

Dariusz BUCHCZIK\*  
Witold ILEWICZ

**TEACHING OF MEASUREMENT PROCEDURES  
FOR SPECIALITY OF MEASUREMENT SYSTEMS  
IN THE INSTITUTE OF AUTOMATIC CONTROL**

Ability to prepare, perform and process data obtained during an experiment is essential skill for engineers. At Measurement System Group at the Silesian University of Technology run the speciality Measurement Systems. At this speciality there is a course on Measurement Procedures. The course is performed for students of the 8<sup>th</sup> semester. The half-year lecture course is supported by classes and laboratory classes at the same semester. The lecture shows the procedures and fields of their applications. It is intended to show variety of procedures and complexity of process of choosing a proper method to the task. The aim of classes is to illustrate the lecture. There are solved hypothetical problems that refer to selected sections of the lecture. The laboratory classes are intended to develop self-reliant proficiency in using procedures on real and simulated data. Students solve problems, perform computations, comment and interpret results.

*Key words: teaching, education, measurement procedures, calibration, regression*

## 1. INTRODUCTION

The genesis of course *Measurement Procedures* is a consequence of establishing speciality *Measurement Systems* for studies in *Automatic Control and Robotics*. A graduate of this speciality should have wide knowledge in the field of procedures used in measurements. Constant and fast progress in computer development lead to automation of measurement processes. In fact, automated measurement systems are indispensable in modern industry. Means of the automation are computers. So designing and constructing optimal and adequate measurement procedures that are later coded

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\* Silesian University of Technology, Institute of Automatic Control, Akademicka 16, 44-100 GLIWICE, Poland, e-mail: buchczik@oak.ia.polsl.gliwice.pl

into form of computer algorithms and used in partly and fully automated systems are very important parts of knowledge of the engineer. Subject *Measurement Procedures* gives to students useful skill to do that and may be included in university curriculum of other specialties, especially concerned of informatics.

In many cases an engineer have to take responsibility for outcome of measurement. Improperly planned and performed experiment or wrong interpretation of results could cause serious losses or even casualties. Some results have to have legal force when are evidence for possible use in a court or when a pension is granted. Therefore the course is considered as one of the most important for the speciality. The course meets the need of completion, expansion and exemplification of problems such as expression of uncertainty in measurement, calibration of measurement instruments and systems, signal processing and many others.

As a part of the University curriculum the subject is addressed to students of 8<sup>th</sup> semester in the speciality *Measurement Systems*. The course consists of three phases: lectures, classes and laboratory classes. A detailed schedule is shown in table 1. Students take an oral examination after completed series of classes.

Table 1. Schedule of Measurement Procedures course

SEMESTER 8 <sup>th</sup>		EXAM
1 <sup>st</sup> half	2 <sup>nd</sup> half	
LECTURES (15 times by 2 hrs)		
CLASSES (15 times by 2 hrs)	LABORATORY CLASSES (7 times by 4 hrs)	

Students acquire elementary measurement knowledge during a course *Principles of Measurements* on 4<sup>th</sup> semester. Other preceding subjects which establish base to *Measurement Procedures* are *Probability and Mathematical Statistics*, *Differential Equations*, *Principles of Dynamics of Systems*, *Fundamentals of Control*, *Identification of Processes*. Skills captured during the classes are useful in other subjects such as *Electrical Accurate Measurements*, *Industrial Metrology*, *Reliability and Intrinsic Safety*, *Automation of Experimental Research*.

## 2. LECTURES

The lecture is a basis for simultaneous classes and following laboratory classes. It is given in a traditional manner - using a blackboard and a chalk. The lecture presents a majority of fundamental procedures and fields of their applications. The state of the art is also discussed. It is intended to show variety of procedures and complexity of process

of choosing a proper method to the task. In research work, it is necessary to formulate the problem, find a solution, discuss the results and proof that the solution is correct and at least good or the best. Obviously, it is impossible to exhaust every bit of the problem but the lecture gives a broad survey.

Special attention is drawn to some analytical problems taken from chemistry. At the Measurement Systems Group the measurements of non-electric quantities have a long-standing tradition. The laboratories are equipped with specialist instruments, which involve utilization of advanced procedures.

The lecture starts from defining the place of the measurement procedures in metrology. Next, the following problems are shown:

- Calibration and evaluation of the results,
- Expression of uncertainty in measurement,
- Linear and nonlinear regression for different types of errors,
- Estimation of a linear model with use of regression and maximum likelihood method,
- Estimation of nonlinear models,
- Gross errors rejection, Huber and median robust estimators,
- Signal smoothing, Brown and Savitzky-Golay procedures, splines, median methods.
- Wiener and Kalman filtering, frequency domain filtering,
- Signal differentiation: properties, dynamic characteristics and errors,
- Problems of jump detection,
- Delay time estimation,
- Power spectrum estimation, resolution enhancement: zeroes padding, decimation, data windowing,
- Signal reconstruction, dynamic errors correction,
- Multivariate estimation with use of the principal component regression and the partial least squares procedures.

The supplementary materials for the lecture are in [1–3] where not only examples but also lots of topical literature items is given.

### 3. CLASSES

The aim of classes is to illustrate the lecture. There are solved hypothetical problems that refer to selected sections of the lecture.

In the field of measurements there is always present random error. As a result of that fact - statistics and calculus of probability take very important role in mathematical modelling and drawing the conclusions about variety of phenomenon that are in scope of measurements so the classes start from a short review of fundamentals of statistic. Next detailed analysis of linear and nonlinear regression is performed. The problem is

strictly connected with calibration of measurement instruments. During classes concerned of linear regression analysis after defining model, the parameters of the model of instrument and inversed response characteristic are determined. Finally the results of measurement and its uncertainty are calculated. Problems of nonlinear regression are introduced on basis of chromatographic data. There are discussed models of chromatographic peaks, estimation of their parameters, a base line correction and noise filtration. Gross errors rejection is also presented during the classes. Various rejection criterions such as Student's, Grubbs' and Dixon's are utilized. Data to be censored are taken from classic scientific literature items. There are executed examples of calculating robust estimators such as cut mean, winsorised mean, median and others.

Timetable of classes determine teacher to show and calculate the highest possible number of examples. The task is difficult. Usually there are discussed at least several relatively simple examples during a class. The tasks can be solved with use of a calculator and statistical tables. More complicated examples (where the number of arithmetical operations is too high), for which long to get results is necessary, are avoided. Data for more complex tasks are selected to obtain result in short time. Approximated results in following stages of procedure are allowed to speed up calculations.

Recent years experiences lead to conclusion that the tasks numerically solved from the start to the end are better understood by students. This way of solving problems is useful to hold students' attention and give them comprehension of solved problems. Such as examples are essential for fixing knowledge presented during earlier lectures. Very complicated examples like estimating parameters of periodical signals or signal spectrum are calculated using computer and the results are presented with multimedia techniques.

#### 4. LABORATORY CLASSES

The laboratory classes are performed during second part of the semester when classes has just been finished. Students have practical skills and are able to select and apply the proper measurement procedure. The aim of the laboratory classes is to develop self-reliant proficiency in using procedures on real and simulated data. Students solve problems, perform computations, comment and interpret results. The following way should be passed by students:

- To acquaint with a measurement task and a type of an acquired data,
- To programme a data processing in a specific environment,
- To apply the procedure to the data,
- To assess and discuss obtained results.

The organisation of the laboratory classes is as follows: students are divided into sections (maximum three, average two persons). Each section has allocated computer-

ised stand with two programming environments: Matlab for Windows and LabVIEW. Some of them are equipped with measuring instruments (e.g. gas chromatograph, EPR spectrometer, vibration measurement system) which allow to realise exercises with use of real data acquired in experiment.

There are performed three exercises each eight teaching hours long (twice for four hours). Each section has different task and each student research its distinct aspect. A separate report for each student is required.

The described order has many advantages. In the first part the whole section works together. They prepare computational tools that will be used by entire section. In the second part students realise their own tasks. They are allowed to choose data sets and what aspects of the procedure will be studied.

The use of ready-made programmes where the results are obtained just after loading the input data is unproductive and wrong from an educational point of view. The procedures used in ready-made libraries are poorly documented and students do not understand how the procedure works.

The topics of the laboratory classes are as follows:

**Filtration of signals.** The problems of filtration of chromatographic and spectrometric signals are discussed. The signal is a sum of peaks of different types. There are used real data (acquired during experiments from the gas chromatograph and the EPR spectrometer) and simulated, based on different peak model (e.g. Gauss, Lorentz, Poisson). The following procedures are examined: simplified least squares polynomial smoothing by Savitzky and Golay, simple and iterated median filtering, frequency domain filtering. Aside from programming problems, the attention is paid to selection of the procedure and their parameters to the data, filtration quality and systematic errors.

**Spectral analysis.** The amplitude and phase spectrum of multisinusoidal signal are studied. First there is discussed selection of sampling frequency and number of samples for the analysed signal. Then there are shown aliasing, leakage and its reduction with use of time domain windows. Resolving the frequency location of closely spaced sinusoids and amplitude measurements for different types of windows are demonstrated. Finally resolution enhancement with use of decimation and zero padding techniques are tested.

**Linear and nonlinear regression.** At this classes students examine different procedures of linear regression. The procedures are appropriate for different types of errors. There are tested procedures of linear regression adequate for constant standard deviation of errors and standard deviation proportional to input quantity (this case is present quite often in practice). Special attention is paid to weighted least squares method. Procedures are suitable for simple regression models because it is the most frequent case in field of calibration of measurement devices.

Topic connected with nonlinear regression methods are put into practice on gas chromatography stand. Chromatographic analysis of mixture of alcohols are a source of

the signal. There are considered models in form of sum of the peaks which parameters are usually nonlinear. Analysed signals are both simple (all peaks are single) and complex (signal consists overlapping peaks). Students programme procedures for estimation of parameters of these signals. Among other matters students test the convergence of different optimisation algorithms and influence of initial parameters on results of analysis.

## 5. CONCLUSIONS

Subject *Measurement Procedures* is one of the most important at speciality *Measurement Systems*. Its significance is a result of bundling into whole theoretical knowledge from many different preceding lectures and classes. However teaching methods emphasise metrological point of view, many other tasks can be solved using shown techniques. This results in students knowledge profile useful for working not only in industry but also in other lines of job activities. Our contacts with graduates confirm that their skills take advantage not only in solving typical engineering problems but also in other domains such as for example economics.

Problems connected with measurement procedures are active field of research for several researchers in Measurement System Group. It guarantees high level and topicality of lectures and classes of *Measurement Procedures*.

## REFERENCES

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