Automation of Monitoring of Geotechnical Instrumentation

ALAN L. HINCKLEY, BERTRAND D. TANNER, AND ERIC C. CAMPBELL

Inexpensive, low-powered, portable dataloggers directly compatible with many sensors commonly used in slope stability and soil mechanics work provide new measurement opportunities by reducing logistic complexity and cost. Pressure, force, and position sensors employing strain gauges, vibrating-wire transducers, or potentiometers are used to obtain soil pore pressures, slope inclination, movement, and strain. Sensors for general meteorological parameters and soil moisture are also accommodated. Accurate strain gauge measurements require the datalogger to have low input noise, high resolution, and precision switched bridge excitation voltages. Vibrating-wire transducers are measured either by plucking the transducer and period averaging the decaying transient or by using a continuously excited sensor and counting the frequency. Programmable dataloggers process measurements on site, reducing data storage requirements and allowing logic decisions based on measured values such as recording of data more frequently during significant events (conditional recording) and setting alarms or controls. Real-time communication to a computer uses telephone, radio, or satellite links. On-site data storage uses solid-state memory modules or cassette tapes. The standard environmental operating range of the dataloggers is −25°C to +50°C, with −50°C to +80°C available through special testing.

New, inexpensive, low-powered dataloggers designed for environmental applications greatly facilitate the measurement of parameters important to slope stability and soil mechanics work. This discussion includes a brief review of data acquisition functions followed by a list of datalogger design features important to environmental applications. The advantages of sensor compatibility and on-site processing are discussed in further detail. Several data retrieval methods are presented and a current application is discussed.

FUNCTIONAL OVERVIEW

Digital data acquisition requires the automated conversion of electronic sensor signals to a digital value [analog to digital conversion (ADC)], which is then stored or transmitted, or both. Although many hardware options exist, certain functional components are common to any data acquisition process. A broad view, from sensors to computer, is shown in the block diagram in Figure 1. In traditional data acquisition systems, each individual measurement was stored, whereas today's processing dataloggers store results from several measurements processed over time (e.g., averages, maximums, standard deviations). In addition, external circuitry was often required to condition sensor outputs for measurement by the datalogger. In many of today's systems, the datalogger performs all of the functions enclosed in the broken line of Figure 1.

ENVIRONMENTAL DATALOGGER DESIGN FEATURES

The design specifications for a datalogger depend on the intended application. A summary of requirements that are important for unattended operation in remote, outdoor environments follows.

1. Wide temperature and high humidity operating range: In addition to surviving, the datalogger must hold stated accuracy specifications over environmental temperatures and high humidities. Today, performance over −50°C to +80°C temperatures is attainable with standard tested components, which eliminates the need for expensive military specification components in most cases. Solar heating can raise datalogger enclosure temperatures 20°C above air temperatures. It has been found that the use of desiccant and weather-tight enclosures provides the simplest and most cost-effective means of protecting the datalogger from dust, rain, and condensing water vapor concentrations.
2. Portability and low power consumption: Field sites where slope stability is a problem generally have difficult access. A datalogger that is small and requires little power reduces installation logistics and is easier to protect from vandals. Efficient design can attain 8 months of operation from eight alkaline D-cell batteries in an application where 12 sensors are measured once per minute.
3. Input transient protection: Environmental dataloggers are vulnerable to major hardware damage caused by large, lightning-induced transients entering the system on sensor leads. Protective hardware, such as transorbs, spark gaps, and the like, and proper grounding procedures are required to minimize damage.
4. Hardware microprocessor reset: Unattended, processor-based instrumentation should contain a hardware reset to restore normal processor execution in the event that it is altered by input transients or intermittent component failure. User-entered programs should exist in write-protected memory to minimize the possibility that the processor can overwrite the program should an abnormal execution state occur.
5. Field observation of measurements: The ability to continuously observe sensor measurements on a display, in engineer-

Campbell Scientific, Inc., P.O. Box 551, Logan, Utah 84321.

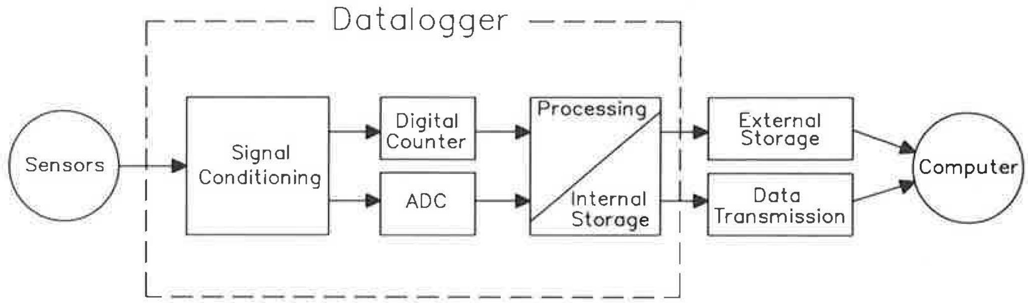

FIGURE 1 Generalized data acquisition sequence.

ing units, provides an invaluable tool for on-site system verification. Observing the processed values stored in internal memory is also necessary.

6. Sensor compatibility: Direct connection and measurement of sensor signals without external signal conditioning circuitry reduce cost, complexity, measurement error, and power requirements. The datalogger's ability to resolve signals to the required measurement precision dictates the choice of sensor.

7. On-site processing: Field processing reduces data storage requirements, scales linear and nonlinear sensor signals to engineering units, and provides logic decisions for control applications.

8. Remote communication capability: The need for real-time data collection is obvious in hazard warning applications such as flood forecast, but the expense of site visitation often makes telephone, radio, or satellite links cost-effective even when real-time data are not needed. Remote collection of the data allows verification of the system at any time. Experience has indicated that significant communication features should include two-way communication, with error checking and detection that result in retransmission in the event of errors. The datalogger should contain internal data storage so data can be retrieved later in the event the communication link is temporarily disabled. The ability to remotely change or restore programs or initiate control functions at the datalogger site is also desirable.

SENSOR COMPATIBILITY

A sensor possesses a property that changes in a known way with changes in the physical parameter being measured. For automated data acquisition purposes, changes in the property must result in an electrical signal. The condition of the measured physical parameter may be related to one of several electrical properties: voltage, current, resistance, frequency, AC impedance, capacitance, inductance, phase, and so forth. Table 1 gives several sensors used in soil stability work and their electrical property.

Except where noted, all of the sensors in Table 1 can be measured directly by a datalogger that makes voltage and frequency measurements. Resistance signals are converted into voltages using bridge completion resistors and precision bridge excitation voltages sourced by the datalogger. Current signals are converted to voltage signals by means of a shunt resistor. Although there are several complex sensors, which require extensive signal conditioning, there are many useful sensors that can be measured directly without additional circuitry by dataloggers with the following features:

1. Low input voltage noise: Thermocouples, remote temperature detectors (RTDs), and strain gauges require input noise levels in the submicrovolt range.

2. High-resolution analog to digital conversion: Resolution is often more critical than accuracy when changes in time or between sensors are desired. A resolution of 1 part in 15,000 (14 bits) measures a pressure sensor with a full-scale range of 15 m (50 ft) to 1 mm (0.04 in.) of water.

3. Programmable voltage gain: To maintain resolution, selectable full-scale input ranges from a few millivolts (metal foil strain gauges) to several volts are required.

4. Switched excitations: Power consumption is reduced by applying resistance bridge excitations at the time of measure-

TABLE 1 SLOPE STABILITY SENSORS

Parameter	Sensor	Signal
Water height and pore pressure	Strain gauge	Ohms
	Vibrating wire	Frequency
Barometric pressure	Potentiometer	Ohms
	Strain gauge	Ohms
	Vibrating wire	Frequency
Linear motion	Potentiometer	Ohms
	LVDT[a]	V-ratio
	Incremental encoder	Frequency
Inclination	Electrolytic[b]	Volts
	Potentiometer	Ohms
Velocity and flow	Incremental encoder	Frequency
	Switch closure	Frequency
	Magnetic pulse	Frequency
Deformation	Strain gauge	Ohms
Temperature	Thermistor	Ohms
	Thermocouple	μV
	RTD	Ohms
	Silicon solid-state devices	
	AD590	μA
	Silicon diode	μA
Precipitation	Potentiometer	Ohms
	Switch closure	Frequency
Soil moisture	AC conductivity	Ohms

[a]LVDT = linear voltage displacement transducer.
[b]Requires extensive signal conditioning.

ment only. Resistance measurements made as the ratio of the bridge voltage to the excitation voltage remove the inaccuracy of the voltage reference from the measurement if the excitation and voltage measurement use the same voltage reference. Switching excitation polarity eliminates thermal electromagnetic frequency errors in low-level bridge measurements. If the measurements are fast enough and the excitation at both polarities is symmetrical in time and magnitude, the same device can be used to measure AC conductivity. These types of measurements are needed for soil moisture blocks and water conductivity.

5. Frequency counting: A switch bounce elimination circuit and an amplifier for low-level AC signals are needed. Dedicated counters are required for low-frequency asynchronous events. Period averaging is required for accurate measurement of a limited-duration signal such as that from the vibrating-wire transducer.

ON-SITE PROCESSING

The advantage of processing measured values to obtain more efficient data storage has been mentioned. Data compression is particularly important in remote applications, where site visitations are costly. Processed results such as averages, standard deviations, and extremes or values recorded conditionally at designated times, events, or when changes occur all reduce data storage and handling logistics.

Linear calibration constants are entered into the datalogger to convert measurements into engineering units immediately. The datalogger displays the sensor signal in engineering units, which enables the user to verify the correctness of the signal and its conversion. Field calibration of sensors is possible. User-entered polynomial coefficients are used to linearize nonlinear measurements. Linearization and the scaling of sensor outputs into engineering units make it possible to correct sensor readings on site (e.g., correcting a piezometer reading for barometric pressure yields pore pressure). Nonlinear signals converted to engineering units can then be averaged, but in their nonlinear form they cannot. The ability to convert sensor signals into correct engineering units is most useful when verifying the performance of the sensors and the datalogger in the field.

The ability to compare values or time with programmable limits and make decisions provides useful control functions such as sampling at a faster rate, measuring a selected sensor, or initiating a radio or telephone communication for an alarm message.

REMOTE COMMUNICATION CAPABILITY AND DATA RETRIEVAL

Remote communication and data retrieval are possible over hard wire, telephone lines, radios, and satellite. Data retrieval is also possible via memory module and cassette tape.

Remote communication through most devices has been improved by the addition of large amounts of internal memory for final data storage. The storage of data at the remote site permits the retransmission of data when error detection and correction routines fail or when data are missed by the computer. The speed of remote data transmission has also been improved by the use of a binary format that increases the effective transmission rate fivefold.

The advantages, limitations, and new developments in remote communication over hard wire, telephone lines, radios, and satellite follow.

1. Hard wire: A shielded pair of twisted leads (user installed) could be used in conjunction with a set of modems to connect one or more dataloggers to a computer. High baud rates are possible over short distances, but high cable costs are likely by the time the 5-km (3-mi) limit is reached.
2. Telephone lines: 300- and 1,200-baud DC-powered modems that meet the environmental requirements are available. The modem and telephone line combination allows remote communication over long distances as long as the line quality is "good." Long-distance telephone charges and installation costs at remote locations could limit the feasibility of this method for some sites. All things considered, telephone lines are one of the most reliable and least expensive methods of data transfer available.
3. Radio: Radio transmission is often the most practical solution to the problem of remote communication in rugged terrain. Data transmission over distances of 40 km (25 mi) is possible with good "line of sight" on voice grade radios. Any station can be used as a repeater to extend the range of a network to 200 km as long as the maximum distance of 40 km between stations is observed. As many as 255 stations are accessible on a single frequency. Data throughput rates can be as high as 30 values per second. Radio transmission may be combined with telephone line transmission [e.g., communicate 32 km (20 mi) over rugged terrain via radio, link to a telephone line, and then communicate 320 km (200 mi) via telephone to the computer].
4. Satellite: A small number of geostationary orbit earth satellite channels are available. Many of these are reserved for government agencies. Transmission rates are currently limited to 30 data values every 3 hr. A faster earth station computer and new satellites should improve channel availability and data transmission rates. Satellite transmission works well for extremely remote sites.

If immediate data transfer is not a requirement, data may be transferred back to a computer more economically by hand carrying the data in a solid-state memory module or on a cassette tape. Data storage capacity on a cassette tape is 180,000 processed values. Storage capacity of the different storage modules is 32,000, 60,000, and 360,000 processed values.

CURRENT APPLICATION

The datalogger was used to study a mudslide located in Steed Canyon above Farmington, Utah. Five semiconductor strain gauge piezometers were used to measure pore pressure. Movement and tilt were measured with a potentiometric extensiometer and a potentiometric inclinometer. Air temperature was measured with a thermistor, precipitation was measured with a tipping bucket rain gauge, and barometric pressure was measured with a capacitance type of transducer. The barometric pressure reading was subtracted from the pore pressure readings to remove atmospheric pressure fluctuations. Data were normally recorded every 6 hr. When changes in any of the pore pressure readings exceeded 1.3 cm of water in a 5-min time period, the data were recorded every 5 min. The datalogger was located in a small, unheated enclosure. The minimum outside air temperature recorded during the winter was −24°C at the site. A lead-acid battery about half the size of a car battery powered the datalogger the entire season. During the first year data were stored in memory and on cassette tape. The second year data were transmitted via satellite.

SUMMARY

Technological developments have led to the creation of new instrumentation for automating the measurement of soil stability parameters. The special design features required for unattended operation in remote outdoor environments have been discussed.

Special features in these small, low-power dataloggers have made them capable of direct measurement of resistance sensors, current sensors, and signals from voltage and frequency sensors. This measurement capability allows accurate sensing of stability and movement of a slope as well as weather factors that affect its stability. Direct measurement of these sensors reduces the complexity and cost of the system.

The processing capability of the dataloggers allows conversion of all signals to meaningful engineering units. The signals, now in engineering units, are then compared with fixed values or other signals to determine whether an alarm should be sent, additional sensors measured, or data recorded more frequently.

Remote communication and data transfer capabilities are improved in the new instrumentation. Instrumentation and software have been developed to allow data transfer via hard wire, telephone lines, radios, and satellite. Data transmission speed and reliability have also been improved.

Publication of this paper sponsored by Committee on Soils and Rock Instrumentation.