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A THREE-STEP APPROACH TO PRACTICAL TRAINING IN MEASUREMENT

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Abstract – This paper reports on a training program in measurement for undergraduate students, in which emphasis is put on a critical attitude with respect to the whole measurement process. A thorough analysis of the measurement environment, the measurement devices and the signal processing are prerequisites for a correct interpretation of the measurement results. These skills are trained using a complete system built up in modules that can be studied separately. The student starts with the characterization of transducers, followed by studying the associated signal processing and finally evaluates the performance of the complete measurement system, all by hands-on experiments.

Keywords: training, education in measurement

1. INTRODUCTION

The mission statement of the Department of Electrical Engineering, University of Twente, reads: "The Department seeks to train students in a spectrum of professional and personal competencies to design signal processing systems; design is a creative process requiring overview and judgement in analysis and in recognition and execution of research questions."

A basic component of these competencies is the correct performance of measurements. Therefore, it is a major responsibility of the university to offer an environment where students can learn how to accomplish measurements according to standardized procedures and that are credible and profitable to other users of the measurement results.

The education in measurement science starts in the first year of the Bachelor phase with a practical training in using electronic measurement equipment, including digital multimeters, generators and oscilloscopes, all connected to a computer and controlled by LabVIEW [1]. In the second year students follow a course on basic Measurement Science, accompanied by intensive practical exercises in a laboratory. The general BSc measurement program is completed by a design project, where students integrate knowledge from various courses (including measurement science, system engineering and control theory), demonstrated by the realization of a mechatronic system comprising all of the elements from these courses. The MSc program offers various advanced courses on particular topics from measurement science, for instance digital measurement systems, pattern recognition and optimal estimation theory.

Obviously, a major part of the teaching consists of practical training with real measurement equipment, according to the assumption that measurement is learned by doing. Unfortunately, cost reduction is often a motive to move from real measurement equipment to virtual instrumentation. Of course, such virtual instruments have their benefits, also in education. Nowadays more and more universities use virtual instrumentation for training purposes [2-4] and profit from their flexibility, reduced routine work and the possibility of remote operation. However, a measurement takes place in the real world, and the training process needs, at least partly, be performed in the same real world. In this contribution we present a laboratory environment that enables students to familiarize with the total spectrum of skills that are to be learned for performing correct and effective measurements. The environment comprises both measurement equipment and virtual tools for the execution of real measurements and the proper interpretation of the results. The new approach is running for two years now, and is highly appreciated by the students.

2. A THREE-STEP APPROACH

2.1 General considerations

Any act of measurement should be accompanied by a discussion on the uncertainty, to justify possible errors in the final result. To find the main sources of inaccuracy and to improve the overall performance of the measurement, all system parts and every step in the measurement procedure must be considered with care.

In the new approach, introduced two years ago [5], the student will investigate three different measurement systems, each in three steps: the transducers, the signals and finally the application itself (Figure 1). In the consecutive steps, focus is on the application of specific knowledge or skills: in the first step students apply physics, in the second step mathematics and in the last step they train experimental skills. This partitioning in three phases is characteristic for all measurement systems in this course.

Students spent in total 10 daily periods (one period is 3.5 hours) for the practical training, alternated with lectures and periods for reflection and self-tuition. The scheduled time for the whole course on Measurement Science is 100 hours.

The practical part of the course comprises an intensive study on three complete measurement systems: (a) an optical sorting system, (b) an acoustic flow measurement system and (c) a system for the measurement of mechanical displacement. Students study the various elements of each of these systems according to Figure 1. A short description of the three measurement systems is given below. The three focus points are given in Figure 2.

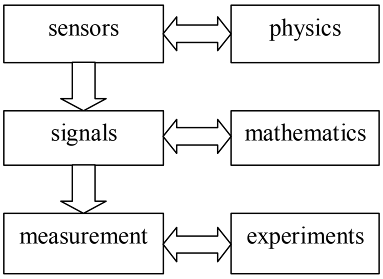

Fig. 1. Three step approach. Left column: study objects; right column: knowledge fields

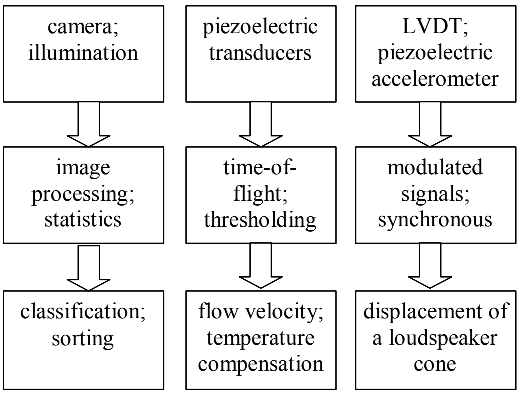

Fig. 2. Three-step approach for three different measurement systems

2.2 *Optical sorting of objects*

The sorting system consists of a conveyer belt carrying various objects, a digital video camera and illumination equipment. There are four classes of objects: M5-nuts, M6-nuts, M5-rings and M6-rings. The system should be able to determine the correct class of each object using the vision system. Of each object the surface area and the circumference are determined from a 2D image obtained with the camera (Figure 3). The measured values are put in an Excel sheet, which enables a quick construction of a scatter diagram (Figure 4).

These two parameters are sufficient for a correct classification, provided the measurements are sufficiently accurate. From a scatter diagram a classification can be made.

Students should learn to determine by experiment the inaccuracy in the measurement of these two parameters. Meanwhile they get acquainted with a vision-based measurement system and the associated problems (for example the illumination and the limited spatial resolution). The training session comprises the following exercises:

- Introduction to IMAQ Vision Builder [6]
- Calibration of a vision-based measurement system
- Image acquisition with various types of illumination
- Execution of measurements
- Introduction to MS-Excel [7]
- Statistical analysis of measurement errors using a spread sheet program.

IMAQ Vision is a LabVIEW library, that can be used to create VI's for vision applications: image acquisition, image processing, image analysis etc. IMAQ Vision Builder is a menu driven program that facilitates the use of this library.

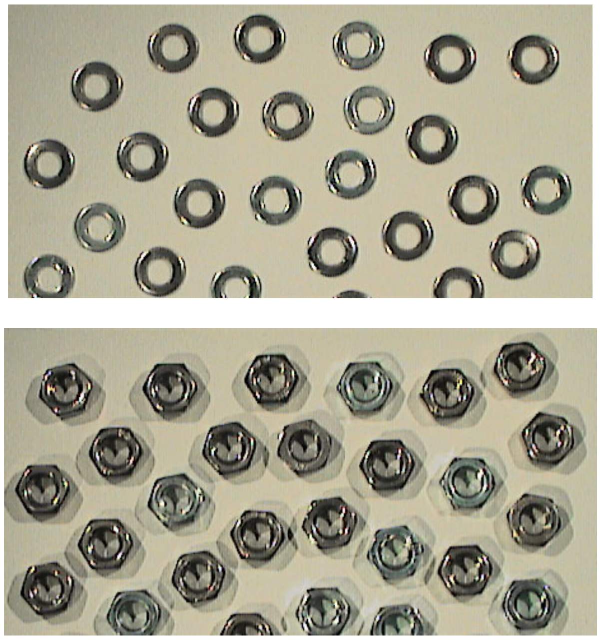

Fig. 3. Examples of images of rings (top) and nuts (bottom)

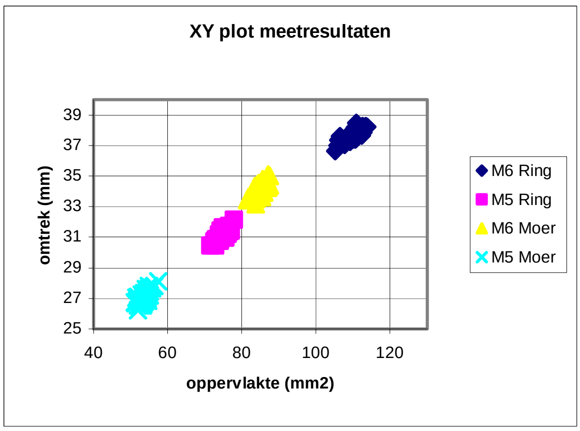

Fig. 4. Example of a scatter diagram made by the student, using the measurement data obtained from a series of images. Horizontal scale: surface area, vertical scale: circumference; legend: M6 ring, M5 ring, M6 nut, M5 nut.

2.3 *Acoustic flow measurement*

In this part of the course students have to measure the velocity of an air flow in a pipe. The measurement is based on an acoustic time-of-flight (TOF) method, using a pair of ultrasonic transducers positioned face to face in the pipe, at a fixed distance. Obviously, the measurement result is corrupted due to a variety of causes and the final result is rather inaccurate because a number of parameters is not accurately known. To avoid the disturbing influence of sound velocity, the TOF is measured once with sound travelling with the flow and once opposing the flow. The student's task is to explore the merits of this principle.

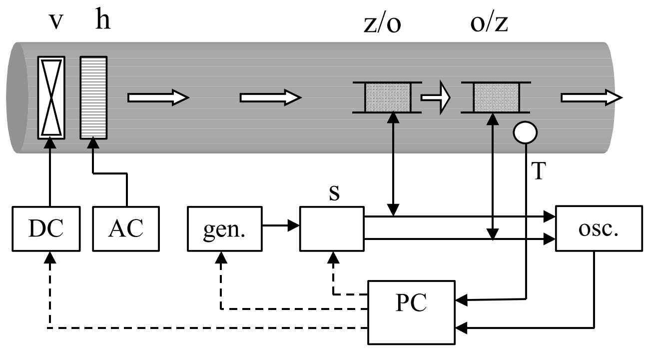

Fig.5. Measurement set-up for the determination of flow velocity. The PC controls a fan v, a burst generator and a switch s (to change between transmission mode to receiver mode). T: temperature sensor, h: heater.

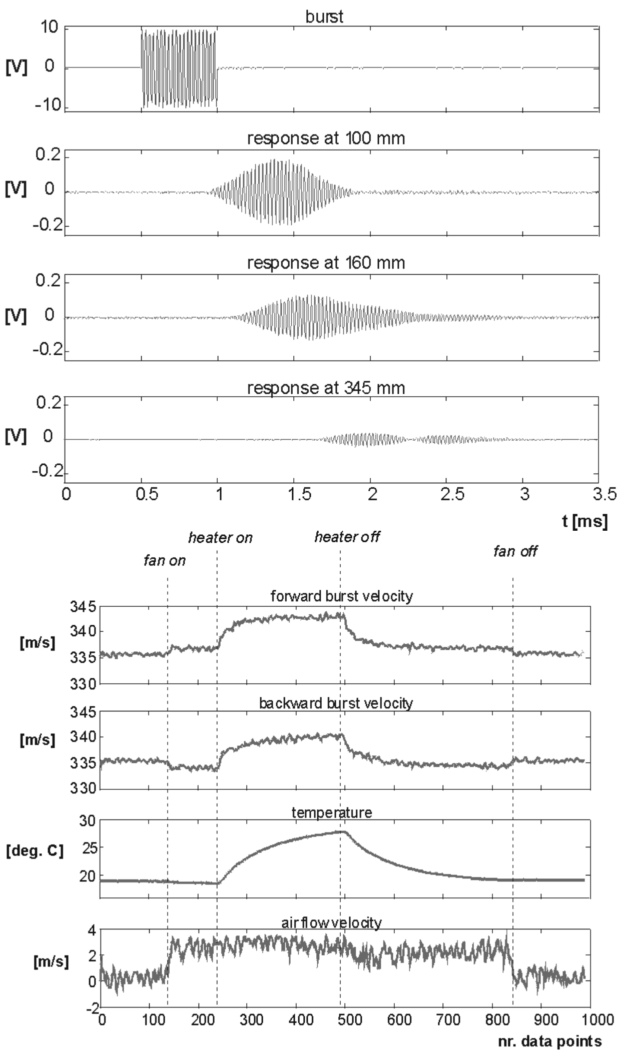

Fig. 6. Plots from the measurement system in figure 5. Top: burst signals (spurious echo in the lowest part); bottom: proof of temperature independent flow measurement.

The training session comprises at least the following exercises:

- Determination of characteristic properties of piezoelectric transducers: resonance frequencies, the response to a burst signal, directivity diagram
- Measurement of the ToF in still air; calculation of the speed of sound
- Measurement of the ToF at various flow velocities and different temperatures

Figure 5 shows the complete setup of the measurement system. It allows the measurement of the ToF in two directions, enabling the elimination of the speed of sound (and the temperature dependence) for an accurate measurement of the flow velocity. Figure 6 (top) shows typical responses on a burst stimulus; the signals in the bottom part demonstrate the elimination of the sound speed when using the two-direction method.

2.4. Mechanical displacement measurement

Students have to measure the movement of a loudspeaker cone, using two different displacement sensors: an LVDT and an integrated capacitive accelerometer. They make acquaintance with the characteristics of both these sensors, and should find out which one is the best choice in a particular situation (static, dynamic). Other aspects that get attention in this section are sampling, modulation and (synchronous) demodulation.

Some of the exercises in this training session are:

- Calibration of the LVDT
- Sampling and exploring the minimum sampling rate
- Determination of position from acceleration signals
- Calibration of the accelerometer
- Measurement of the transfer function of a loudspeaker.

A particular result is given in figure 7, showing how the modulated displacement signal of an LVDT is demodulated by synchronous detection.

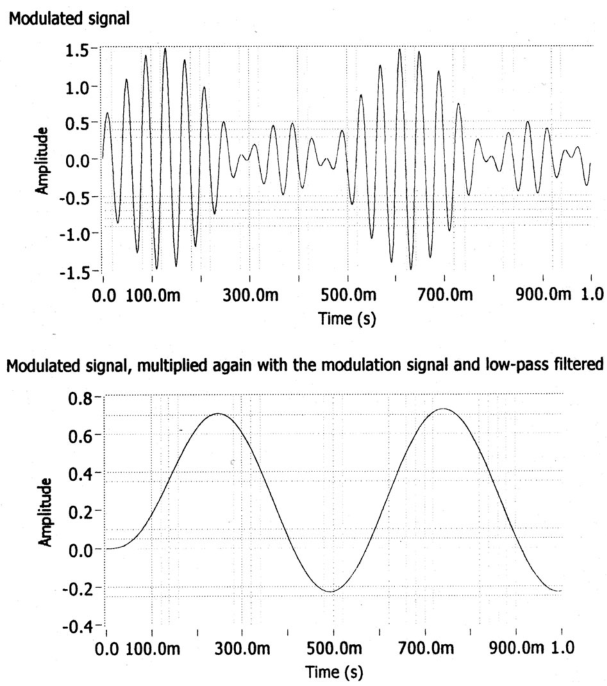

Fig. 7. Modulated and demodulated signals.

3. VIRTUAL INSTRUMENTATION

Recurrent problems with experimental training are the limited resources and the restricted learning time of the student. The first aspect is often circumvented by the use of virtual instruments and simulations only. Obviously, this solution does not really contribute to the development of experimental skills. The question of the limited learning time can be minimized by a well balanced combination of soft and hard tools and easily accessible tutorial aids (lecture notes, help files).

Using virtual tools, the flexibility of the measurement system is increased. The software offers the student a possibility to modify the parameters of the test signals and to quickly store and analyze measurement data. It also offers a powerful diagnostic tool. Virtual instruments also introduce specific problems (quantization errors, sampling rate, limited signal window and timing errors) and therefore need to be examined by the student as well.

The core of the software used in this training course is LabVIEW. This program is capable of controlling the oscilloscope and generator settings, reading the oscilloscope and controlling the whole measurement sequence. Once a measurement procedure has been set up, the measurement itself can be executed in a short time, and repeated an arbitrarily number of times. The latter allows also a statistical analysis of the measurement data.

In order to benefit most of the approach as outlined above, the student should be able to execute as many measurements as possible with a minimal preparation time. On the other hand, the student must obtain sufficient insight in the measurement set-up to understand the basic functions and operation. To that end, the connection of the hardware modules is part of the assignment.

In this phase of the teaching program students lack experience in LabVIEW. Moreover, most programming does not contribute to the understanding of the measurement system and is therefore prepared in advance. However, to make students familiar with using LabVIEW a special short instruction is given prior to the actual exercises.

Control of costs is an important aspect in the set-up of a practical training course, in particular when large groups of students must pass the whole training sequence in a restricted period of time. The construction of many duplicates of the whole measurement set-up as described would be too expensive. To allow the students work in parallel only parts of the system are duplicated. For instance, for the first step of the ultrasonic system a simple experimental set-up is made available consisting of a ruler with a couple of transducers that can easily be positioned and replaced. Such subsystems can be duplicated at low cost. Furthermore, some tasks can be performed completely off line, for instance the processing of the image data from the vision system.

4. EVALUATION AND CONCLUSIONS

The three-step concept outlined in this paper is running this year for the second time. A short evaluation after the first time showed already some benefits. Students are forced to perform a systematic analysis and characterization of all system parts (including errors) prior to the execution of the final measurement. They are trained to acquire a critical attitude towards measurement experiments and to present measurement results together with a discussion on the inaccuracy. The time students need to work on line has been minimized whereas the experimental training has been maintained at an acceptable level.

The evaluation also showed some weak points. Reliability of the set-up is an aspect that should not be ignored. Unexpected failures, signal interference, erroneous wiring and subsequent system break down make students uncertain and may also lead to unacceptable time loss. The second year most of these kind of failures were eliminated or avoided by a more reliable design.

The whole training takes 10 daily periods: one period for LabVIEW and three periods for each of the three measurement systems. Although the course is quite intensive, students appreciate this way of learning, because of the strong connection between theory and practice. They make acquaintance with many aspects of a measurement system at the same time, in a coherent and realistic environment. It is believed that such an approach stimulates the motivation to learn theoretical aspects although it is hardly possible to demonstrate a quantitative improvement of the concept.

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