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Environment Monitoring Using LabVIEW

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Technical Memo

Abstract

A system has been developed for electronically recording and monitoring temperature, humidity, and other environmental variables at the Silicon Detector Facility located in Lab D. The data is collected by LabVIEW software, which runs in the background on an Apple Macintosh. The software is completely portable between Macintosh, MS Windows, and Sun platforms. The hardware includes a Macintosh with 8 MB of RAM; an external ADC-1 analog-to-digital converter that uses a serial port; LabVIEW software; temperature sensors; humidity sensors; and other voltage/current sensing devices. ADC values are converted to ASCII strings and entered into files which are read over Ethernet. Advantages include automatic logging, automatic recovery after power interruptions, and the availability of stand-alone applications for other locations with inexpensive software and hardware.

The Platform

A Macintosh SE/30 was chosen because of its low price and small footprint. Many of them are already considered surplus. Their monitors are built-in small black-and-white screens, they have not been manufactured for a few years, and they can only accept one non-standard expansion board. One advantage of the Mac SE/30 over many other models is that the machine will immediately reboot following a power interruption. When the software is put into the Startup Folder, data logging will resume automatically after an interruption.

Our platform has 40 MB of disk space and uses System 7.0 with 8 MB of RAM. Disk space required for output storage is minimal. With sixteen channels logged every ten minutes, under 5 MB of disk space is used per year. The LabVIEW software requires at least 4 MB and System 7.0 uses an additional 2 MB. The output files can be viewed over an Ethernet connection or by TCP/IP. The SE/30 is only used for data logging. The files are typically viewed with a Microsoft Excel spreadsheet.

It is also possible to use a Windows system on an IBM compatible as the platform, if 8 MB of RAM is available. The LabVIEW software is completely transparent between Macintosh, Sun, and Windows platforms.

The ADC

The means of converting analog signals from the monitoring sensors to digital information that can be processed by a digital computer is through an analog to digital converter (ADC).

There are two basic sorts of ADCs: flash converters, which are extremely fast and correspondingly expensive; and slope-conversion converters, which are relatively inexpensive but far slower. Since there is no need for data conversion rates into the hundreds of thousands to millions per second, we have settled on a solution that is both versatile and economical.

Sampling data from sixteen to thirty-two sensors every ten minutes does not require the more powerful internally-mounted boards. The ADC-1 unit from Remote Measuring Systems¹ met our needs well. It is a serial unit, which means that it can be connected to the platform using a serial port. This has two advantages: Firstly, it can be very easily moved from one platform to another, since it does not require that the computer be opened up and a card be plugged into a slot. This was especially fortunate since it was programmed on a Macintosh with one slot configuration, and later installed for use with a Mac SE/30, which has only one non-standard slot, which we use for Ethernet communication. Secondly, we were able to install the ADC-1 close to the sensors. This allowed the computer to be stationed in a more convenient location and saved hundreds of feet of cable. Only one 9600 baud four-conductor cable to the serial port was necessary.

The ADC-1 uses a dual-slope conversion.² A capacitor is connected to each input and integrates the voltage for 2048 clock counts. Then it is connected to a internal reference source of the opposite polarity and the number of clock counts is read when the integration capacitor reaches zero; then this value is transmitted by a UART modem chip along the serial line. The ADC-1 has a sensitivity of 0.1 mV, so it therefore reads input voltages from -409.5 mV to +409.5 mV (twelve bits of resolution). The integration time is about 15 ms for each measurement, which provides plenty of bandwidth for measuring a few dozen channels every ten minutes.

Options on the ADC-1 include 32 analog inputs, instrumentation amplifiers with various fixed gains, digital inputs, digital outputs, and X-10 capabilities. The last two of these options enables the unit to act as a controller under software control for various applications.

¹ADC-1 STD serial analog ADC available from Remote Measurement Systems, 2633 Eastlake Ave., Suite 200, Seattle WA 98102 for \$499. Their phone number is 206.328.2255.

²Remote Measurement Systems, ADC-1 Owner's Manual, V.2.07, Feb. 1993, p. 56, ff.

Temperature Sensors

The most common need we had was to measure temperature. This was done with the AD590JH temperature sensor from Analog Devices.³ It is a small metal "can," similar to a transistor package with three leads. It is a current source with two leads; the third lead is the case ground, and is not used. We soldered the wires from the cable directly to the sensor, used shrink-wrap around the solder joints, and dipped the unit into Plasti-Dip to make a sealed water-proof unit that was reasonably rugged (we have a sensor mounted outdoors). A ceramic package is also available that might be useful for cementing directly to apparatus, rather than measuring air temperature.

Since the AD590JH is designed to produce 1 μA per degree Kelvin within its temperature range (or 1 μA per degree Celsius), we connected a one kilohm resistor across the ADC-1 input, which allowed one bit to equal one-tenth degree Celsius. The software converts the bits to Fahrenheit. Thus, room temperature produces a voltage drop of about 298 mV at 70°F. This gives about 0.2°F sensitivity. If more sensitivity is desired for some application, the sensor output can be amplified. This limits the range but increases the sensitivity. We found a sensitivity of 0.2°F to be satisfactory for our purposes.

Temperature calibration was done by adding a small offset to the software offset array on the "front panel" of the software monitor display. The offset array is of the form $a[2]x^2 + a[1]x + a[0]$. Since the temperature sensors were very close to the final value, only $a[0]$ needed to be modified. The conversion formula for Kelvin to Fahrenheit is $1.8 \cdot K - 459.67$. The AD590JH is nearly linear, so the $a[2]$ parameter is 0, the $a[1]$ parameter is 1.8, and $a[0]$ is -459.67. (Other sensors may need other parameters; these are added by the user for the appropriate channel.)

It is important to remember that the least significant bit (LSB) is mathematically indistinguishable from noise; so it is important to not make judgments of data on the basis of a single bit, which comes to $\pm 0.2^\circ\text{F}$. The 100 μf tantalum capacitor lessens the effect of noise, but it is important to ignore fluctuations at this level.

Humidity Sensors

We also used an RHT-1, a humidity sensor available from Remote Measurement Systems. It is very roughly calibrated when purchased, and has a theoretical sensitivity of about 1% relative humidity (RH) when calibrated. From looking at the data, it was apparent that the sensor approached equilibrium at a rate that decreased exponentially with time. Thus, for a large humidity change, the sensor would respond within seconds, but took upwards of hours to approach equilibrium within one bit resolution, at which time noise would be indistinguishable from any further improvement in accuracy. The sensor works by reaching an equilibrium with the water vapor from the air into a dielectric film, which varies its conductivity. This process is exponential and is strongly affected by temperature.

This sensor is inexpensive (around \$50) but it is very slow to respond. We may replace it in the future with a sensor that responds more rapidly. For instance, the "resistive polymer" humidity sensor used in the CT485RS series of temperature and humidity recorders⁴ responds nearly ten times faster than the RHT-1 sensor. Remote Measurement Systems claims that their sensor was calibrated within 25%, but this was far too inaccurate to be trustworthy for most purposes. As a result, we decided to calibrate the sensor.

³The AD590JH is available from Newark Electronics for about \$4 each. The metal case version is recommended for greater durability, better availability and lower price. See Appendix II for more details.

⁴White Box, Inc., 2 Riverbend, Riverbend Executive Center, P.O. Box 4508, Stamford, CT 06907.

We calibrated the sensor by putting it into a small sealed vessel with a pan of salts with a small amount of water. Different salts will reach different RH equilibria.⁵ Table 1 gives examples of salts that were used for calibration purposes. We used Ammonium Sulfate and Potassium Acetate for a two-point straight-line fit.

Salt		20 °C/68 °F	25 °C/77 °F
Ammonium	Sulfate	81% RH	80% RH
Ammonium	Nitrate	65% RH	62% RH
Potassium	Carbonate	44% RH	43% RH
Potassium	Acetate	22% RH	22% RH

Table 1. Salts used for humidity sensor calibration

Calibration was done overnight, so that the system of water, salts and sensor reached a stable equilibrium. At room temperature (68°F) ammonium sulfate stabilizes at 81% RH, and potassium acetate at 22% RH. If the ambient room RH is between 30 to 70% RH (which is typical), a small amount of water will have to be added to the ammonium sulfate to allow it to reach 81% RH. The potassium acetate, on the other hand, will remove water from the air, bringing down the humidity to 22% RH. These salts should be shielded from normal room humidity prior to use, as they may remove enough water from the air to turn into a pool of salty liquid. This is especially true of the potassium acetate, and the potassium carbonate to a lesser degree. These salts were obtained from the Materials Research Lab, but they can be ordered easily from several sources. Each calibration requires a couple of grams of salt.

Raw voltage readings were taken from each humidity source and converted into RH from the ADC counts. The ADC counts were converted (1 count equals .1 mV) to relative humidity by solving two linear equations. For our sensor, 22% RH was about 120 mV, and 80% RH was around 40 mV, although each RHT-1 sensor will vary widely before calibration.

To smooth the input to the ADC-1 a 100 µf tantalum capacitor was placed across the resistors for both temperature and humidity sensors. The voltage source for all of the temperature and humidity sensors and for the ADC-1 power was a standard stockroom 1 amp 5 volt DC package supply.

The Software

We chose LabVIEW because it has a several clear advantages. It has an extremely large library of software drivers that are available. The software is graphical in nature, allowing faster code writing without syntactic errors. Troubleshooting is also extremely easy. Code can be written and debugged significantly faster with this software than with other more traditional languages. (Of course this does not make it necessarily simple; it does however shorten the code development time drastically.) The graphical interface is very well suited for user friendliness and intuitiveness, and can be designed rapidly with sophisticated programming tools. Code written in other languages can be run under LabVIEW with a feature called Code Interface Nodes.

Another advantage is that the software is portable over Macintosh, MS-DOS Windows, and Sun platforms without rewriting. Code can be put into a free-standing

⁵Salts may be ordered from Aesar Corp. of Ward Hills, MA 01835-0747 (Phone 800-322-8247).

application that can be run at other locations without the need to buy a license for another development system at the new location.⁶

The software features a "front panel" that is very intuitive and easy to use. It resembles a virtual hardware front panel, with indicators, controls and switches that are used with the keyboard and mouse. See Appendix III for a view of the front panel.

LabVIEW requires 4 MB of RAM. However, it runs synchronously in the background, while accepting asynchronous interrupts. This allows other tasks to be run, or data to be examined without interrupting the monitoring program.

Functioning of SiDet Monitoring software version 1.4

We found that a ten minute sampling rate was appropriate for our needs. However, the interval can be set from six seconds to several hours by changing the front panel control, and several copies of the software can run concurrently with different file name prefixes and different sampling times. Dialog windows at the bottom of the screen allow the user to type in headers as desired, which go at the top of each day's log. The file is closed at the end of each data acquisition, and when another data acquisition takes place, the software looks for a file with the specified name, opens it, and appends the latest sensor data.

The file specification is the date, with the day of the month given first; then the first three letters of the month name; and then the year. The user can specify a prefix to the file, so that separate files with different sampling rates can be recorded independently. This is useful when new sensors are being calibrated and for troubleshooting.

The file prints the current date and time of the first acquisition on the third line. The first and second lines are available for users to add comments, which can be entered in the dialog input boxes. The fourth and fifth lines are intended for header information for the columns. The data begin on the sixth line. The first entry is the current time in hours and minutes. The second through seventeenth column is where the ADC-1 records each scaled analog input.

At the start of each day a new file is created as a text file Excel spreadsheet, and the first five lines are written to a file with the unique filename containing the user-defined prefix and the date. The time and date for each acquisition is recorded, appended on the following line. Files are generic ASCII text files that are tab-delineated spreadsheets, which can be read from any graphical, spreadsheet or word-processor application. Since the Mac SE/30 is networked over Ethernet, data files are easily read from remote locations at the Lab.

On the front panel display, shown in Appendix III, there is a Stop button that will halt execution after the next acquisition. The chart allows display of the last 144 data points of the channel selected under the chart. The axes are auto-scaled, and the last value read is displayed in the digital display below the chart. The user can specify the filename prefix by typing into the "Output file prefix" control box. For calibration, the calibration array control can add parameters of the form $ax^2 + bx + c = y$, where y equals the desired scaled value, and x equals the raw signal read from the ADC. By taking three accurate measurements or more, the parameters a , b and c can be determined. If only two data points are available, a straight line fit can be used.

⁶A LabVIEW "Full Development" package costs \$1995, and can be used to develop and run programs on a single platform. For an additional \$995 the "Application Builder" software enables the Full Development package convert those programs into platform-independent stand-alone applications, and includes a license for distribution of up to fifty copies.

Further developments

The software was originally designed for 16 analog channels. This is being expanded to 32 channels. A multiplexer is being developed for this Environment Monitoring System to allow several ADC-1 units to be read and logged.

It is also possible to send commands to the ADC-1 to control processes, perhaps at the command of the user by clicking a virtual button on the software display; or in response to some data condition (*e.g.* turning on an alarm if a temperature goes above a setpoint). This has been implemented at Lab D.

Presently one channel may be displayed on the screen in an auto-scaling strip chart. The user may select which channel is being monitored, and the latest value is also displayed in a digital indicator. It is possible to display multiple channels with a minor software rewrite.

A wide variety of sensors can be added to the ADC-1, as long as input voltages remain within range. We are adding particulate counts to it in the near future. It can also be used for strain gages, thermocouples, anemometers, etc. with appropriate input conditioning.

More elaborate sensors, such as the Met One Laser Particulate Counter,⁷ require more elaborate software to be read and logged by the software. This hardware communicates by means of a serial line, and has to be interfaced with a driver for the device and a multiplexer for accepting both the ADC-1 and Met One Laser Particle Detector serial lines. Due to the variety of command languages for various serial devices by diverse manufacturers, these additional drivers can be non-trivial additions. Devices with simple current or voltage outputs, however, are trivial additions. As the activity at Lab D increases, further additions to the system will be added.

⁷Met One, Inc., Grants pass, OR 97526. We are planning on adding output from this device soon.

Appendix I

ADC-1 Technical Specifications, from ADC-1 Owner's Manual

16 Analog-to-Digital Inputs

- Integrating dual slope A/D with conversion at 20 to 140 Hz.
- 12 bit (plus sign) A/D provides resolution of one part in 8192 (0.1 mV sensitivity) .
- Accuracy to +1/2 LSB.
- Input Range: modifiable from 0.4 V to +4.0 V.
- Maximum Input Voltage 5 V.
- All 16 inputs differential.
- Temperature coefficient of 40 ppm/°C.
- Common Mode Rejection Ratio 50 μ V/V.
- Input impedance 10 Meg Ω . 110 dB noise rejection at 60 Hz.
- Optional instrumentation amplifier allows 2 micro volt sensitivity for one bank or two banks of inputs each.

4 Digital Inputs

- Modes: toggled or latched.
- Maximum sample rate @ 9600 baud is 400 Hz.
- Functions for both normally open and normally closed circuits.

6 Direct Wire Controlled Outputs

- Latched TTL drivers with maximum current of 200 mA at 5 VDC.
- Maximum Voltage: 5.6 V.
- Maximum control rate @ 9600 baud is 400 Hz.

AC Line Carrier Remote Device Control (X-10 compatible)

- Sends signals over normal household/office AC wiring to control 32 independent devices using BSR, X-10 Leviton, Sears or Radio Shack remote control modules.
- 8 House codes are switch selectable to reach 256 possible units.
- Signal frequency 120 kHz, 1 ms pulse duration, 8 V amplitude.
- Code Transmission Time: 0.4 sec/message.
- Transmitter and AC line connection in separate optically isolated enclosure minimizes 60 Hz noise.

(Note: additional options such as 32 single-ended inputs, and additional controlled outputs can be added for about \$250)

Appendix II

(AD590 information from Analog Devices Linear Products Databook)

AD590 FEATURES

Linear Current Output: 1 $\mu\text{A}/\text{K}$
Wide Range: -55°C to $+150^{\circ}\text{C}$
Probe Compatible Ceramic Sensor Package
Two-Terminal Device: Voltage In/Current Out
Laser Trimmed to $\pm 0.5^{\circ}\text{C}$ Calibration Accuracy (AD590M)
Excellent Linearity: $+0.3^{\circ}\text{C}$ Over Full Range (AD590M)
Wide Power Supply Range: +4 V to +30 V
Sensor Isolation from Case
Low Cost

PRODUCT DESCRIPTION

The AD590 is a two-terminal integrated circuit temperature transducer which produces an output current proportional to absolute temperature. For supply voltages between +4 V and +30 V the device acts as a high impedance, constant current regulator passing 1 $\mu\text{A}/\text{K}$. Laser trimming of the chip's thin film resistors is used to calibrate the device to 298.211 μA output at 298.2 $^{\circ}\text{K}$ ($+25^{\circ}\text{C}$).

The AD590 should be used in any temperature sensing application below $+150^{\circ}\text{C}$ in which conventional electrical temperature sensors are currently employed. The inherent low cost of a monolithic integrated circuit combined with the elimination of support circuitry makes the AD590 an attractive alternative for many temperature measurement situations. Linearization circuitry, precision voltage amplifiers, resistance measuring circuitry and cold junction compensation are not needed in applying the AD590.

In addition to temperature measurement, applications include temperature compensation or correction of discrete components, biasing proportional to absolute temperature, flow rate measurement, level detection of fluids and anemometry. The AD590 is available in chip form making it suitable for hybrid circuits and fast temperature measurements in protected environments.

The AD590 is particularly useful in remote sensing applications. The device is insensitive to voltage drops over long lines due to its high impedance current output. Any well-insulated twisted pair is sufficient for operation hundreds of feet from the receiving circuitry. The output characteristics also make the AD590 easy to multiplex the current can be switched by a CMOS multiplexer or the supply voltage can be switched by a logic gate output.

Covered by Patent No. 4,123,698.

PRODUCT HIGHLIGHTS

1. The AD590 is a calibrated two terminal temperature sensor, requiring only a dc voltage supply (+4 V to +30 V). Costly transmitters, filters, lead wire compensation and linearization circuits are all unnecessary in applying the device.
2. State-of-the-art laser trimming at the wafer level in conjunction with extensive final testing insures that AD590 units are easily interchangeable.

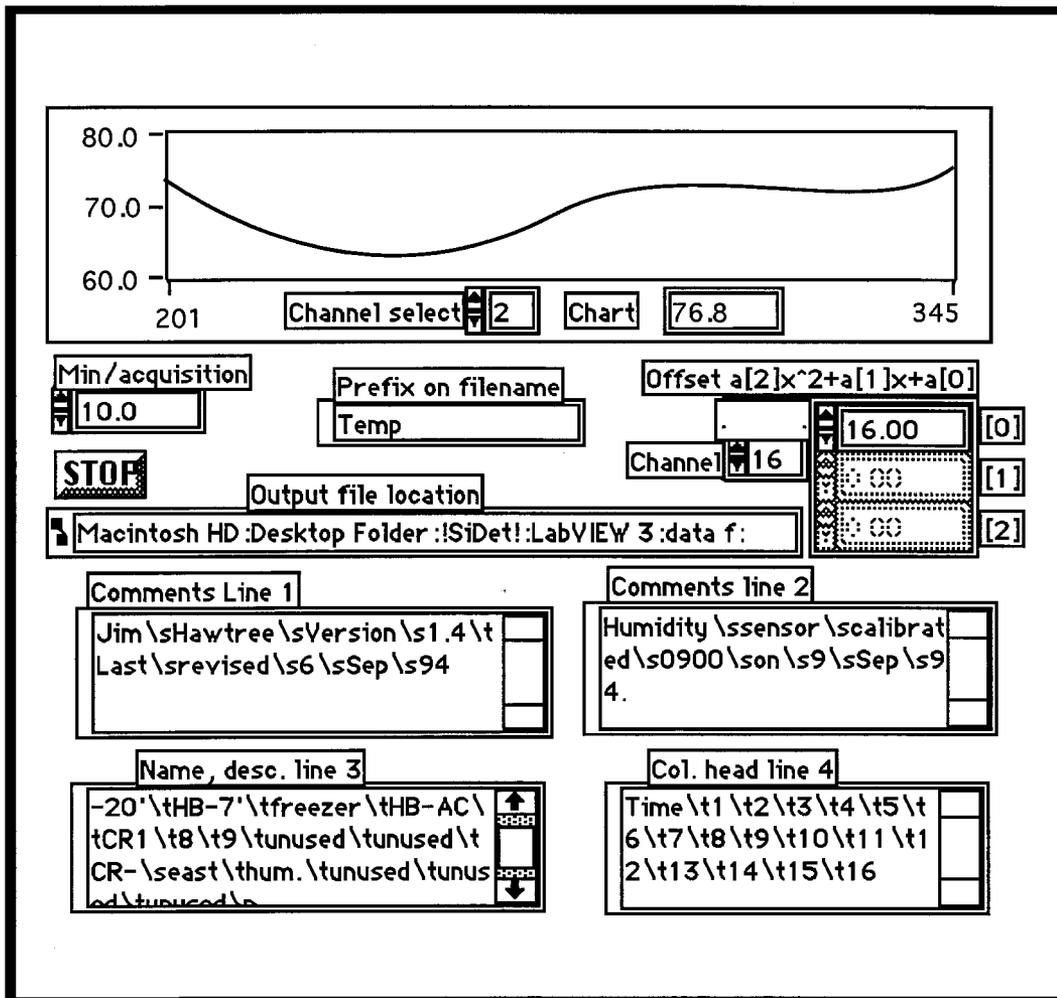
3. Superior interference rejection results from the output being a current rather than a voltage. In addition, power requirements are low (1.5 mW (@ 5 V @ +25°C). These features make the AD590 easy to apply as a remote sensor.

4. The high output impedance (>10 MΩ) provides excellent rejection of supply voltage drift and ripple. Changing the power supply from 5 V to 10 V results in only a 1 μA maximum current change, or 1 C equivalent error.

The AD590 is electrically durable: it will withstand a forward voltage up to 44 V and a reverse voltage of 20 V. Hence, supply irregularities or pin reversal will not damage the device.

Appendix III

Example of software "front panel" as it appears on computer terminal:



Appendix IV

Sample chart showing Excel template for data display:

9 Sep 94 temperature/humidity

