

**Developing a Minor Program in Computer-based
Measurement and Instrumentation
For Undergraduate Science and Engineering Majors**

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Abstract

The Department of Mathematics and Computer Science at Fort Valley State University has recently implemented a minor program in computer-based instrumentation and measurement. The primary objective of this project is to enhance the mathematics, physics, computer science, and electronic engineering technology programs at Fort Valley State University by designing and offering a minor in the field of computerized measurement and instrumentation. The minor program is structured around four courses: a two-course sequence in instrumentation and measurement systems, a course in applied statistics and a capstone. A salient feature of this program is its interdisciplinary nature since it serves various majors including physics, engineering, computer science, and chemistry.

To support the aforementioned program a state-of-the-art computer-based instrumentation laboratory has been established. This lab is equipped with twelve (12) Pentium III PCs, data acquisition boards, signal conditioning modules, automation electronics, various passive and active sensors, and LabVIEW software. The lab also includes two experimental set-ups that can be fully controlled, monitored and operated by computer systems using virtual instrumentation technology. They also feature on-line capabilities that allow users to operate them remotely through the Internet.

The new curriculum has positively impacted our existing programs in many respects. For the first time, our students have been able to perform applied research in their fields of engineering and science and publish/present their findings in a national scientific conference. In addition, the lab has been utilized as an instructional facility in teaching of a number of courses in mathematics, physics and engineering.

This paper describes the efforts undertaken with respect to curriculum development and the technological infrastructure put in place to offer this minor program. Also included in this paper are student comments and a general discussion regarding the program's positive educational impact and implementation challenges.

Introduction

Fort Valley State University, a historically black institution located in Middle Georgia, with a student population of over 2500 offers comprehensive undergraduate programs in arts and sciences, agriculture and education.

The Department of Mathematics and Computer Science offers four degree programs, a B.S. in Computer Science, a B.S. in Computer Information Systems, a B.S. in Mathematics and a B.S. in Education with a major in Mathematics. In addition, the department offers physics, basic engineering and geology courses.

In response to a proposal solicitation from NASA to enhance existing science, engineering and technology programs at educational institutions, the department submitted a proposal (that was subsequently funded) to implement a minor program in computer-based instrumentation and measurement. The primary goal of this minor program is to extend the existing curricula in mathematics, computer science, physics, and engineering in a specialized minor program, which requires students to integrate their knowledge and skills from these diverse fields of studies. This program also aims to increase the representation of minorities in advanced technical fields that are of special interest to high-tech industries including NASA.

A modern computerized instrumentation lab is currently being developed at the Department of Mathematics and Computer Science of FVSU to support the curriculum of this minor program. The laboratory is already equipped with some experimental setups that could be used to perform scientific experiments for lab science courses offered at FVSU. These setups are fully controlled, monitored and operated by computer systems using virtual instrumentation technology. Some of these setups also feature on-line capabilities that allow users to operate them remotely through the Internet.

The significance of this program goes beyond the integration of curriculum and technology in an academic setting. Students entering in this program will have the opportunity to pursue high-tech careers in the field of computer-based instrumentation. In recent years, rapid advances in computer hardware and software systems coupled with falling prices in electronics have prompted various industrial sectors to implement computer-based measurement and automation in their plant operations. Today, with the help of advanced software systems (such as LabVIEW¹) and powerful PCs it is possible to design and develop complicated virtual instruments which have dramatically improved the accuracy, robustness and efficiency of measurement systems over traditional ones. These advances in turn have created a need for skilled and knowledgeable college graduates in this field. Thus, it is imperative that institutions of higher learning offer programs to train students in this area².

Curriculum Development

The curriculum in computer-based measurement and instrumentation at FVSU is structured around four courses that feature progressively more advanced topics, and sophisticated hands-on laboratory based projects and experimental analysis. This structure complies with the “major electives” and “free electives” course requirements in place for science and engineering majors

at Fort Valley State University. Students in these majors are usually required to take a minimum of two major electives and two free electives. Thus, it is possible for students to obtain this minor without having to take additional courses beyond their major requirements.

Course One:

This is the first course of a two-course sequence in *modern instrumentation and measurement systems*. This four-semester hour course is designed as a junior-level course with Calculus I and a high-level programming language such as C/C++, Fortran, Visual Basic, or Pascal as its prerequisites. The purpose of this course is to acquaint the student who has no previous knowledge of the subject with

- the fundamentals of instrumentation,
- computer hardware,
- analog and digital signals,
- functional descriptions of measuring instruments,
- performance characteristics (both static and dynamic) of instruments, and
- typical measuring sensors such as thermocouples, LVDTs, linear motion sensors, pressure sensors, and voltage and current sensors.

This course is delivered through three hours of lecture and one two-hour laboratory session each week. Laboratory experiments are preceded by about half an hour of lecturing related to the particular measurement system as applied to a given experiment. The general approach is to perform a relatively small number of experiments, so that the instructor has sufficient time to introduce methods of computer-based measurement systems, measuring devices, sensor calibration techniques, and LabVIEW software system. The experiments are designed mainly to illustrate the basic concepts used in modern measurement systems.

Course Two:

This is the second course of the above sequence devoted to *scientific measurement and instrument design*. The contents of this four-semester hour course include topics in

- modern measuring devices used in many fields of science, particularly those offered at Fort Valley State University (such as physics, chemistry, biology, and agricultural engineering),
- signal processing techniques,
- measurement noise and error sources,
- experimental analysis,
- computerized data acquisition and processing systems, and
- virtual instruments

The course materials are offered in form of three lecture hours and a two-hour laboratory session per week.

Course Three:

The curriculum also includes a senior level (three-semester hour) course designed to introduce the basic concepts and methods of *statistical estimation, time series, forecasting and filtering*. The suggested prerequisite for this three-semester hour course could be Statistics or Calculus I. Typical course contents include:

- Statistical distributions such as normal, student, and uniform

- Data Qualification including mean, variance, skewness, flatness, and statistical errors
- Sampling theorem and aliasing
- Time domain signatures such as autocorrelation, crosscorrelation, and probability density functions
- Univariate time series models for system monitoring such as autoregressive and autoregressive moving average models
- Introduction to frequency domain analysis including fast Fourier transforms and filter design
- Introduction to Kalman-filtering

Several examples will be given from various fields including signal processing, global positioning systems, inertial navigation systems, and atmospheric data assimilation.

Course Four:

The final course in the minor program is a three-semester hour *capstone seminar course* in instrumentation and experimental analysis which is designed to extend the breadth and depth of students' knowledge by providing them with valuable undergraduate research experience.

- At the beginning of the term, students enrolled in the course will form groups and select a research topic. Each topic would have to be approved by the instructor, based on the relevance of the research to the student's field of study.
- Scholars from academia and industry will be invited to give presentations to students.
- The course includes at least two field trips to industrial facilities. These field trips will help students gain a better understanding of the applicability of the methods and concepts learned in the course of study.
- For successful completion of the course, the final presentation and report is required to be of a quality suitable for presentation in state and national conferences.

This course will be offered during Fall 2002, and once a year thereafter.

To summarize, the main purpose of the two-course sequence is to provide students with the knowledge and expertise needed to design and conduct high-tech scientific experiments. The third course further helps improve their knowledge of data and information processing as well as their analytical thinking and problem solving skills. Finally, the capstone course provides students with valuable undergraduate research and teamwork experience.

The curriculum described above can be easily adopted by similar institutions with minor modifications to meet the specifications of their individual program. For instance, the "statistical estimation, time series, forecasting and filtering" course can be substituted with a similar course in statistics and/or probability. In this case, one might consider introducing topics related to data analysis such as time domain, frequency domain and Kalman filtering in either the second or the fourth course of the curriculum.

Instrumentation Laboratory

A modern computerized instrumentation lab has been developed at the Department of Mathematics and Computer Science of FVSU to support the curriculum of the minor program. This lab is equipped with twelve (12) Pentium III PCs, data acquisition boards, signal conditioning modules, automation electronics, various passive and active sensors, and LabVIEW

software.

The lab also includes two experimental set-ups that can be fully controlled, monitored and operated by computer systems using virtual instrumentation technology. They also feature on-line capabilities that allow users to operate them remotely through the Internet. These set-ups are: (1) a motor-generator with a variable speed motor and a variable resistive load and (2) a variable-speed water pump, flow and level system.

Laboratory Experiments

The pedagogical approach used in conducting computer-based experiments is to introduce the principle of computer-based measurement through a series of simple hands-on experiments. Students learn the importance of signal conditioning, sampling rate, instrument resolution and accuracy, error sources, and the type of sensors (active or passive) in designing simple scientific experiments. With the knowledge gained in these experiments, students are better equipped to design more advanced computer-based measurement systems. Since the minor program is structured around the needs of science students, it is imperative for us *not* to focus primarily on experiments involving only engineering applications.

On-Line Lab Experiments

The current lab facilities have been further enhanced by adding experimental set-ups with on-line capabilities. The purpose of installing these set-ups is to provide students with an opportunity to perform experiments that cannot be carried out during regular lab hours due to time constraints³. This technology is particularly cost effective in cases where it is prohibitively expensive to install more than one set-up of the experiment. In addition, it offers ample flexibility for the students to conduct experiment at their own convenience. These set-ups allow multiple users to access the experiment by placing them in a “time queue” with prescribed time duration allocated to each user.

On a more specific note, the lab is equipped with a motor-generator station (Figure 1) and a flow-level station (Figure 2) which can be operated both locally and remotely through the Internet. For instance, students use the motor-generator set-up to remotely measure motor and generator voltages, rotational speed, generator current, exerted torque on generator, and motor, generator and ambient temperatures.

During these two experiments, the *entire* lab time is used to explain the lab procedures and underlying concepts in a fairly detailed manner. Perhaps one of the main advantages of this method is the fact

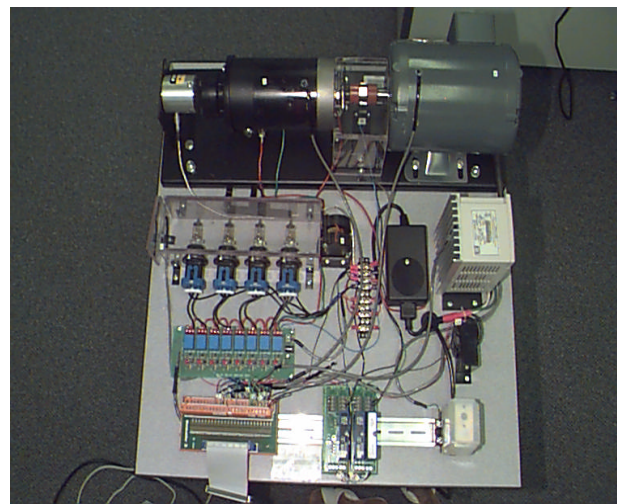


Figure 1: Motor-generator experimental set-up.

that students get a ‘physical feel’ for the experiments and are able to ask questions regarding both the theory and experimental procedures due to the availability of time. They are subsequently required to carry out the experiment on the Internet later on at their own convenience. This automatically solves the problem of requiring twelve or more students to work on a single experimental set-up at the same time, as would be the case for more traditional lab set-ups.

Students who conducted the above experiments on-line have been surveyed and their responses are included in the following section.



Figure 2: Flow-level experimental set-up

Student Feedback

The two-course sequence in minor program has been evaluated using an evaluation instrument (SIR II) provided by the Education Testing Services (ETS). Table 1 shows student responses in categories related to course effectiveness and outcomes as well as student effort and involvement. The total number of students responding to the evaluation instrument was five and the number of students enrolled in the two-course sequence was six.

Table 1: Student assessment of the course effectiveness

<i>Assessment Item</i>	<i>Student responses taken from Sir II report</i>		
Course Outcomes and Student Effort and Involvement	5 Much More Than Most Courses	4 More Than Most Courses	3 About the Same as Others
My learning increased in this course	20%	80%	
My interest in the subject area has increased	60%	20%	20%
This course helped me to think independently about the subject matter	20%	60%	20%
I studied and put effort into this course	20%	40%	40%
I was prepared for each class (writing and reading assessments)	20%	20%	60%
I was challenged by this course	20%	60%	20%
This course actively involved me in what I was learning	20%	60%	20%

In addition to the above assessment instrument, students were required to submit a course critique at the end of the second course to assess the strengths and weaknesses of the curriculum and procedures used in the two-sequence course. The analysis of their critiques is shown below.

- Over eighty three percent of students felt that the skills they learned in these two courses would make them more marketable in the high-tech job market.
- Nearly all students agreed that the G programming (LabVIEW) used in these courses was

- totally a new experience and helped them improve their creative and organizational skills.
- Two students expressed their interest in pursuing graduate studies in this field.
- Fifty percent of students expressed some difficulty in learning data acquisition topics such as Nyquist sampling theorem and gain factors.

In regard to the on-line experimentation, the following are some selected comments provided by the students:

- We can pick the time to meet to run the labs instead of being required to be here for a set class time
- The ability to perform experiments from remote locations
- You can run experiments during class time or at 3AM as well as turn in your reports at any time over the web
- I liked the freedom of the lab
- It worked out well being able to work at different times
- This was a new experience. Especially running the experiments on the Web, and sending the assignments by e-mail

Some major concerns were slow connection, network congestion, non-availability of the remote site, and long queues due to too many co-current users.

Discussion

Since its implementation, the computer-based measurement and instrumentation has shown its positive impact on the quality of education and the curriculum used in computer science, mathematics, physics, and engineering at FVSU in many ways. For the first time in many years, undergraduate students in the Department of Mathematics and Computer Science were able to present their research in a scientific student conference. Through the use of lab facilities, some of the mathematics faculty was able to use experimental data in courses including differential equations and partial differential equations. Furthermore, the lab facilities developed for this program has significantly enhanced the technological infrastructure in the department. In fact, the state-of-the-art technologies utilized in this lab were recognized in an article published by the most respected local newspaper in the Middle Georgia. In addition, the lab facilities have also provided the departmental faculty with opportunities to perform applied research in the area of their expertise. The program has also generated academic interest in other departments within the university. For instance, the Department of Chemistry has expressed a keen interest in extending the existing minor program to a certificate program in computer-based measurement and instrumentation designed specifically to complement the chemistry major. In addition to its academic applications, plans are underway to use the program to train technicians and professionals who work for local industries in this field. For example, we are now in the process of establishing training courses for Robins Air Force Base and Blue Bird bus manufacturing company.

Perhaps the most challenging obstacle for institutions similar to ours that are interested in establishing such a program could be the lack of trained and knowledgeable faculty in this field. Fortunately, a number of institutions of higher learning and commercial companies in this field are offering training classes with large academic discounts. These classes might serve as a starting point for educators interested in this field.

The other challenging task could be the selection of suitable textbooks and lab manuals. Unfortunately, the choices in this respect are very limited and often it is necessary to complement a selected textbook with handouts from other sources. For instance, the textbook currently used for our first sequence course is "Sensors for Measurement and Control"⁴ and for the second course is "Introduction to Engineering Experimentation"⁵. Both these textbooks are complemented with a number of handouts. Perhaps, the only available lab manual that could be suitable for academic purposes is "Survey of computer-based experiments"⁶. Similar to the textbook situation, however, the instructor might need to supplement the lab manual with his/her own lab notes and handouts. In our case, a lab manual that met the needs of the curriculum of the minor program as well as the project budget was devised.

Conclusions

This paper presented a model program for creating and implementing a minor program in computer-based measurement and instrumentation. The curriculum of the program is designed to foster students majoring in physics, chemistry, computer science, or engineering. The main objective of this program is to equip students with the knowledge and skills required to meeting the technological challenges of a highly digital and computerized world. The implementation of this program could also produce a positive impact in science and engineering curricula (as discussed earlier) as well as high-tech skill sets of students who complete the program. Therefore, by offering courses / programs in computer-based measurement and instrumentation, we ensure that student obtain knowledge and skills beyond those gained by taking basic courses such as computer programming and/or an introduction to computers. The fact that today many industries are rapidly implementing computer-based measurement and automation in their systems should be another convincing reason for institutions of higher learning to start offering structured programs in this field. This can also help the further growth of this field that has been traditionally led by industry.

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