Instrument Development Laboratory

The Instrument Development Laboratory (IDL) designs, builds, and deploys advanced state-of-the-art instrument systems and custom application software in support of the ongoing experimental research efforts within the W.R. Wiley Environmental Molecular Sciences Laboratory (EMSL). As depicted in Figure 1, the IDL staff supports EMSL researchers by providing a wide variety of design and fabrication services (both hardware and software), custom engineered solutions to research problems, and in-depth experience in the interface and control of commercial instrumentation. Because most EMSL user projects have unique needs, the IDL staff is especially skilled in the integration of commercial and custom hardware/software packages to suit the exact specifications of specific research projects. Some of the IDL's most recognizable services are:

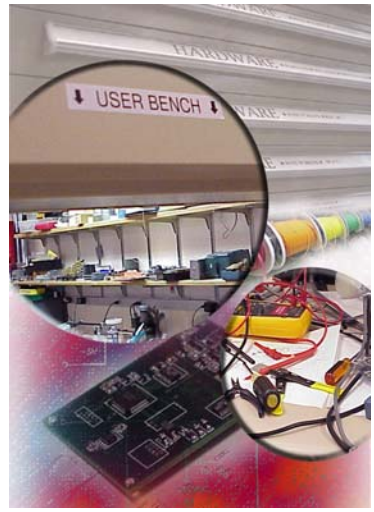

Figure 1. The IDL and its staff provide a wide variety of support to EMSL users.

- High voltage expertise
- RF (radio frequency)
- High-speed analog and digital systems
- Digital signal-processing and field-programmable gate array technologies
- Databases
- Laboratory automation
- Data acquisition
- Instrument control
- Common communications methodologies
- Software design and implementation (C, C++, Visual Basic, JAVA)
- Embedded Systems and personal digital assistants.

In addition to providing support to EMSL users within individual laboratories, the IDL also maintains a fully equipped design and fabrication facility within EMSL. This facility supports in-house electronics development and provides open use of its many state-of-the-art test and measurement equipment.

The IDL Philosophy

In an effort to reduce the cost of software development and to reduce development time, IDL has adopted the following operational philosophies:

- Develop reusable, modular, object-oriented code
- Tailor work to suit the needs of the EMSL scientific community
- Maintain code modules (controls) within a library that holds both commercially and locally developed software

- Develop software that is specific to instrumentation, whether commercially available or locally developed.

While the IDL is an EMSL support group, it is not limited to working only within EMSL. The IDL capabilities and the expertise of its staff are available to external customers. However, costs incurred during each project must be fully covered, including labor, parts, and test equipment costs.

Partnering with Us

Working with the IDL team is convenient and efficient, and is always customer-interactive. Contact with IDL staff can be made via telephone, shop walk-ins, the support queue, email, or by simply speaking with an IDL member in person. Names, telephone numbers, and email addresses for IDL staff members are listed at the end of this section. The specific services IDL offers are briefly described below.

The IDL design laboratory offers a staffed electronics and fabrication shop for EMSL research staff and facility users. Customers of the IDL will find a fully stocked parts supply, electronic components and small hardware, test and measurement equipment for check-out, and ready assistance from IDL staff members during business hours. For immediate hardware assistance, customers may access the IDL electronics laboratory and receive assistance from any IDL member. For uncomplicated work that takes very little time, there is usually no charge to EMSL staff for the services of IDL staff. For larger projects, staff may also access the IDL electronics laboratory and speak with an IDL member, who will happily assist the customer in defining the work to be done and begin the process of designing solutions.

Custom software design, development, and support are critical services offered by IDL to its customers. The IDL staff specializes in several key services related to research—data acquisition, instrument control, laboratory automation, systems integration, data analysis and visualization, data management and archiving, and handheld and embedded systems. Using a modular code design model as their basis, IDL software developers can efficiently develop software in a number of languages, tools, and scripts (e.g., Visual Basic, Java, C, C++, Labview, Assembly, Access, and SQL Server). In addition, software developers are skilled in a number of instrument control strategies, including general purpose interface bus, Serial (RS-232), IR, TCP/IP, Analog and Digital I/O, and high-speed event counting and timing.

The IDL maintains a support queue accessible by customers via email (idl-support@emsl.pnl.gov). The queue is monitored daily, and customers are encouraged to submit their requests for any type of service offered by the IDL.

The IDL website at http://idl.emsl.pnl.gov provides a full description of IDL capabilities, access to the support queue, team highlights, recent projects, statement of work access, and a downloadable business plan.

IDL technical support is readily available to assist researchers by providing software modifications, troubleshooting, fabrication, and research instrumentation support.

Collaborative research offers many exciting aspects, and the IDL has several proven capabilities—design of electronics hardware, control and monitoring software development, data management and automated data analysis, systems engineering, and embedded control.

What You Can Expect from the IDL

- **A statement of work** will be written for services requiring a significant amount of IDL staff time or resources. Each statement of work will provide contact information, a project description, start and completion dates, and cost justification. Statements of work are considered to be changeable documents that not only allow customers to have a clear understanding of IDL's role, but also allow internal tracking of work performed.
- **Full documentation** will be provided upon project completion, including schematics, descriptions of hardware and software, flow diagrams, setup information, operating procedures, and developer contact information.
- **Technical support and modifications** to IDL-developed systems will be provided.
- **A commitment** to maintaining and providing state-of-the-art resources will be provided.

IDL Advisory Board

This IDL Advisory Board has members from each of the research groups served by IDL and an IDL representative. The committee has been instrumental in forming the current IDL project-costing model and guiding the purchases of generic test and measurement equipment maintained by the IDL. Committee meetings serve as a useful forum for exchanging ideas, identifying questions or concerns, and providing information about the strategic direction of the directorates as it pertains to future development needs.

The IDL Advisory Board members are:

Gordon A. Anderson, IDL (Chair)
Michael K. Bowman, High Field Magnetic Resonance Facility
Mark H. Engelhard, Interfacial & Nanoscale Science Facility
Wayne P. Hess, Chemistry & Physics of Complex Systems Facility
Nancy S. Foster-Mills, Environmental Spectroscopy & Biogeochemistry Facility
Scott R. Studham, Molecular Science Computing Facility

IDL Project Highlights

Quantifying Peptide Abundance Ratios

M Goshe[(a)]
(a) North Carolina State University, Raleigh, North Carolina

Regulation of protein expression and modulation of post-translational modifications (PTMs) are biochemical processes that are vital to cellular function. Phosphorylation and glycosylation are two of the more important PTMs in eukaryotic cells because they are involved in many cell signaling cascades and pathways.

This paper describes analysis of yeast sample datasets to identify the changes occurring in protein abundance and the phosphorylation/glycosylation states of the detected proteins.

Various methods using stable isotope labeling have been reported to examine global protein expression levels, but few have the ability to quantify and monitor PTMs. A combination of metabolic labeling using $^{14}N/^{15}N$ isotopically enriched media and the phosphoprotein isotope-coded affinity tag approach using liquid chromatography tandem mass spectroscopy has been developed to identify and quantify phosphorylation and glycosylation for global proteomic studies.

Protein-identification and abundance-change analyses were performed using Instrument Development Laboratory (IDL)-designed software (ICR-2LS and LaV2DG) (see the visualization example in Figure 1). Datasets originated from previous collaborations with the primary author and were stored in the Proteomics Research Information and Management System. Dataset complexity and size required automated procedures for rapid processing and tools for inspecting and visualizing results. Original algorithms were developed and implemented in order to assist with data interpretation. Results of the analyses are expected to be published with IDL contributors to the research listed as co-authors.

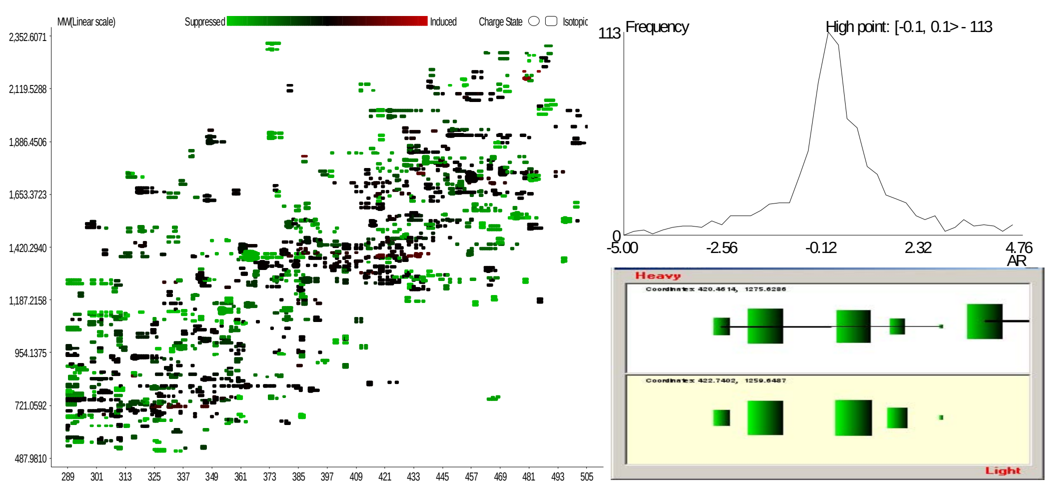

Figure 1. Complex datasets were searched for isotopic pairs and inspected using IDL-developed software.

Digital Signal Processing with Field-Programmable Gate Arrays

T Seim,[a] M Buschbach, [a] and E Choi[a]
(a) W.R. Wiley Environmental Molecular Sciences Laboratory, Richland, Washington

Very large-scale digital circuits called field-programmable gate arrays (FPGA) are being used to perform real-time signal processing of ultrasonic signals produced by chemical reactions. These arrays make it possible to move computations that were previously done by computers down to the transducer level. The advantage of this approach is greatly accelerated signal processing, which means faster analysis of ultrasonic phenomena with higher precision and significantly lower measurement noise.

Photo-acoustic spectroscopy is a new area of chemical analysis that offers the selectivity of absorbance spectroscopy at nearly the same sensitivity of reflectance spectroscopy. With this technique, the analyte is exposed to an intense pulse of non-coherent white light. The injection of this optical energy triggers a chemical reaction that yields an ultrasonic emission as a byproduct. An ultrasonic transducer is used to detect this emission.

The frequencies of ultrasonic signals can extend into the megahertz range, which requires digitizing rates of up to 10 times those frequencies. Computers have difficulty just transferring data at those rates, let alone performing any meaningful processing of the data. FPGAs have two highly desirable traits; they have a very large logic density, containing up to 10 million logic gates, and they are field programmable. The very large logic density gives them the complexity to perform involved signal processing tasks such as digital filtering and pattern recognition. Field programmability permits this functionality to be rapidly and cost effectively applied to a diverse range of applications. The detection of very weak ultrasonic signals requires the repeated co-adding of many waveforms to increase the signal-to-noise ratio. An FPGA has internal random access memory that is used to store the co-added waveforms of each of its 16 transducers. Internal logic controls the number of samples per waveform, the sampling rate, and the number waveforms to co-add.

A novel self-calibration feature allows the coupling coefficient between the transducer and the medium to be measured for accurate quantitative measurements. When operated, the transducer is pulsed to turn it into a sound emitter or transmitter. When the pulse is stopped, the transducer becomes a receiver. The emitted sound pulse reflects off the sample well and is detected by the same transducer that produced it. The pulse magnitude is a measure of the degree of acoustic coupling between the transducer and the sample, thereby allowing system calibration.

The instrumentation package includes for each of its 16 transducers, in addition to the FPGA, an electronic pulse generator, a fixed-gain analog amplifier, a variable-gain amplifier, an analog multiplexer, and a high-speed (10-MHz) analog-digital converter. The FPGA communicates with a personal computer through the computer's printer port. The computer writes to FPGA registers to control all aspects of data acquisition. A block diagram of the data-collection and analysis system is shown in Figure 1. A commercial FPGA development board was used as the foundation for this design. The application-specific interface electronics were developed on a custom electronics card that plugs into the development system, as shown in Figure 2. This design allowed rapid prototyping of the initial system.

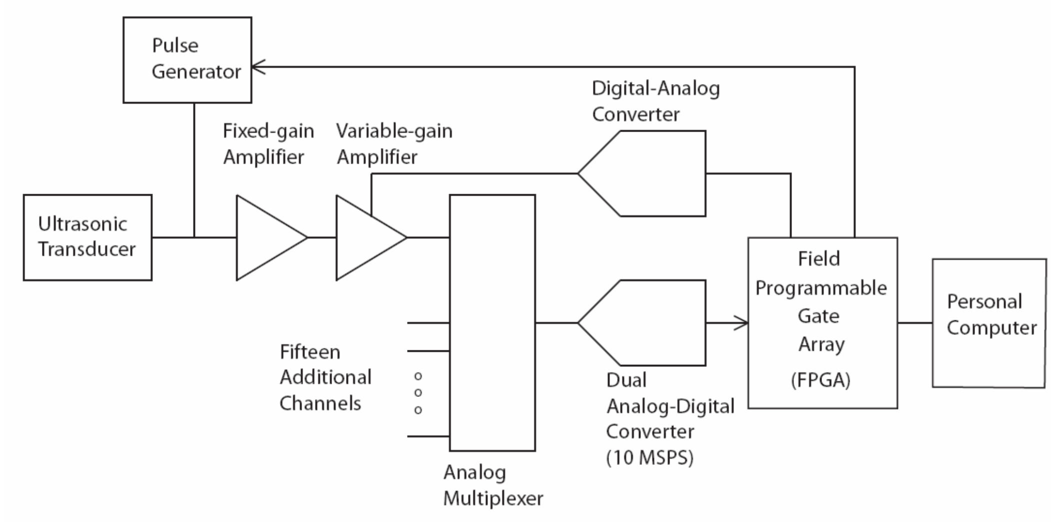

Figure 1. Block diagram of the data collection and analysis system based on FGPA technology.

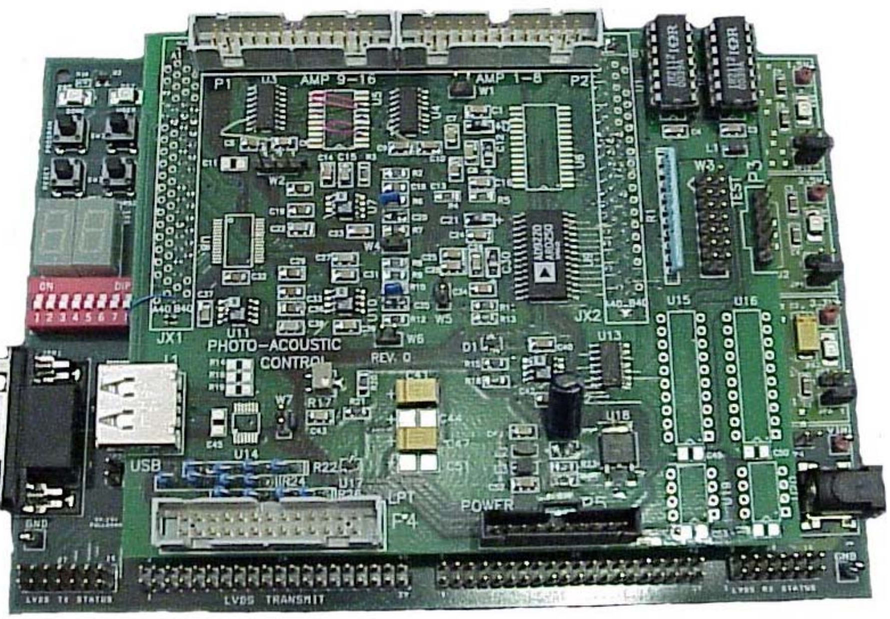

Figure 2. Commercially available FPGA development board with custom engineered application-specific interface.

Laboratory Robotics: Automated Liquid Chromatography Cart

K Swanson,[a] B Taylor,[a] E Livesay,[a] and R Zhao[a]
(a) W.R. Wiley Environmental Molecular Sciences Laboratory, Richland, Washington

The Instrument Development Laboratory (IDL) multidisciplinary staff worked closely with the scientists in the W.R. Wiley Environmental Molecular Sciences Laboratory (EMSL) High Performance Mass Spectrometry Facility to develop the automated liquid chromatography (LC) cart (Figure 1) to enhance the throughput of samples on the Fourier transform ion cyclotron resonance (FTICR) and ion trap mass spectrometers.

Figure 1. Automated LC cart.

For versatility and convenience, different valve and pump configurations can be set up on different carts. The mobile cart configuration makes it extremely convenient for researchers to move an LC set-up from one mass spectrometer to another instrument, or a sample from one cart configuration to another cart. The cart automation software and the system integration were done by IDL staff. The electronics, wiring and cart assembly were also done by IDL staff.

These carts and the high-throughput FTICR mass spectrometers are integral parts of the cutting-edge equipment used in the important proteomics research being done in the EMSL.

The LCMSControl software application encompasses all the functionality necessary to operate the LC Cart and to invoke data acquisition on the mass spectrometer with which the cart is associated. Written for the Windows platform, LCMSControl allows an operator to build and automatically process a list of samples. For each sample run, the software instructs the cart's autosampler to retrieve a measured volume from a designated vial in one of the autosampler's trays. Then, through a precisely timed sequence, it controls the sequencing of all the valves on the cart to pass the sample through the separation column to the mass spectrometer, and then signals the mass spectrometer's control computer to begin data acquisition. When the acquisition interval is completed, the application then instructs the mass spectrometer to stop acquisition. In addition, LCMSControl can monitor the levels of the solvents used in the separation process and refill the pumps that supply those solvents as needed. The operator interface for LCMSControl is shown in Figure 2.

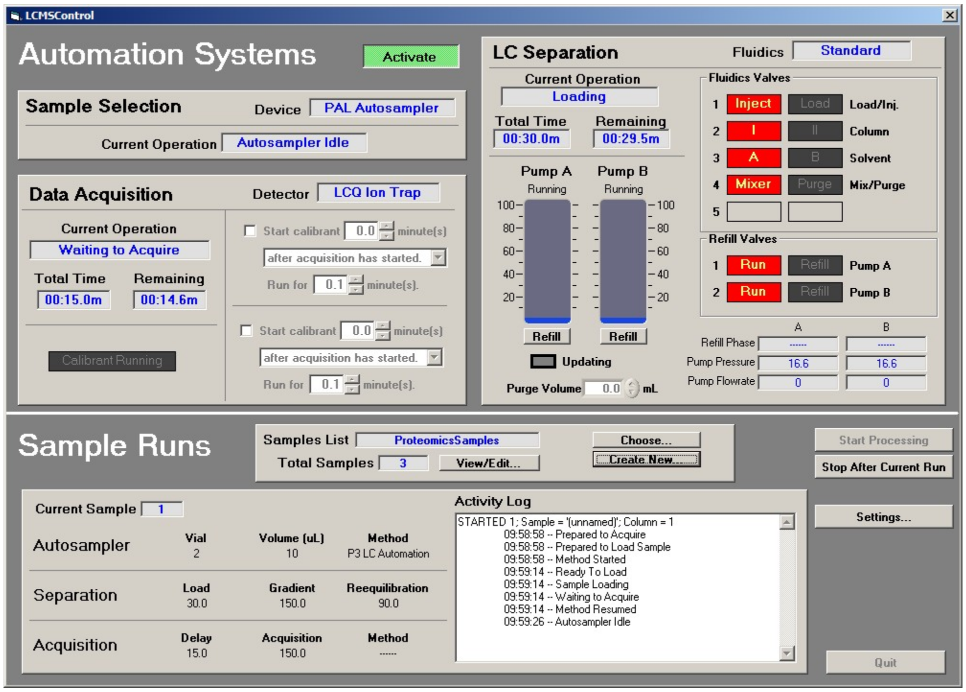

Figure 2. Automated liquid chromatography cart operator interface screen.

Used in this way, the LCMSControl application enables continuous, unattended cart operation for three or four days, during which time as many as 32 samples may be processed. In addition to the dramatic increase in overall throughput of the proteomics laboratory, the LCMSControl application has greatly improved data-collection consistency.

The LCMSControl application is designed to interact effectively and seamlessly with the several types of cart configurations and mass spectrometers found in the proteomics laboratory.

Staff

Gordon A. Anderson, Staff Scientist, Technical Lead
(509) 376-9558, gordon@pnl.gov

April L. Green, Senior Secretary
(509) 376-0591, april.green@pnl.gov

Kenneth J. Auberry, Senior Research Scientist
(509) 376-1453, kenneth.auberry@pnl.gov

Michael A. Buschbach, Scientist
(509) 376-7207, michael.buschbach@pnl.gov

Eric Y. Choi, Graduate Student
(509) 376-4509, eric.choi@pnl.gov

Paris DiLisle, Hardware Technician
(509) 376-9226, paris.dilisle@pnl.gov

James L. Eick, Technician VI
(509) 376-4540, james.eick@pnl.gov

James C. Follansbee, Research Scientist
(509) 376-4689, james.follansbe@pnl.gov

Marie C. Gibbons, Student
(509) 376-1971, marie.gibbons@pnl.gov

Gabriel F. Guillen, Student
(509) 376-1727, gabriel.guillen@pnl.gov

David C. Prior, Technologist
(509) 376-3923, david.prior@pnl.gov

Thomas A. Seim, Senior Research Scientist
(509) 376-2533, thomas.seim@pnl.gov

Kenneth R. Swanson, Senior Research Scientist
(509) 376-0826, kenneth.swanson@pnl.gov

Beverley K. Taylor, Technician VI
(509) 376-5095, beverley.taylor@pnl.gov

Nikola Tolic, Senior Research Scientist
(509) 376-3090, nikola.tolich@pnl.gov