

23 Oct 1987

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Norbert H. Maerz

Missouri University of Science and Technology, norbert@mst.edu

M. B. Dusseault

R. W. Gillham

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Recommended Citation

N. H. Maerz et al., "An Economical Field Datalogger," *Proceedings of the 1st Canadian Symposium on Microcomputer Applications to Geotechnique (1987, Regina, Saskatchewan, Canada)*, pp. 33-39, Oct 1987.

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An Economical Field Data Logger

N.H. MAERZ, M. Sc.

M.B. DUSSEAULT, Ph. D.

R.W. GILLHAM, Ph. D.

Department of Earth Sciences, University of Waterloo

Waterloo, Ontario, Canada

SYNOPSIS

Data acquisition is important in geotechnical and hydrological field investigations. Commercially available data acquisitions systems are often not well suited to field use, and can be costly. An alternative to buying a data acquisition system is to build one, and recent advances in computer micro-chip technology have made it easy to understand, design and build simple data acquisition devices.

The design of a data acquisition system developed at the University of Waterloo, along with an example of its use, is discussed in the paper. The intent was to sample 16 channels at 12 bit resolution for prolonged periods under adverse field conditions. Other design parameters included portability, battery operation, and a sealed unit to guard against moisture ingress.

INTRODUCTION

Precise and accurate measurements are required in all geotechnical and hydrological field investigation and monitoring programs. Variables of interest might include pressure, temperature, displacement, strain, or acceleration. Typically, data are required in remote locations such as mines, tunnels, slopes, or dam sites, in extremes of temperature and humidity.

In the past, measurements have been recorded manually or on analog plotting devices such as a strip chart recorder. With the increasing use of computers for analysis of these measurements, there is also an increasing need for electronic data acquisition devices, or data loggers, to automatically record and store these measurements in digital form, which can be used immediately in analysis.

Commercially Available Data Acquisition Devices

Many different data acquisition devices can be purchased. These range from expensive dedicated units to inexpensive plug-in boards for popular desk-top microcomputers. Prices for these devices range from hundreds of dollars to hundreds of thousands of dollars. Many of the more expensive devices have capabilities far beyond the needs of a typical geotechnical or hydrological application.

Few commercial devices are ideally suited to field use, for the following reasons:

1. Field data acquisition devices should be capable of operating under adverse conditions: protection from rain, humidity, and extreme temperatures is necessary. Measurements must not be affected by fluctuations in temperature, humidity, magnetic field, low frequency vibrations, and so on. In addition, the device must be battery powered. Few commercial devices meet these criteria; most are designed to operate in the laboratory under relatively ideal conditions.
2. The device should be capable of being reprogrammed for different applications. Many of the less expensive data acquisition devices have limited programming capabilities. Programming is often done by pressing buttons in cryptic sequences, and functions are limited.
3. The device should be capable of being serviced, at least to some extent, in the field, by the user. Commercially available data acquisition devices are usually "black boxes" to the field user. Should a malfunction occur, it must be sent to the manufacturer for repair. With the high cost of field investigations, this type of delay can be very costly.

An Alternative Data Acquisition Device

Building a simple device is a viable alternative to purchasing a commercial data acquisition system for some applications. Recent technological advances in computer micro-chip technology have made it possible for relatively unskilled persons to build and develop computer hardware applications, such as data acquisition devices. Although this approach requires more personnel time initially, extended applications and the development of the skill in-house will usually offset the greater time investment.

In the last few years, a class of microprocessors have been developed that, although not powerful by today's standards, are relatively simple to understand, operate, and interface to other electronic circuitry. These chips are single chip microcomputers, rather than microprocessors, and are programmable in BASIC, and thus easy to program. Their design allows anyone with a small knowledge of electronics to build a small data acquisition or control system using such a chip. Two examples of such chips are the National Semiconductor INS8073 and the Zilog Z8671. Descriptions of simple circuits based on these two chips are given by McKowen and Sarns (1981), and Ciarcia (1981). Both of these articles are presented in popular microcomputing journals, both geared for the layman rather than the technical expert.

There are advantages to building a data acquisition system based on such chips, either from scratch or from simple computer boards:

1. The cost of producing these systems is a fraction of the cost of purchasing a suitable system. This is especially important if many units are needed.
2. The system is completely programmable in a simple language (BASIC). This will permit users with limited programming experience to program the data acquisition system. A series of canned programs for various applications will rapidly develop in-house.
3. The design, architecture and workings of the machine will be known to the user. If a malfunction occurs, repairs can be made quickly and on the spot.

There are also disadvantages to building a data acquisition system. This includes the development cost, which can be more than trivial. Another factor to consider is the power of the system. If high resolution or high rates of data acquisition are required, the design may be out of the range of these simple devices. In such cases it may be prudent to purchase a proven commercial design.

ELEMENTS OF ELECTRONIC DATA ACQUISITION

Electronic data acquisition consists of several discrete operations which are required to make, process, and store a measurement: analog signal generation; analog signal conditioning; analog to digital conversion; and, digital signal processing and storage.

Of these, only the last two are considered here. The sensing devices which make measurements and generate analog signals are in most cases highly precise instruments, which must be purchased. Examples are pore pressure transducers, linearly variable displacement transducers (LVDT), thermocouples or thermistors, and various potentiometers and resistance devices such as strain gauges. Signal conditioning is relatively straightforward, and is often done as part of the signal generation package. For a general summary on mechanical measurements see Beckwith, Buck and Marangoni (1982).

The analog to digital conversion is at the heart of a data acquisition system. An analog signal is a continuous time dependent electrical signal and all sensory devices output analog signals, whereas computing devices require digital signals. For an analog signal, typically the voltage, current, or frequency level will be in some way proportional to the information being transmitted, and will vary continuously with time. A digital signal on the other hand consists of a train of parallel or serial pulses, on which the transmitted information is coded. This information contains the value of the parameter being monitored at discrete and specific times.

In a data acquisition system, the analog to digital conversion is accomplished by a single microchip, controlled by the microprocessor. In the case of a varying voltage signal, analog to digital conversion is simply the process of repeatedly measuring the analog voltage at fixed time intervals, and coding it into a binary (digital) number.

Processing acquired data can be done instantly (in real time) or data can be stored for later processing. For some types of data acquisition real time processing is not important; it can be done later on a more powerful computer. However, in any type of control application, real time processing is needed. If the system is in any way a warning device, real time interpretation is vital. If the progress of a test being monitored is to be altered in accordance with the measured outputs, real time processing is also needed.

The real time processing of information is best carried out on a computer, hence the design presented here is well adapted for that use. Consider the following example. Temperature monitoring is necessary over several days at one hour intervals, but if the rate of change of temperature exceeds 5°C per hour, it is necessary to sample more frequently for a period. This can be coded very simply with the following logic:

- Store data every hour (interval DEL)
- Sample every minute (interval del)
- Store T(i), t(i) (degrees and hours) in temporary storage
- Calculate dT/dt using finite difference approximation

$$dT/dt = \frac{T(i) - T(i-1)}{t(i) - t(i-1)}$$

- If dT/dt exceeds 5°C, change DEL to 5 min, and check every step
- If not, continue recording only every hour

A number of simple logic loops like this can be written, and it is even possible to store only derivative data, rather than data at every time step. For use as an alarm, say for both absolute strain and for rate of change of strain, the logic is similar, only once strain or $d(\text{strain})/dt$ exceed prespecified limits, a signal is sent to an alarm circuit.

Storage of the acquired data can be done in a number of ways. The data can be recorded on magnetic media, or on paper. Alternatively, the data can be retained in the core memory of the microcomputer, for later transmission to a more powerful "host" microcomputer.

Design Criteria For A Low Cost Data Logger

When building a field data acquisition system the following design criteria should be kept in mind:

1. Low cost. The device should be economic, especially if multiple devices are needed.
2. Simplicity. The device should be easy to understand, operate, and repair.
3. Reliability. The device should give consistent results, and would suffer a minimal number of breakdowns.
4. Low power requirements. The device should be capable of functioning for an extended period of time, on battery power.
5. Environmental tolerance. The device should be capable of functioning over a wide range of temperatures and humidities, without a loss in performance or drift as a result of temperature change.
6. Programmability. The device should be easy to program, yet be flexible in every aspect of sampling, processing and storing of the data. Also, real time responses to the data should be programmable.
7. Hardware compatibility. The device should be capable of being interfaced with a wide variety of sensing devices.
8. Data Storage. The device should have enough core storage to record measurements for an extended period of time. This storage should be non-volatile. (Magnetic storage can be unreliable in field conditions).
9. Sampling speed. The device should have multiple channel inputs, and the sampling speed should permit cycling through all channels, yet allow successive samples on the same channel to be reasonably close together.

A "HOME-MADE" DATA LOGGER

At the Department of Earth Sciences at the University of Waterloo, a low cost data acquisition system has been designed and built. The system is based on a simple 28671 micro computer, which was previously developed at the Department.

The datalogger was designed as a self-contained unit housed in a single hermetically sealed box (Fig. 1), powered by a single 12 volt automobile battery. It is designed to stand alone when recording data, requiring a host microcomputer (Fig. 2) for purposes of programming. The data gathered by the datalogger can be unloaded by the host microcomputer in the field, or the datalogger can simply be carried back to the office and the data unloaded there.

The datalogger is capable of operating in the field at temperatures between -10 to 70°C , for periods up to 2 weeks. It is capable of sampling 16 channels at 12 bit resolution in approximately 1 second. The datalogger will store up to 1056 complete 16 channel samples in its core memory. Sampling rates, sequences, and responses are controlled by the BASIC software.

The total cost of parts for the datalogger was under \$1000. The box, connectors and external wiring accounted for over half of this amount.

The 28671 Microcomputer

The U. of W. EARTH SCIENCES Z-8 BOARD VERSION 1.1 was developed in 1983 by Dr. Ian Gibson of the Dept. of Earth Sciences, University of Waterloo. It was conceived as a low cost, simple, versatile device which could be dedicated to a number of tasks including data acquisition and control applications.

Conceptually, the Z-8 is a very simple microcomputer, consisting essentially of four components: A single-chip 28671 microcomputer, 24K bytes of interchangeable RAM or ROM memory, parallel I/O (input/output) capability to attach external devices and an RS232 serial port, for communication. Although earlier versions of the computer were simply wire wrapped on breadboard, the current version microcomputer is mounted on a single 23×18 cm. printed circuit board (Fig. 3). It includes no keypad or display device, but rather is by default programmable through the serial I/O lines by means of an ASCII terminal or a "host" microcomputer.

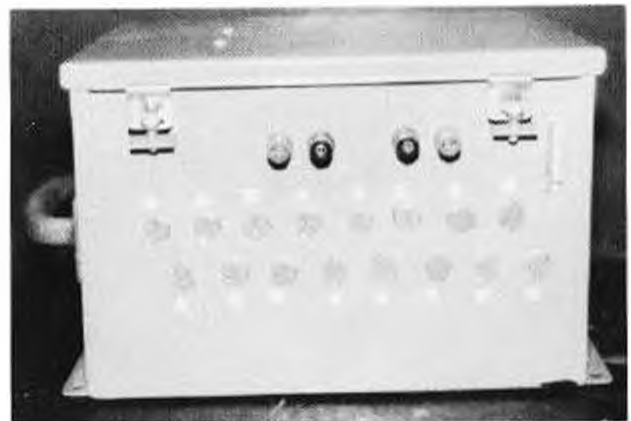


Fig. 1. The "home made" data logger.

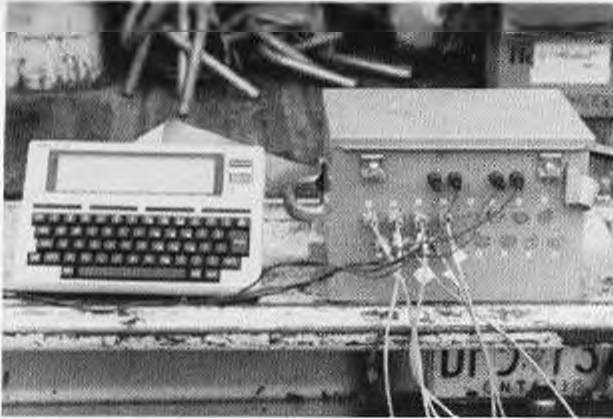


Fig. 2. The data logger and the M100 host.

The architecture of the microprocessor and surrounding components is as simple as possible. This allows someone who has little electronics knowledge to deal not only with the programming software, but also with the addition of hardware applications by hardwiring and interfacing them directly to the board.

Programming the 2-8 board is simple because the BASIC interpreter, which resides in ROM on the 28671 chip, allows simple and direct addressing of any part of the memory. A machine language program, if required, is simply written to an unused part of the memory. It is then executed as a subroutine that is called from a BASIC or machine language program. (No linking or loading is necessary.)

The Analog to Digital Converter

A single chip 12 bit analog to digital conversion chip, and a 16 channel multiplexer chip were wired directly onto an empty space on the printed circuit board (Fig. 4). The multiplexer and analog to digital conversion chips were selected for their simplicity and low power consumption. Alternatively, chips could be selected which were capable of a much higher sampling rate, but also with a high power consumption.

The Field Power Supply

Because microcomputers require three different voltages (+5 Volts D.C., +12 Volts D.C., and -12 Volts D.C.) and a single battery is incapable of supplying both a negative and a positive potential, a power supply was designed for the datalogger.

This design utilized a switching principle to convert the 12 volt battery potential to the required voltages. The switching design allows a 70-80% power conversion efficiency, as opposed to the 30-40% that would have been realized using a standard voltage regulator. The rechargeable lead-zinc automobile battery was chosen to drive the power supply, as it is a relatively powerful battery at a relatively low price.

The Memory Battery Backup

The core memory of microcomputers is capable of storing information only as long as the microcomputer power supply is on. This is known as volatile memory. It is possible to use non-volatile memory such as bubble memory, but it is both expensive and difficult to use. Therefore a different strategy was used to preserve the contents of the core memory during power shutdown.

Standard nickel-cadmium batteries were put into a circuit which allowed them to be charged when the microcomputer power supply was on, and which powered the memory chips when the power was off. In the case of a power failure, the contents of the core memory are retained.

The Host Microcomputer

The 28671 datalogger is designed as a dedicated stand-alone device. However, for the purpose of loading software and unloading data, a host microcomputer is needed. This host controller is needed only periodically, therefore one host can serve more than one datalogger.

The host microcomputer can be any device that can communicate along a serial (RS232) line. This device can be anything from an ASCII terminal to a mainframe unit connected along a telephone line. Most microcomputers are capable of this, including IBM PC, Apple, TRS-80, etc.

The microcomputer chosen was the Tandy Corporation (Radio Shack) Model 100 (Fig. 5). This was by far the most reasonable, at less than \$1000, but also one of the most useful of the portables on the market. Combining CMOS microchip technology (low power chips) with LCD (liquid crystal display) allows the machine to function for about 8 hours on 4 AA batteries. Furthermore, an internal nickel-cadmium battery saves all the memory contents for up to one month when the machine is shut down. The

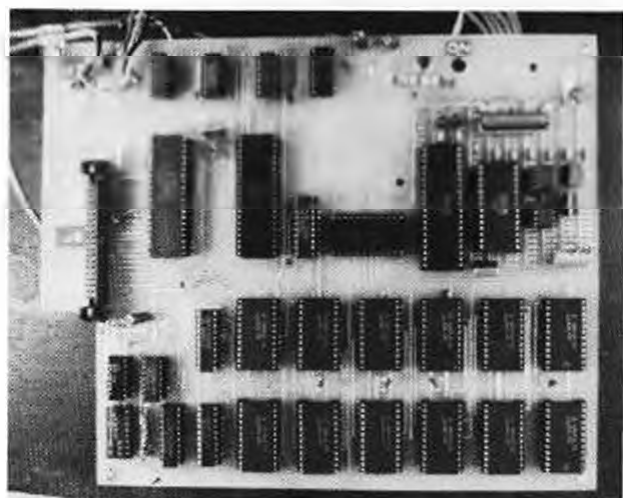


Fig. 3. The 28671 based microcomputer.

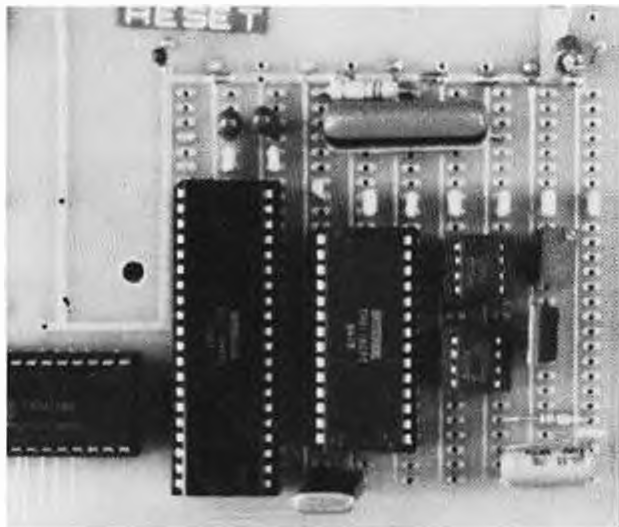


Fig. 4. The "kluge" area of the Z8671.

machine comes complete with a full standard keyboard, 40 characters by 8 line display, RS232 serial port, Centronics parallel port, a 300 baud direct connect telephone modem, and a cassette tape interface.

BASIC programs for the datalogger are prepared by the Model 100's text editor, and loaded down to the datalogger by the telecommunications package that was written for this purpose. Data is uploaded from the datalogger, also by the telecommunications program. The data can either be continuously unloaded as the measurements are being made, or they can be recovered at a later time. From the Model 100, the data can be printed out on a hardcopy, stored on magnetic tape, sent by telephone line to another computer, or analyzed directly.

The disadvantage of the M100 as a field device is simply that it is not environmentally sealed, or suitable in cold weather. It is far from rainproof, and LCD displays do not operate at temperatures below freezing. However, as the M100 is intended to be used not as a dedicated machine, it could normally unload data on a once a day basis; the entire procedure would take only 5-10 minutes. For this amount of time the M100 could be protected from the elements in, for instance, the interior of a car or truck, with a cable connecting the M100 to the Z-8.

CASE STUDY: MEASUREMENTS OF HYDRAULIC HEAD

In one study, the datalogger was used to record tension pressure head in the unsaturated zone during simulated rain.

In this field test, six tensiometers were installed in a vertical profile at different depths (from 10 to 100 cm) in the unsaturated

zone. The tensiometers were connected, via hydraulic lines, to six amplified pressure transducers capable of measuring negative pressures (Fig. 6). A rain simulator distributed water over the surface of the ground for 30 hours.

Hardware Adaptions to the Datalogger

The datalogger box was used to provide the excitation voltage to the pressure transducers. A second automobile battery was added to the system, and an 8 volt power regulator was installed inside the box to supply the excitation voltage. Three wires were connected from each transducer to the datalogger; excitation, signal, and common ground.

The analog to digital converter in the datalogger was adjusted to accept the 1 to 3.5 volt output span of the transducer in the negative pressure range. The pressure transducers were then individually calibrated. The digital number measured by the datalogger was calibrated directly against hydraulic head using a laboratory manometer.

Software Adaptions

A few software adaptions were made to the program controlling the datalogger. The number of channels to sample was set to six. The sampling rate was set by providing a fixed time between samples which was set at 15 minutes. The revised program was downloaded to the datalogger from the Model 100 micro-computer.

Results

The data were collected and stored in the memory of the datalogger for the duration of the simulated rain test. After the test, the data was transferred to the Model 100 micro-computer. The Model 100 was then transported back to the office, where the data was transferred to an Atari 1024ST for subsequent analysis and graphics. Fig. 7. shows the results of the test, a progressive delay response to infiltration.



Fig. 5. The TRS 80 Model 100 microcomputer.



Fig. 6. Tensiometer and pressure transducer.

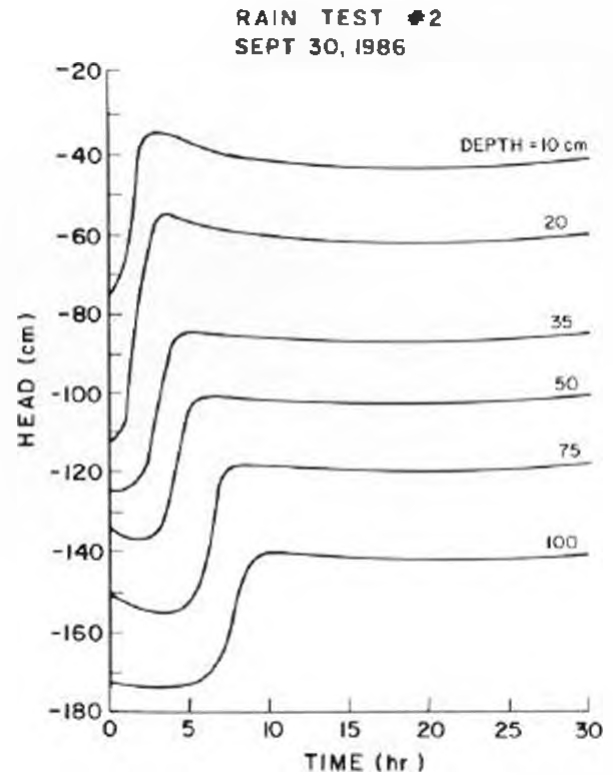


Fig. 7. Results of one simulated rain test.

SUMMARY AND CONCLUSIONS

Modern electronic technology has revolutionized the field of data acquisition. In addition to the dramatic increase in sophistication of the technology there is a marked trend toward simplification of design. It is no longer necessary to be an electronics expert to design, build, operate, and repair simple but effective computing devices.

The design of a simple homemade data acquisition system demonstrates this. The system is simple, built using simple, low cost, off-the-shelf components. It is, despite its simplicity, an extremely flexible device, in fact much more flexible than many of the high price sophisticated commercially available dataloggers.

For the field researcher, there are many advantages in using such a data acquisition system over commercially available models.

1. The price of such a system is typically a fraction of that of a commercially available system.
2. The system is completely flexible with respect to functions, as all programming is done by the user. The flexibility of commercial systems depends entirely on the program provided by the manufacturer, and reprogramming may be impossible or difficult.

3. Components are cheap and can easily be added on to the datalogger by the user. For a commercial system, adding components usually requires ordering from the manufacturer with attendant delays, or even sending the unit in to the main shop to be modified, and these can incur substantial costs.
4. The data acquisition system is designed for field operation. It is hermetically sealed and battery powered. Few commercial systems have these characteristics at low cost.
5. If a malfunction occurs, the data acquisition system is simple enough that it can be repaired by the user, quite often in the field. Commercial systems are usually too complex to be repaired by the user, and would normally need to be sent to the manufacturer for repairs. This represents a loss of time and money.
6. Our system is cheap enough that the user doesn't have to worry about insurance or accident. The loss of an entire unit in the field represents less than four man-days of a junior engineer's charge-out rates.
7. The expertise developed in-house during designing, building and using these units is transferable to other activities in the company.

ACKNOWLEDGEMENTS

The authors would like to thank Paul Johnston and Richelle Allen for providing the data from the simulated rain test. Dr. Ian Gibson is always most helpful. We thank the Natural Sciences and Engineering Research Council of Canada for their support of academic research endeavour.

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