary. The standard averaging and DFT (S-AVE, S-DFT) algorithms are only suitable for processing synchronous sampling data under the condition  $f_s = Nf$  [3,7,8], where  $f_s$  and  $f$  are sampling frequency and signal frequency, respectively,  $N$  denotes the number of the sampling points per signal period. In this case the averaging values of any periodic signals can be exactly calculated by the standard averaging algorithm, and the spectral functions of spectral limited periodic signals (e.g. sinusoid signal and sinus series) can be also exactly calculated by the standard DFT algorithm if the

sampling theorem is fulfilled. For spectral unlimited periodic signals (square, ramp and triangle etc.) the spectral-leakage is caused by the DFT due to the discrete and limited sampling data.

If the synchronous sampling condition is not fulfilled, i.e., the signals are asynchronously sampled, errors will be caused by the standard averaging and DFT algorithms [3,7,8]. For instance, for processing a sinusoid signal by the averaging, the amplitude is reduced and the phase is changed according to the factor  $\alpha$  from sampling condition  $f_s=(N+a)f$ .

These problems can be demonstrated by the signal processing programs in the training experiment system. For the demonstration periodic signals wished-for are generated by the simulator and sampled synchronously or asynchronously by the PC system. Averaging and DFT calculations are carried out using the sampling data. Errors are shown on windows if the signals are asynchronously sampled. The errors are disappeared if the signals are synchronously sampled.

To reduce the errors for asynchronous sampling data, interpolated and iterative self-corrected averaging and DFT algorithms [3,7,8] are applied in the next step to the training experiment system. The interpolated algorithms (IP-DFT, I-AVE) are suitable only for the data processing sampled asynchronously with higher sampling frequency, while the iterative self-corrected algorithms (ISC-DFT, ISC-AVE) are also suitable for processing asynchronous sampling data with very low sampling frequency. The results are corresponding to the measurement examples in references [3, 7, 8]

By this training the students can recognize the problems and solving methods of signal and data processing, which are not discussed in normal learning books and are very important for practical uses.

### 3.2 Instruments and Measurement Programming

The training of the instruments and measurement programming consists of two parts. The first part is the training of the instruments language to realize the instruments control and the data communication between instruments and the computer. The USER can send commands from computer to the instruments and get status and data from the instruments. The second part concerns with the training of the programming for measurement and data processing by using computer language (C++, Delphi, etc.).

The signal generator and oscilloscope are used for the training of instruments language. After the initialization of the interface IEEE 488 one can send commands to the signal generator to generate different signals and then send commands to the oscilloscope to measure the signals. Table 1 shows a simple example for generating a square and measuring its maximal and minimal voltages. The commands send is realized by the *commands send* function of the experiment program. After having sent the command: MEASURE:VMAX?, one can get the measuring value of the maximal voltage from the oscilloscope using the *get data* function of the program.

**Table 1.** Example for generating a square and measuring its maximal and minimal voltages

Commands to the signal generator (address 710)		Commands to the oscilloscope (address: 707)	
*CLS	{clear status}	*CLS;RST	{clear status and reset}
*RST	{reset the generator}	:AUTOSCALE	{autoscale}
:FUNC:SHAP SQU	{set square}	:CHAN1:PROBE X10	{set the probe factor to 10}
:FREQ 1kHz	{set the frequency to 1kHz}	:WAVEFORM:SOURCE CHAN1	
:VOLT 1.0	{set the amplitude to 1.0V}		{set source to channel 1}
:VOLT:OFFS 0	{set the offset to 0V}	:DIGITIZE CHAN1	{acquire data & stop}
		:MEASURE:VMAX?	{Vmax query}

The training of programming for measurement and data processing aims at the evaluation of measuring results using the sampling data. The programs are written by a high level computer language and should be compiled as DLL (Dynamic Link-Library) files in order to be easily integrated in the programs library. This is a special training of computer programming using the Dynamic Link-Library, which is very useful for the development of computer-controlled measuring systems.

Figure 3 shows a simple communication between the main and user programs. The user program as DLL file (mcdll.dll) is integrated in the programs library. The main program (p\_pccm1.dpr) can call up the functions of the user program from the programs library via the interface-unit (mclib1.pas). The user program can be run in the main program using the sampling data, which are sampled by the measuring functions of the main program.

The user program can be compared with a corresponding reference program by parameter calculation of different test signals, so that the correctness of the user program can be examined. This makes the training effective.

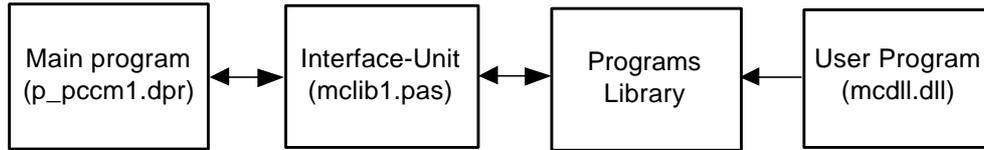


Figure 3. Communication between the main program and user program using an interface-unit

### 3.3 Measurement of Electrical Quantities

The training for measurement of electrical quantities is realized by the data sampling program together with the user's programs or reference programs from the programs library. Different parameters can be directly measured by the measuring system (CCMS). They can be also calculated by the programs with the use of the sampling data. Therefore the USER can be trained by parameter measurement and calculation of different signals.

Test signals, e.g., sinus, square, triangle and ramp, can be generated by the signal generator and sampled by the oscilloscope and the PC-system. Their parameters, e.g., frequency  $f$ , maximum  $V_{max}$ , minimum  $V_{min}$ , peak-to-peak value  $V_{pp}$ , average value  $V_{AVE}$  and effective value  $V_{RMS}$ , etc., can be calculated by the user program and the corresponding reference program.

Using the measuring circuits parameters of the devices under test, e.g., impedance, transfer function, etc., can be measured by the CCMS. The parameters measurement depends on the used measuring circuits and is realized by sampling the input and output signal waves of a measuring circuit. Figure 4 shows two simple impedance measuring circuits as examples.

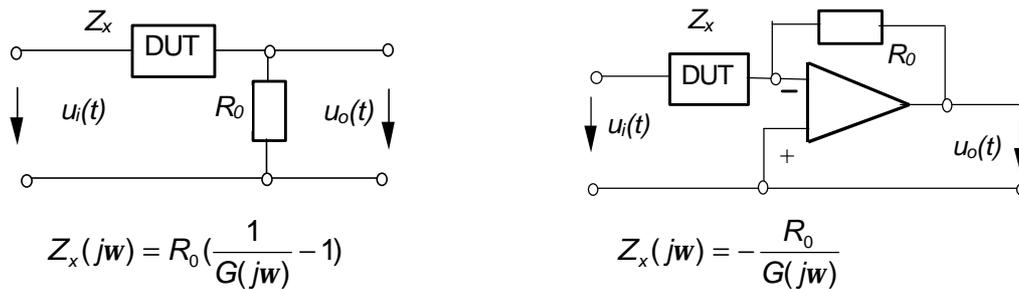


Figure 4. Impedance measuring circuits based on the measurement of transfer function  $G(jw)$

The impedance  $Z_x(jw)$  of the DUT is determined by the measurement of the transfer function  $G(jw) = U_o(jw)/U_i(jw)$  and the known resistance  $R_0$ . The transfer function can be determined by the DFT algorithms [3,7] with the use of the sampling data.

The training aims at the measuring principles, measurement calculation and programming of electrical quantities, and measuring accuracy comparison of different measuring circuits, etc.

### 3.4 Self-Calibration of Measuring Systems

The self-calibration of measuring systems is an important part of measurement technology. Self-calibrated measuring methods have been developed recently [3,4,5,6]. They can be applied to all measurement areas to improve the measuring accuracy with relative low costs. Simple self-calibration methods and interpolated self-calibration methods are integrated in the training experiment system. The USER can be trained by self-calibrated measuring methods for the measurement of transfer function and impedance, etc.

Figure 5 shows two interpolated self-calibrated impedance measuring circuits. For the system self-calibration reference resistors  $R_{rk}$  ( $k=1,2,3$ ) are used in the measuring circuits. The reference resistors are measured by the CCMS during the self-calibration. The measurement of the impedance  $Z_x$  of the DUT is realized in the same way. Using the measuring values  $Z_{or_k}$  ( $k=1,2,3$ ) and  $Z_{ox}$  the final result can be calculated by the linear interpolation [3,5,6]:

$$Z_x = \frac{G_x - G_{r2}}{G_{r1} - G_{r2}} \frac{G_{r1}}{G_x} R_{r1} + \frac{G_x - G_{r1}}{G_{r2} - G_{r1}} \frac{G_{r2}}{G_x} R_{r2} \quad (1)$$

if the linear interpolated self-calibration (LISC) is used (see Figure 5a). In a similar way quadratic interpolated self-calibration will be examined.

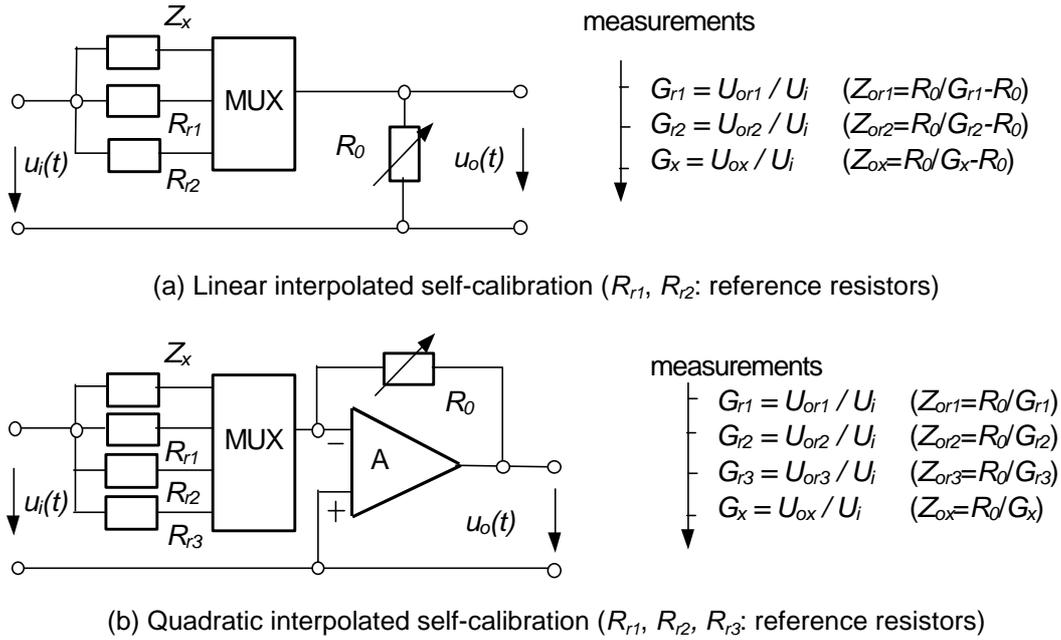


Figure 5. Interpolated self-calibrated impedance measuring circuits

Using the self-calibration measuring methods the measuring accuracy can be easily improved with lower costs without changing the fundamental measuring system (CCMS). Examples are shown in the references [3,5,6].

In summary the training experiment system provides a lot of training programs about the fundamentals of the measurement technology, new algorithms of signal and data processing, and modern self-calibrated measuring methods.

#### 4 CONCLUSIONS

The training experiment system developed with standard instruments are very useful for the teaching and training of the modern measurement technology, especially, computer-controlled measuring systems. The practical works are shown in Figure 6. In the system normal measurement technology is combined with the newest measuring methods, measurement is connected with signal & data processing, instruments and measurement programming, etc. The chosen methods contribute to improve the knowledge and skills of the students by their own activities in solving a complex measuring task.

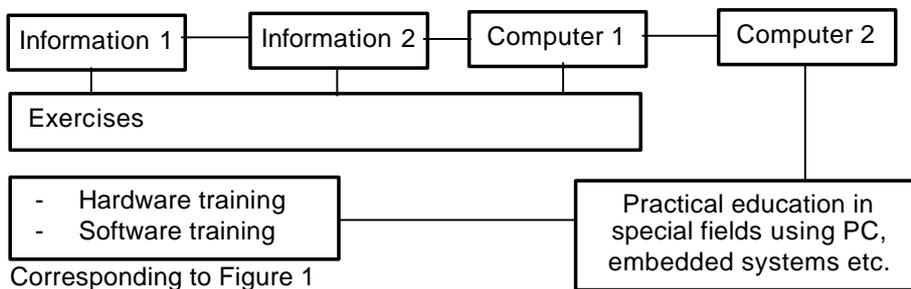


Figure 6. Practical works in the training of computer-controlled measuring systems

This training experiment system should be developed as standard training system for teaching computer-controlled measurement technology and signal & data processing for students and engineers. This supports not only the development and applications of the computer-controlled measurement technology, but also helps the widening of new measuring methods and new algorithms of signal and data processing.

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