APPENDIX B
COMPUTER-BASED LABORATORY SOFTWARE AND HARDWARE*

WHAT IS A COMPUTER-BASED LABORATORY SYSTEM?

In most modern experimental laboratories, electronic sensors are used to collect data automatically. When a sensor is attached to a computer, a very powerful data collection, analysis, and display system is created. Computers coupled with appropriate software packages are capable of analyzing signals and displaying them on the screen in easily understood forms. Using these capabilities, a “real time” picture of the data in a symbolic representation, such as a graph, can be obtained.

The use of real world data and graphical representations provides an immediate picture of how a physical quantity such as an object’s position or temperature changes over time. This picture leads to a better understanding of the data’s significance. A system for the capture and display of scientific data, consisting of a microcomputer, an electronic interface, software, and sensors, is often called a microcomputer-based laboratory system. MBL is a commonly used nickname for such a system. Another common name is simply computer-based laboratory system. (CBL is not used as a nickname because a recent new data recording system that works with a programmable calculator instead of a computer has been dubbed “CBL.”) In this appendix all of these systems will be referred to collectively as Computer-Based Laboratory systems.

At present there are a number of Computer-Based Laboratory systems with electronic interface devices, associated sensors, and software that allow either a Macintosh or PC-compatible computer to be used as a laboratory instrument. The electronic interfaces transform signals from the sensors into forms which the computer accepts as input. In this appendix we will briefly describe three Computer-Based Laboratory systems, each of which uses a distinct electronic interface: The Universal Laboratory Interface (ULI) distributed by Vernier Software; the Signal Interface II (SI2) distributed by PASCO scientific; and the Multipurpose Laboratory Interface (MPLI) distributed by Vernier Software.

The ULI is designed for use with properly outfitted Macintosh or PC-compatible computers. The ULI information presented here is specific to the ULI II; however, with only slight modifications, the information also applies to a ULI I. The Signal Interface II is also designed for use with either a Macintosh or PC-compatible computer. The MPLI interface is designed for use only with PC-compatible computers.

In the Workshop Physics program, several sensors are needed to undertake the recommended activities. These sensors include a radiation sensor, an ultrasonic motion sensor, a force sensor, a temperature sensor, a voltage sensor, a magnetic field sensor, and a rotational motion sensor. This appendix contains a brief description of each of the sensors. Detailed information for the setup for each type of computer-based laboratory system and the use

*Portions of this Appendix are adapted with permission from apparatus and software manuals published by Vernier Software and PASCO scientific Company.

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of the associated software are included in the system manuals.

THE UNIVERSAL LABORATORY INTERFACE (ULI)

The Universal Lab Interface (ULI) was designed to provide a way to connect a variety of sensors to any computer using a standard RS 232 or RS 422 serial port. Designed and manufactured by Transpacific Computer Company, the ULI is distributed by Vernier Software. The ULI is a small computer that monitors sensors attached to it and relays the sensor readings to a computer executing the proper software. The ULI provides a 12-bit Analog to Digital Converter (ADC), four 5-pin DIN (analog) connections, two 6-line telephone-style ports, and two audio-style jacks for digital inputs. The ULI has an open architecture to allow developers to design new sensors and software. A developer’s guide is available from Vernier Software.

![Fig. B.1. The Universal Lab Interface (front view)](image)

The ULI is compatible with many sensors and several pieces of software that provide the functionality needed to perform experiments related to the Workshop Physics and Real Time Physics curricular materials. The software, developed at Tufts University for the ULI, runs on DOS or Windows based PC-compatibles and on Macintosh computers. The software is feature rich and allows significant flexibility; therefore, many experiments beyond those developed for Workshop Physics courses can be performed. Some features of the ULI software include real time data graphing, generation of tangent lines to graphs, integration, curve fitting, and the spectral analysis of data using a fast Fourier transform (FFT) routine.

PASCO SIGNAL INTERFACE II (SI2)

The Signal Interface II (SI2) was designed and is distributed by PASCO scientific. The SI2, similar to the ULI, provides a way to connect a variety of sensors to a Macintosh or Windows based PC-compatible computer. The SI2, however, uses a high-speed parallel connection to the computer via a Small Computer Signal Interface (SCSI) port. Use of the high-speed SCSI connection allows the SI2 to be used simultaneously for both data collection and experiment control. The SI2 provides four audio-style ports for digital input/output and three 8-pin DIN connectors for analog input/output. Input and output on the three analog channels are performed using a shared 12-bit ADC and DAC pair.

![Fig. B.2. The Signal Interface II (front view)](image)

The SI2 has a wide range of sensors and accessories that allows the attached computer to become a digital voltmeter, a triple-trace digital storage oscilloscope, an electronic stop watch, a digital frequency counter, a spectrum analyzer, a radiation monitor and much more. With the addition of the external Power Amplifier, the interface can be used as a DC power source and a function generator. The software for the SI2 is a completely integrated package called the Science Workshop which is functionally the same on both Macintosh and Windows based PC-compatible computers. The Science Workshop provides control and monitoring functions for all the capabilities of the SI2 and its associated sensors. Display and analysis options in the Science Workshop include plots, meters, histograms, data tables, curve fitting, integration, and FFTs.

MULTIPURPOSE LAB INTERFACE (MPLI)

The MultiPurpose Lab Interface (MPLI), distributed by Vernier Software, provides an
interface that allows DOS® or Windows® based PC-compatible computers to be used as laboratory instruments. The MPLI interface can be used with any Windows® or DOS® based PC-compatible computer with at least one free Industry Standard Architecture (ISA) expansion slot. The main advantage of the MPLI is that it can be run on older DOS based machines (8086/8088/80286 processors). The MPLI comes with a custom ISA expansion board that must be inserted into the PC-compatible computer. This expansion board provides a high-speed parallel interface between the MPLI and the computer. The MPLI contains three 8-pin DIN (analog) ports that share a 12-bit ADC for monitoring sensor data. The MPLI also provides an internal 16-pin DIP socket for expansion circuits created by developers. A developer’s tool kit is available from Vernier Software.

Fig. B.3. The MultiPurpose Lab Interface (front view)

A wide range of sensors is available for use with the MPLI interface. Many of the same sensors that are used with the ULI and the SI2 can also be used with the MPLI interface. Both DOS® and Windows® versions of the MPLI software are available. The Windows® version of the MPLI software supports all of the sensors and includes data analysis tools such as tangent lines, integration, a three channel storage oscilloscope, FFTs, histograms, spreadsheet-like calculated columns, and curve fitting. The DOS® version of the MPLI software supports all sensors except the motion sensor. To use a motion sensor with the DOS® based MPLI, a special software package called Motion Plotter must be used. The Motion Plotter software, when accompanied by an MPLI and the proper sensors, can graph distance, velocity, acceleration, and force. The DOS® based MPLI software has a three-channel storage oscilloscope, graphing capabilities, and real-time Fourier analysis.

SENSORS FOR THE COMPUTER-BASED LABORATORY SYSTEMS

The Motion Sensor

The Ultrasonic Motion Detector from Vernier Software is an analog sensor that connects to the ULI or MPLI computer interfaces. The ULI and motion detector are supported by the “Motion” software. The MPLI Windows based software supports the use of a motion sensor. To use a motion sensor with the MPLI and DOS® requires the Motion Plotter software. The PASCO scientific motion sensor is a digital sensor intended for use with the SI2. The SI2 and Science Workshop software support the use of two motion sensors simultaneously to record positions, velocities, and accelerations of both objects in a collision experiment.

Fig. B.4a. Ultrasonic Motion Detector from Vernier Software is designed for use with the ULI (U-MD) and MPLI (MD-M).
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![Motion Sensor from PASCO scientific](image)

**Fig. B.4b.** Motion Sensor from PASCO scientific is designed for use with the SI2 (CI-6529).

**Note:** The codes in parenthesis are the appropriate Vernier Software or PASCO scientific part codes for the sensors.

A motion sensor uses ultrasonic sound pulses to measure the distance to the closest object located in front of the sensor (i.e., along its “line of sight”). The distance measured is always the distance to the object that is closest to the sensor and within the sensor’s field of view. (The field of view is a 16 degree cone along the sensor’s line of sight.) The range of distances that can be measured is from 0.4 m to 6 m for the Vernier sensor and from 0.4 m to 8.9 m for the PASCO sensor. If the location and orientation of the sensor are known, the distance measured is directly related to the position of the object. This subtle relationship between distance and position can be simplified by defining a coordinate system with the sensor at the origin and a position axis along the sensor’s line of sight. In this coordinate system the distance measured by the sensor is equivalent to the one-dimensional position of the object.

To determine distances, the motion sensor emits pulses of ultrasound and receives reflections of these pulses after they bounce off objects within the sensors field of view. The frequency of this ultrasound is about 50 KHz. Since the speed of ultrasound in room temperature air is known, the computer motion software can calculate the distance of an object by timing how long the pulse takes to reflect off the object and return to the sensor. This is similar to how a bat “sees” and it is also how a Polaroid® auto-focus camera determines the distance to an object in order to focus properly.

The software packages for use with the motion sensors use distance measurements at evenly spaced times to calculate, using standard difference equations, the average values of velocity, and acceleration over each time period. Values of position, velocity, acceleration, and force can each be displayed in a variety of graphical formats as functions of time or as functions of each other. They may also be displayed in raw format as a data table. The motion sensor and its software form a useful tool for the analysis of complicated data from one-dimensional motions and forces.

**The Force Sensor**

There are two distinct types of force sensors recommended for use in the Workshop Physics activities. The Force Probe from Vernier Software is a Hall Effect based force sensor and is designed for use with the ULI. Alternatively there are a pair of strain gauge based force sensors from PASCO scientific. These strain gauge based force sensors are called the Student Force Sensor and the Force Sensor and are designed for use with the SI2. Versions of the Student Force Sensor and the Force Sensor are also available, from either PASCO scientific or Vernier Software, for use with the MPLI or ULI interfaces.

**The Hall Effect Force Probe**

A Hall Effect force sensor, like a motion sensor, actually measures distance. If you examine the sensor, you will see a cylindrical-shaped magnet attached to a strip of brass. The strip of brass acts as a leaf spring. The magnetic field surrounding the magnet is sensed by a Hall Effect transducer mounted at the end the force sensor’s handle. For small flexures, the brass leaf spring acts like a Hooke’s law spring, and therefore the position of the magnet is linearly related to the applied force. As the brass sheet that holds the permanent magnet flexes under a push or a pull, the magnetic field strength at the Hall Effect transducer changes. The transducer produces a current that varies linearly with the magnetic field strength. The current in the transducer is sensed electronically by the ULI and sent to the computer. The “Motion” or “Data

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Logger” computer software uses calibration information, and the linear nature of the relationships between the applied force, the position of the magnet, and the Hall Effect transducer current, to calculate the applied force.

![Image of Hall Effect Force Probe from Vernier Software for use with the ULI (U-FP).](image1)

The sensitivity of the Hall Effect force sensor can be adjusted by moving the head of the sensor (which includes the magnet) relative to the handle. Moving the magnet closer to the Hall Effect transducer (built into the end of the handle) makes the force sensor more sensitive but limits the range of forces that can be measured. Moving the magnet further out makes the force sensor less sensitive and allows it to be used with a wider range of forces.

**The Strain Gauge Force Sensors**

The Student Force Sensor and the Force Sensor from PASCO scientific are both based on the measurement of strain in a metal beam. In the Student Force sensor, a pair of strain gauges are mounted on a single cantilevered beam that flexes under applied forces. As the beam flexes, the strain gauges are stretched or compressed, depending on the direction of the applied force. Stretching (pushing on the beam) or compressing (pulling on the beam) the strain gauge increases or decreases respectively the electrical resistance of the strain gauge. The change in resistance is used to generate an output voltage for the sensor.

![Image of Student Force Sensor from PASCO scientific is designed for use with the SI2 (CI-6519) and from Vernier Software for use with the ULI and MPLI (SFS-DIN).](image2)

Therefore, the maximum voltage is output when the maximum positive force is applied to the sensor (a push of 20 N), and the voltage is a minimum when the maximum negative force is applied to the sensor (a pull of 20 N).

The Force Sensor is designed to have adjustable sensitivity, to be more accurate over a wider range of forces, and to be less...
susceptible to resonance effects during collision experiments than the Student Force Sensor. The Force Sensor is based on a standard “binocular beam,” that looks like a metal plate with the front view of a pair of binoculars cut out of it. There are four strain gauges mounted on the beam, two on each side at the points where the cutout “binoculars” are closest to the edge. When an applied force creates a lateral strain in the beam, the strain gauges generate an output voltage that is proportional to the applied force. The Force Sensor can be adjusted, using a range select switch, to have a maximum range of $-10$ N (pull) to $+10$ N (push) or $-50$ N to $+50$ N. A tare button is also provided to allow the sensor to be zeroed manually.

The Science Workshop software for the SI2 and the DOS or Windows based MPLI Software have built-in capabilities for the use of force sensors. With a ULI, the Motion or Data Logger software can be used. It is also common to use a force sensor in combination with a motion sensor to perform experiments to verify Newton’s laws of motion. All of the above software packages are capable of these experiments with the exception of the DOS® based MPLI software. To perform these experiments with a DOS® based MPLI system, the Motion Plotter software is required.

**The Radiation Sensor**

The type of radiation sensor recommended for use in the Workshop Physics program consists of a Geiger counter and associated electronics which provide a signal output that can be attached to a digital input on a computer-based laboratory system. Suitable radiation sensors with computer output ports and cables are the Radiation Monitor distributed by Vernier Software and the Radalert and the LabNet Geiger-Müller Interface distributed by PASCO scientific. The Radiation Monitor and Radalert are hand-held units that can be used with or without a computer and interface system. The LabNet Geiger-Müller Interface requires the SI2 and Science Workshop or other compatible interface/software combination.

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**Fig. B.6a.** The Radiation Monitor from Vernier Software.

**Figure B.6b:** The LabNet Geiger-Müller Interface from PASCO scientific is designed for use with the SI2 (SE-7997).

**Fig. B.6c.** The Radalert from PASCO scientific is designed for use alone, with the SI2, with the ULI and with the MPLI (SE-7996).
A radiation sensor is used to detect gamma particles or beta particles emitted from the nuclei of atoms in a radioactive source. In the study of physics, it is useful to count the number of particles that are detected to learn about such topics as counting statistics, natural radioactivity, and the half-lives of some relatively short-lived radioactive sources. All of the radiation sensors mentioned above detect particles in approximately the same manner. Each uses a stainless steel chamber, called a Geiger tube, that has been emptied of air and filled with a noble gas (usually Neon or Argon). When a beta or gamma particle, the result of a radioactive decay, passes through the Geiger tube, electrons are ripped away from the noble gas atoms. These electrons are attracted to a high voltage anode contained in the tube. As the electrons move to the anode, they knock more electrons free from the gas atoms, creating a cascade effect. The arrival of electrons at the anode creates a current. This current drives an electronic circuit that sends a signal to the computer. The computer interprets the signal that is received as an “event.” Several other electrical and chemical processes allow the noble gas ions to acquire new electrons and return to their neutralized ground state.

Counting software designed to work with a computer interface allows you to count the discrete events detected by a sensor. For the ULI, the counting software is the “Event Counter” program. The Science Workshop program for the SI2 and the MPLI software for the MPLI both contain counting capabilities. Events that can be counted are not limited to the presence of particles emitted from a radioactive source but depend on the sensor that is used and include pulses of light or sound bleeps. The software programs allow the number of counts in an interval of time to be displayed graphically or in a data table. The software can calculate averages and other statistics for repeated trials. Data can be displayed in the form of a graph of counts/interval vs. time, or as a histogram of frequency vs. counts/interval or in both formats simultaneously.

The Voltage Sensor

The analog ports on all of the interfaces accept analog voltages as input. These voltages are converted to a binary number using a 12 bit ADC (a ULI I has a 10 bit ADC). The Science Laboratory software with the SI2 and the MPLI software with the MPLI interface allow voltages between ±10 V to be measured. These software packages also allow the SI2 and MPLI to be used as three-channel digital storage oscilloscopes. The ULI with the Data Logger software is able to measure voltages between 0 and 5.12 V. Exceeding these maximum voltages may cause damage to the interfaces.

Fig. B.7a. Voltage Measurement Leads from Vernier Software is designed for use with the ULI, MPLI and SI2 (TL-DIN).

Fig. B.7b. Voltage Sensor from PASCO scientific is designed for use with the SI2 and MPLI (CI-6503).
The Temperature Sensor

There are a wide range of temperature sensors available from both Vernier Software and PASCO scientific, only two of which are shown in Figure B.8. These temperature sensors use a precision temperature-sensitive integrated circuit whose output is linearly related to temperature. The sensors are covered in a Teflon® heat shrink tubing to make them resistant to chemical solutions including oxidizing agents and organic solvents. The Vernier Standard Temperature Probe comes with a small black box that contains signal-conditioning circuitry and has a temperature range of −50 °C to +150 °C. The PASCO Temperature Sensor connects directly to the SI2 and has a temperature range of −5 °C to +105 °C. The probes should not be operated outside these ranges or damage may occur.

![Standard Temperature Probe from Vernier Software](image)

**Fig. B8a.** Standard Temperature Probe from Vernier Software is designed for use with the ULI and MPLI (TPA-DIN).

![Temperature Sensor from PASCO scientific](image)

**Fig. B8b.** Temperature Sensor from PASCO scientific for use with the SI2 (CI-6505A).

The Magnetic Field Sensor

Both the Magnetic Field sensors shown in Figure B.9 are based upon Hall Effect transducers. A Hall Effect transducer produces a current that varies linearly with the magnetic field strength at the location of the transducer. The current in the transducer is sensed electronically by the computer interface and is sent to the computer.

The Vernier Magnetic Field Sensor has a single Hall Effect transducer. This single transducer measures the magnetic field strength parallel to the hand-held wand of the sensor. The sensitivity of the sensor can be selected to measure magnetic field strengths in two ranges, either ±3.2 Gauss or ±64 Gauss. When using the ±3.2 Gauss range, this sensor is sensitive enough to measure the strength of the Earth’s magnetic field.
The Rotary Motion Sensor

The PASCO and Vernier Rotary Motion Sensors use optical encoders to measure the angular displacement of a shaft. An optical encoder consists of a transparent disk with a known number of opaque lines etched radially at evenly spaced intervals. The spacing of these lines dictates the resolution of the optical encoder. There are two photogates, each of which creates a closed circuit when its light beam passes through a transparent section of the disk. Conversely, the circuit is broken when the light beam is blocked by one of the opaque lines. As the probe is rotated, the output of each of the photogates is a square wave, because its light beam is repeatedly blocked and unblocked. The two photogates are slightly offset, so that as the disk rotates clockwise, photogate 1 is blocked before photogate 2. If the disk rotates counterclockwise, then photogate 2 will be blocked before photogate 1. Therefore, the direction of rotation can be determined by the phase relationship of the square waves from the two photogates.

The PASCO Magnetic Sensor contains two Hall Effect transducers installed at right angles to each other. Therefore, the magnetic field strength at the location of the transducers can be measured in two directions. However, the two perpendicular field strengths can not be measured simultaneously. This sensor measures magnetic field strength in the range of 10 Gauss to 2000 Gauss with a resolution of approximately 10 Gauss. Therefore, the Magnetic Sensor can not be used to measure the strength of the Earth's magnetic field.
between the angular displacement measured by the probe and the actual angular position. The direction of rotation is determined by the software, which monitors the phase relationship between the square waves from the photogates. The software also calculates angular velocity and angular acceleration by using difference equations. For the version of the PASCO Rotary Motion Sensor used with the ULI, the “Rotary Motion” software performs these functions as well as a variety of data analysis functions similar to those in the “Motion” software. A model of the PASCO Rotary Motion Sensor is also available for use in conjunction with the Science Workshop software and SI2 interface.

Additional and up-to-date information about the Computer-Based Laboratory systems, software, or sensors described in this appendix can be obtained from:

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