Testing Data Acquisition Systems for Use in Monitoring Building Energy Conservation Systems

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ABSTRACT

Dedicated microprocessor-based data acquisition systems are beginning to be used to monitor the energy savings from building energy conservation retrofits. These systems capture data from important monitoring points and store the values for periodic transfer to a central location. While there are many data loggers available that appear suited to this task, choosing between them is complicated by a large number of manufacturers, a lack of standard communications protocols, and most significantly, no standardized tests for reporting their capabilities. This paper addresses the last point with a battery of tests that were developed and applied to data loggers from nine manufacturers.

INTRODUCTION

The Texas LoanSTAR (Loan to Save Taxes And Resources) program was established in 1988 by the State of Texas' Governor's Energy Office. This $98.6 million program uses a revolving loan financing mechanism to fund energy conserving retrofits in state, public school and local government buildings. One important facet of the program is the Monitoring and Analysis Program (MAP), which was established to measure and report energy savings from the retrofits. Before retrofits are installed in a building, a data logging device is connected to monitor information, such as electricity consumption or steam condensate use, that allows the effectiveness of the retrofit to be measured.

To ensure the highest level of confidence in the results of the MAP, data loggers from each manufacturer participating in the program were put through a series of bench tests. Since few standards for testing data logging equipment have been developed, it was decided to design the tests to reveal the logger's accuracy and limits on the behavior of attached sensors.

DESCRIPTION OF TEST BENCH

To test the data acquisition systems, a test bench consisting of 3 PCs (IBM compatible personal computers), special signal generating hardware, a digital storage oscilloscope and a controlled temperature chamber was assembled as shown in Figure 1. The first PC controls the signal generating hardware and can simulate the outputs of sensors typically used to monitor buildings. Up to 4 analog signals and 20 digital signals can be generated simultaneously. The oscilloscope is used to inspect these signals and investigate how each data logger affects them. The second PC is connected to the data logger via modem or a direct serial line to initialize it, monitor each test's progress, and obtain the results at the end of the test. The third PC uses special software to monitor the communications between the second PC and the data logger.

These tests took place with the data logger placed in a controlled temperature chamber fabricated from a used household refrigerator and a digitally controlled heating element. Dry ice was used to obtain temperatures below the refrigerator's normal ability.

DESCRIPTION OF DATA LOGGERS

The data loggers used in this program are special purpose microcomputers dedicated to monitoring signals provided by one or more sensors, periodically storing the time stamped value (integrated or instantaneously sampled) of each signal, and transmitting the stored values to a polling computer on command. A wide range of sensor types may be connected to loggers from various manufacturers. The sensors fall into 3 groups, digital, analog and power. Each of the loggers listed in Table 1 are capable of recording values from one or more of those sensor groups.

RATIONAL OF TESTS

A digital sensor is typically a dry contact that closes at a rate proportional to the quantity being sensed. An example is the KYZ pulse initiator on many watt-hour meters. There is a limit to the rate at which a logger can sense these pulses. Furthermore, each logger reacts differently to bouncing contacts, semiconductors used in place of contacts, and the resistance across the contact (which is increased by long wire runs between a data logger and the sensor).

An analog sensor puts out a continuous (as opposed to discrete) signal that is proportional to the quantity being sensed. This signal may be resistance (RTDs), current (typically 4-20mA), or voltage. The data logger must convert that analog signal into digital values for storage. This A-D conversion can be sensitive to the ambient temperature in the logger's location. Since the A-D operation is a quantization, there is a minimum amount the analog signal must change before the logger can sense it. In addition, most measured quantities have little meaning as an instantaneous sample, so they must be integrated over each recorded interval. This integration is a precision operation sensitive to the timing of the samples and the speed of the A-D conversion.

A few loggers are capable of directly sensing the output of potential and current transducers, and therefore can record electricity use without an external watt-hour transducer. A special (and potentially dangerous) test station is required to test this capacity so it is not addressed in this paper. However, such a station has been developed at the Energy Systems Laboratory and the results of the tests performed there will be reported separately.

DESCRIPTION OF DIGITAL TESTS

Most loggers provide a small current to their digital channels so that the sensor needs to be only a dry contact. As each logger was brought to the bench, a multimeter and variable resistor were used to determine what kind of signal the logger provided and how much current had to pass through the contacts before the logger recognized them as closed (see Table 1). This information is important if the sensor uses semi-conductors instead of dry contacts or if very long runs of wire are between the logger and the sensor. The type of contact closure was also noted (see Table 1 and Figure 2).

To determine how long the sensor must keep the contacts open or closed for the logger to accurately record a pulse, a string of pulses alternating between, for example, 25 ms (.025 second) closed and 40 ms open was sent to the logger (see Figure 3). The number of these pulses was chosen to span more than 2 recording periods.

$$\text{number of pulses} > \frac{2 \bullet \text{integration period}}{(\text{close time} + \text{open time})}$$

The logger would then be polled to see if it counted the right number of pulses. Experiments showed the boundary between working and not working was connected in [0ms,100ms]x[0ms,100ms] so two-dimensional bisection was used to reduce the number of tests.

RESULTS OF DIGITAL TESTS

The results of the tests on each logger were plotted as closed time vs. open time (Figure 3). Plus signs indicate the logger accurately recorded pulses at that closed-open pair. Dark boxes indicate the logger failed. The grey area indicates those points that are inferred to be bad.

Most of the loggers tested exceeded their published specifications for recording digital pulses. One was able to accurately record the fastest signal our equipment could generate. Two exhibited unexpected behavior. Of those, one would consistently count fewer pulses than were sent. Conversations with the manufacturer revealed that the logger was not latching the digital inputs, so if its microprocessor was busy when the pulse changed state, the signal would pass by unnoticed. The other consistently counted more pulses than were sent. It is suspected that the inputs are very sensitive to signal values between those of an open or closed switch resulting in reading "chatter" (Figure 2d). The manufacturer is working on a module to add to their logger that will fix this problem.

DESCRIPTION OF ANALOG TESTS

The temperature stability of those loggers capable of monitoring analog signals was tested by providing at least three constant signals: the maximum and minimum values the logger could record, and the average of those two. When necessary, more signals were used to investigate possible problem points (for instance, zero volts on a system that sensed -5V to +10V). The logger recorded these signals for several hours while being exposed to a range of sweeping temperatures (Figure 1). At the end of the test, the recorded voltages were plotted against the actual levels and against the temperature.

In order to investigate the loggers' ability to correctly integrate, three signals were generated: a triangle wave with a long period, a triangle wave with a short period, and a ramp (Figure 4). For instance, if a logger sensed 0-5V and was set to integrate over one minute intervals, the first wave would have a period of 100 minutes, the second a period of 5 seconds, and the ramp would go from 0 to 5V across the 200 minute duration of the test. The logger was set up to integrate the two triangles, and instantaneously sample the ramp. The values from the ramp, along with some additional timing obtained usually through the digital channels, indicate at which instant in the interval instantaneous sampling takes place.

RESULTS OF ANALOG TESTS

Figure 5 shows the results of the temperature dependency test on one logger, plotted both as a time-series and against the temperature of the test chamber in which the logger was placed. The three constant signals were set at -4.985V, -.005V, and 1.41V. This logger showed a very slight temperature dependency that was most apparent at the extreme values it could sense. Although not shown, the logger's behavior for a constant +5V signal is quite similar to that of the -5V signal. A special test was run on one of this logger's analog channels set to sense a 1000 Ohm RTD. In this configuration, the logger showed more significant errors at temperatures below 15F (Figure 5c). However, these temperatures are outside the manufacturer's recommended operating range. Typically, loggers are designed to operate in an environment of 32-122F.

The results of an integration test are displayed in Figure 6. In Figure 6a, the long wave is plotted as a time series along with the difference of the measured and actual value. This logger was very accurate at integrating the long period triangle wave. Figure 6b shows the recorded values for integrating the fast triangle. In this case, the integration period was one minute, and the fast triangle had a period of 5 seconds. The errors here are due to aliasing: the logger actually sampled the signal every 4 seconds. The instantaneously sampled ramp value matched the expected value close enough to allow the small difference in the real-time clock speed of the logger and the signal generating computer to be measured.

DISCUSSION

Users of a data acquisition system should have some idea of the accuracy of their equipment, especially when that equipment is used for revenue purposes or verifying retrofit savings. The tests reported here were designed to confirm the accuracy of data loggers from nine manufacturers. Although most of the models tested lived up to their specifications, a few failed badly. Had these systems been used at face value, serious errors could have gone by unnoticed.

Most of the units tested performed beyond the manufacturer's specifications for digital inputs. Some were found to have design flaws resulting in errors that were not related to the signal rate. Noticing that pulse widths at a typical LoanSTAR site vary from 1.5 seconds to 40 seconds, one might argue that the need to measure pulses a few milliseconds wide is rare. However, our experience has shown that certain watt transducers are capable of producing pulses in this range.

While the temperature dependency of analog measurements is slight in the conditions normally found in a building's mechanical room, one logger showed a significant dependency for very cold temperatures. This should serve as a reminder to keep the data acquisition systems at room temperature. Avoid hanging them outside, especially during severe wintertime weather.

The rigorous integration test has only been performed on one type of data logger. The other loggers either had problems with their digital channels or no digital channels at all, making it impossible to establish the precise timing required for the integration test.

Having a wide variety of data loggers available at one time has provided an opportunity to study different communications protocols (see Table 1). A single program that will allow unattended polling of many different loggers in a uniform fashion is under development. When completed, it will be placed in the public domain (excluding source code for those portions of the program that would reveal any manufacturer's proprietary information).

ACKNOWLEDGMENTS

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We would like to acknowledge the participation of the following manufacturers who willingly subjected their data acquisition systems to our tests. All manufacturers have been sent copies of their test results. For information about results from a specific system, please contact the manufacturer.

Automated Measurements, Inc., 508 SW Jefferson, Corvallis, OR 97333

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

Gfe Energy Management, 1980 Post Oak Boulevard Suite 1495, Houston, TX 77056

Gulton Industries, Inc., Gulton Industrial Park, East Greenwich, RI 02818

Lambert Engineering, 601 NW Harmon Blvd, Bend, OR 97701

Landis & Gyr Metering, Inc., P.O. Box 7180, Lafayette, IN 47903

Process Systems, Inc., 24 Starway, Willis, TX 77378

Slumberger Industries, 180 Technology Parkway, Norcross, GA 30092

Synergistics Control Systems, Inc., 5725 Bundy Road, New Orleans, LA 70127

These tests were conducted with the assistance of a PC based signal generation and recording system with an icon-based programming language from Strawberry Tree Incorporated. Signal inspection and diagnoses of malfunctioning loggers was simplified with a digital storage oscilloscope from Textronix. Our appreciation goes to these companies for their superior products.

Strawberry Tree Inc., 160 South Wolfe Road, Sunnyvale CA 94086

Tektronix, Inc., P.O. Box 500, Beaverton, OR 97077

Manufacturer	A	B	C	D	E	F	G	H	I
Maximum Pulse Channels	16	8	4	4	4	4	8	4	14
Maximum Analog Channels	15	none	16	4	none	none	32	none	14
Analog Type[1]	V,R,C,W	none	V	V	none[3]	none	V,R,C	none	V
Maximum Memory	32K	128K	40K	256K	48K	64K	512K	?	512K
Communications Protocol[2]	P	P	D	P	P	P	D	P	D

[1] V = Voltage, R = Resistance, C = Current, W = poWer

[2] P = Proprietary, D = public Domain

[3] This manufacturer supplies special modules that convert analog signals such as temperature to pulses

Manufacturer	Min[3] On Time	Min[3] Off Time	Max Square Frequency	Triggering Event	Pullup	Trigger Current
A	30/40	15/40	16.7Hz	closure	4.5V 3mA	2.3mA
B	32/100	35/100	14.3Hz	transition	13.9V 7.3mA	-
C[4]	-/3	-/4	125Hz	opening	1.8V 47uA	20.5uA
E	26/30	27/30	18.5Hz	transition	10.4V 3.8mA	.5mA,3mA[5]
F	81/80	83/80	6Hz	opening	20.7V 11.8mA	1.58mA
H	27/30	27/30	18.5Hz	closure	17.5V 23.75mA	8.5mA

[3] Observed/Manufacturer's published specifications

[4] Logger performs correctly to the limit of our abilities to test it

[5] Input exhibits hysterisis

Table 1
Typical Logger Characteristics

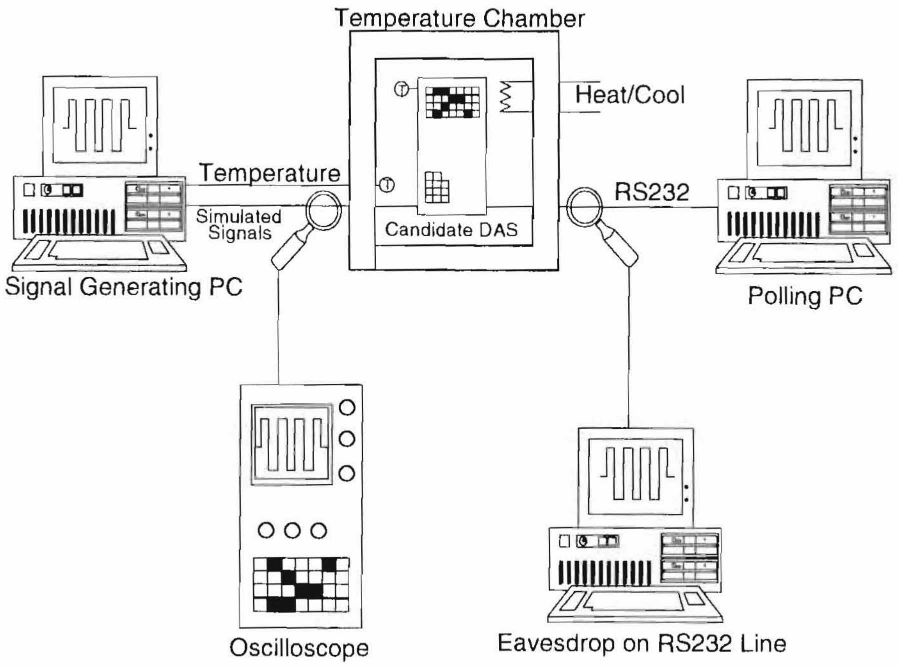

Figure 1
Testbench Setup

Three personal computers, an oscilloscope, a controlled temperature chamber and specialized hardware and software provide a platform for testing data acquisition systems.

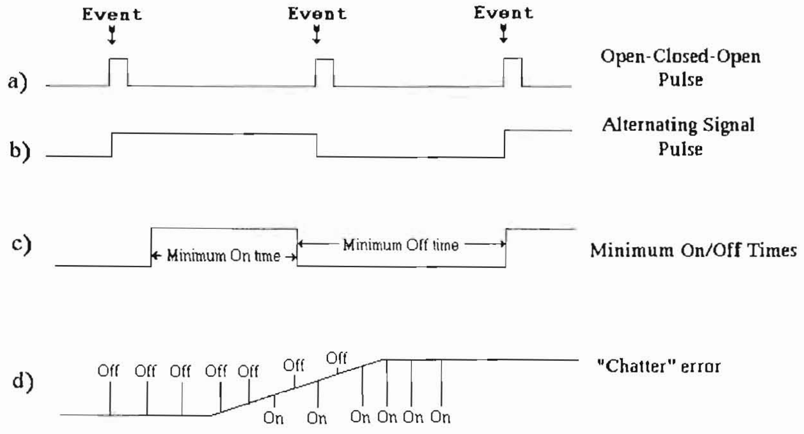

Figure 2
Digital Signals

A digital signal is usually generated by opening and closing a switch. Some loggers read just the closing or opening event, some read both. For each logger, there is a limit to how close together the events may occur. Furthermore, some loggers may be sensitive to intermediate signal levels and will record "chatter".

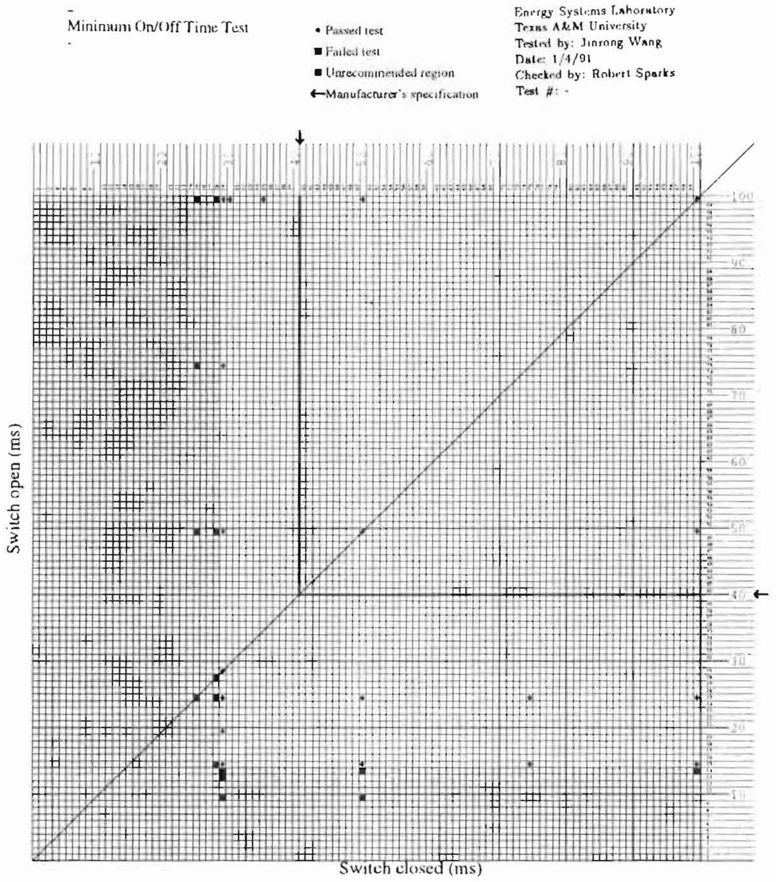

Figure 3
Digital Test Results

When pulses arrive too fast, loggers lose the ability to accurately count them. The digital test searches for the boundary between working and not working. Figure 2c describes the signal used for the digital tests.

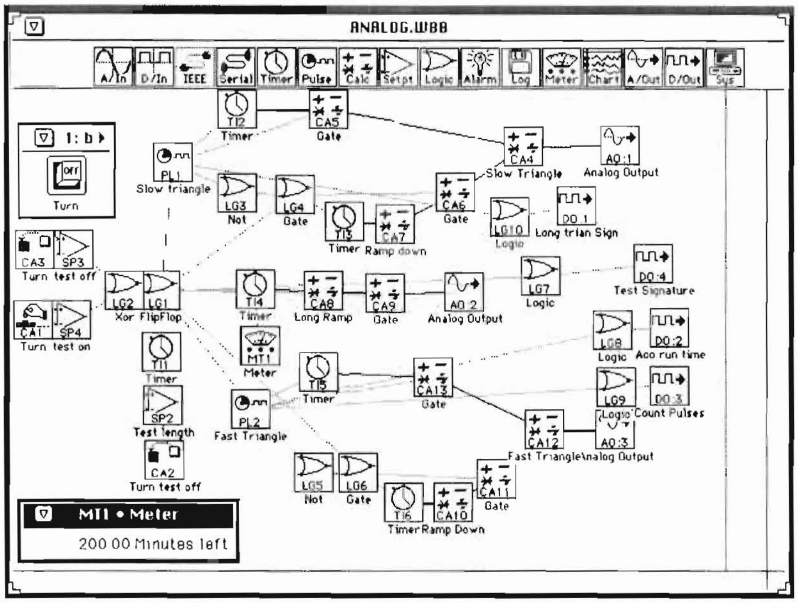

Figure 4
Analog Test Setup

This is the worksheet used to generate signals for the integration tests (see figure 6) using a commercially available D-A software package. Two triangle waves and a ramp are being generated here. The values sent to the analog output icons will appear on a termination board next to the PC. When the user clicks the Signal On button, the waves start. The digital outputs (denoted be DO:n) are used to synchronize the logger and the signal generating PC.

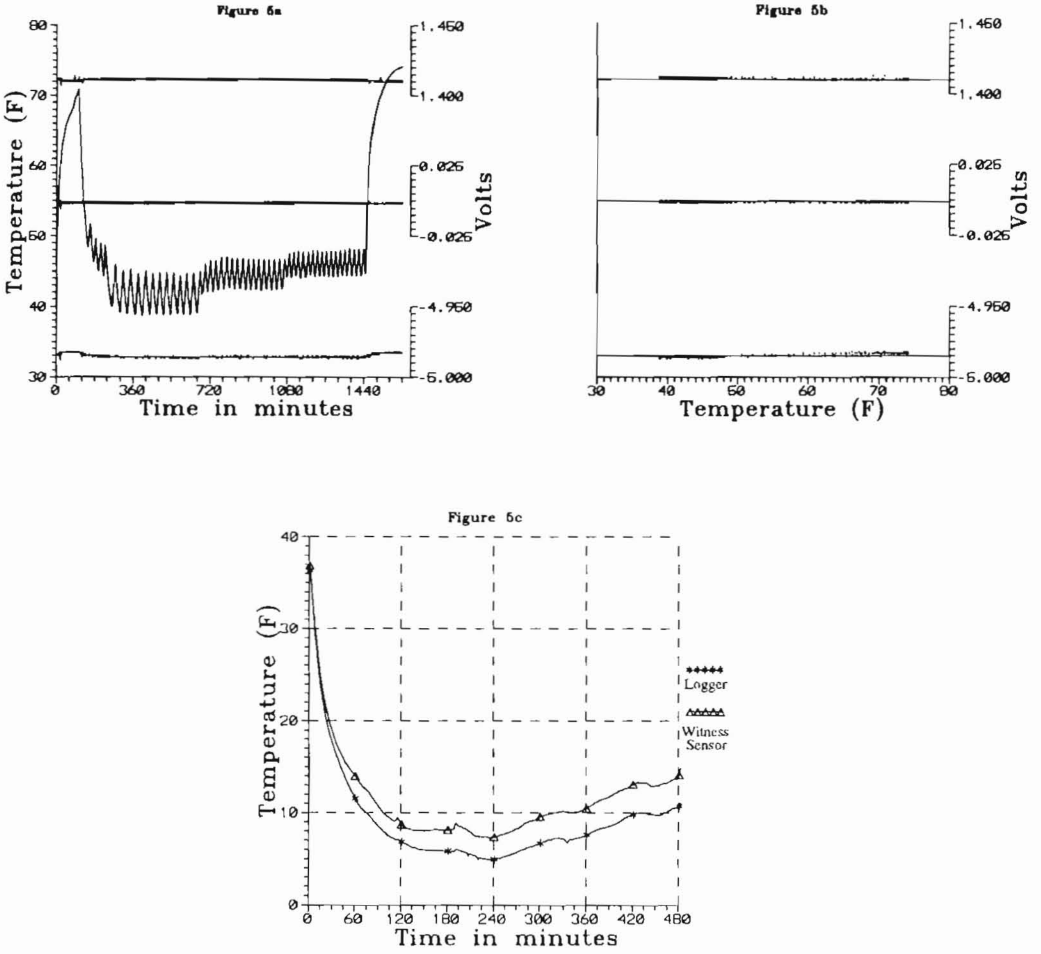

Figure 5
Temperature Dependencies

Each logger was provided 3 constant signals and exposed to a varying temperature. The results are plotted as a time-series (a) and against temperature (b). Figure c) shows the results of a special test on an RTD channel where a logger began to show a significant temperature dependency.

Figure 6a
Long Triangle

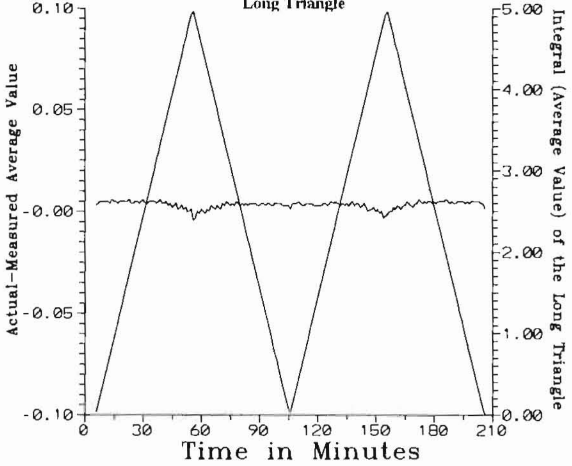

Figure 6b
Short Triangle

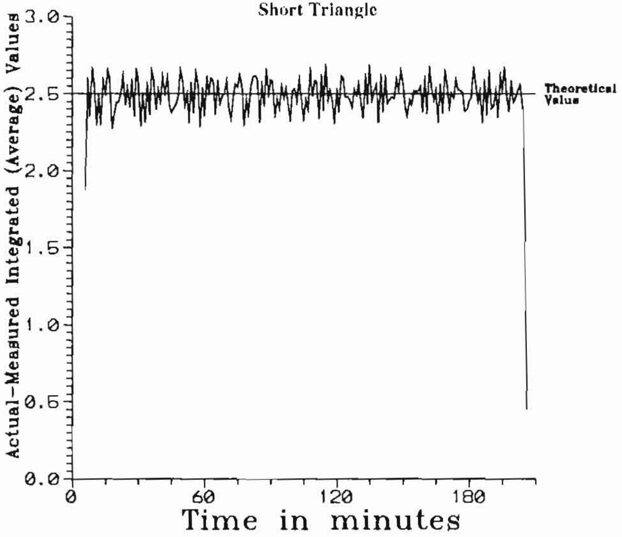

Figure 6
Integration

The integrated value (average) of the long period triangle wave recorded by the logger is plotted along with the difference between the measured and actual value in figure a). Figure b) shows the difference between measured and actual for the integrated value of the short period triangle. The errors in this case are due to aliasing.