Development of Spring Creek data acquisition system
by Robert Matthew Williams

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Electrical Engineering
Montana State University

Abstract:
The subject of this thesis is the development of a computeroperated remote data acquisition system located on Spring Creek.

The experimental Spring Creek station is the location of various weather and stream monitoring instruments all interfaced to the data acquisition system for remote interrogation by an HP 2115-A computer. A user may also call the computer from his location and obtain reports from the computer by using an acoustic coupler and teletype.

This thesis may be summarized as follows: First a physical description of the Spring Creek station and data communications link is made. Second, a hardware description including instruments, interfaces, and modifications is presented. Third, the software development for the system is described followed by some details on the real-time use of the system. Finally, a few remarks on the present and future systems are made.

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Signature Robert Matthew Williams

Date August 20, 1977

DEVELOPMENT OF THE SPRING CREEK DATA ACQUISITION SYSTEM

by

ROBERT MATTHEW WILLIAMS

A thesis submitted in partial fulfillment
of the requirements for the degree

of

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R. M. W.

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ABSTRACT

The subject of this thesis is the development of a computer-operated remote data acquisition system located on Spring Creek. The experimental Spring Creek station is the location of various weather and stream monitoring instruments all interfaced to the data acquisition system for remote interrogation by an HP 2115-A computer. A user may also call the computer from his location and obtain reports from the computer by using an acoustic coupler and teletype.

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DEVELOPMENT OF THE SPRING CREEK DATA ACQUISITION SYSTEM

Chapter I

INTRODUCTION

A data acquisition system is a term ascribed to various systems capable of obtaining information or data from various instruments, sensors, or transducers. Exactly how the information is obtained and what is done with it is dependent on the requirements for a given system. For example, the information may only be used for record keeping and not needed directly for weeks or months at a time. Other systems, such as those used in industrial plants, may use the results immediately to control some manufacturing process. The complexity of a system is also dependent on sampling rates, number of sensors monitored, and accuracy required.

The Spring Creek data acquisition system has been developed to provide an economical system for meteorological and hydrological monitoring. One particular requirement met in developing the system is that of automatically obtaining a daily report or summary containing useful data concerning a given instrument.

HISTORICAL BACKGROUND

Data acquisition systems have been built since the early 1950's. Early systems used mechanical multiplexing crossbar switching and vacuum tube technology. By the early 1960's, data could be stored on magnetic tape for later processing on such computers as the IBM 701 or 704. This type of arrangement precluded any immediate use of meaningful data.[1] By the late 1960's, the cost of computers had reduced to the point that data acquisition systems could be connected to computers in real-time. A system of this type is capable of obtaining data and processing it into a useful form on an immediate basis. This information could be used for automatic control. Industrial plants have made great use of computer-controlled data acquisition systems.[2] The Spring Creek system does not use the obtained data for control but has been developed as a real-time computer-controlled system for ease of obtaining useful environmental data in final form. An additional feature of this system is the capability of providing current environmental data for other people via the telephone system using an acoustic coupler and teletype.

The data acquisition system at Spring Creek has evolved from previous systems developed at Montana State University. In 1966, the Bridger data acquisition system was developed for the Montana Water Resources Reserach Center. Refer to Cannon (1967) for report

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1. Westwick (1972)
2. Rigby (1968)

on the system. The system was designed to measure various weather parameters in the Bridger Range and to transmit the corresponding data back to Montana State University using VHF radio. "Data acquisition system" was the terminology ascribed to the collection of electronic instruments and modules located at Bridger. This included an electronic clock, event counters, analog scanner, digital voltmeter, and digital translater. In addition, a controller was added that could be programmed to initiate the system at various intervals of time by the electronic clock. The scanner gated various analog instrument signals to the digital voltmeter and the translator would encode the data in ASCII serial form to be transmitted by the telemetry system. The translator also encoded the event counter values and the clock output for record keeping. At Montana State University, a VHF radio receiver and teletype were operated automatically to obtain a printout and punched paper tape of the data from Bridger. However, all the data was in the form of the voltage read by the digital voltmeter at Bridger. It was necessary to convert each value to meaningful data such as degrees fahrenheit, wind speed in miles per hour, etc. Programs were written for IBM 1620 II computer to perform this conversion. The cost of this subsequent processing was high and the conversion was frequently delayed many months. The remoteness of the site made it difficult to check the system and provide adequate maintenance. Calibration of the instruments was a problem and generally done infrequently or incorrectly. As a result, data records had little value. Some of these factors prompted the evolution of the present Spring Creek data acquisition system.

The Spring Creek site was chosen for its accessibility as well as for the opportunity to develop water quality monitoring equipment. Communications between the Spring Creek site and Montana State University uses telephone rather than radio. Other differences will be noted later, but the most fundamental change is the complete control and operation of the system by an HP2115A computer located in a laboratory at MSU. The term "data acquisition system" will be referred to in this thesis as the remote equipment located at the Spring Creek site. Much of this came from Bridger and was modified as described below. The overall operating system includes the computer, and the remote data acquisition system at Spring Creek.

ORGANIZATION OF CHAPTERS

This thesis will discuss in greater detail the various aspects and parts of the Spring Creek data acquisition system. Chapter II will cover the location of the site and available resources. A description of hardware development as it pertains to modification, instruments, and interfaces will be contained in Chapter III. Software development for the computer is covered in Chapter IV with a look at the complete operating system from a data gathering standpoint in Chapter V.

Chapter II

PHYSICAL DESCRIPTION OF SYSTEM

This chapter presents a description of the location and some physical components of the Spring Creek system. The data acquisition system itself is covered in Chapter III.

DESCRIPTION OF THE SPRING CREEK STATION

The Spring Creek experimental station is located one mile southeast of MSU in an undeveloped city park. An agreement with the city was made to make use of the park for a field station. Figure 1 shows the present physical layout of the Spring Creek Station. A thirty foot square fenced-in enclosure is located 100 feet from Spring Creek itself. An eight foot square building was built in the center of the enclosure for an instrument shelter and contains instruments, a pump, and the data acquisition system. It is provided with 220 volt commercial power and telephone. In 1971, a concrete dam was built on the stream so that it could be controlled. There is a small pond upstream and a by-pass ditch used to route the creek around the dam. A V-notch weir has been installed between the concrete walls for flow measurements to be discussed in more detail later. About twenty feet downstream from the pond a Parshall flume was installed with stilling well, float, and Stevens type F recorder. The flume is not accurate at low flow rates so that the V-notch weir setup is presently used. Next

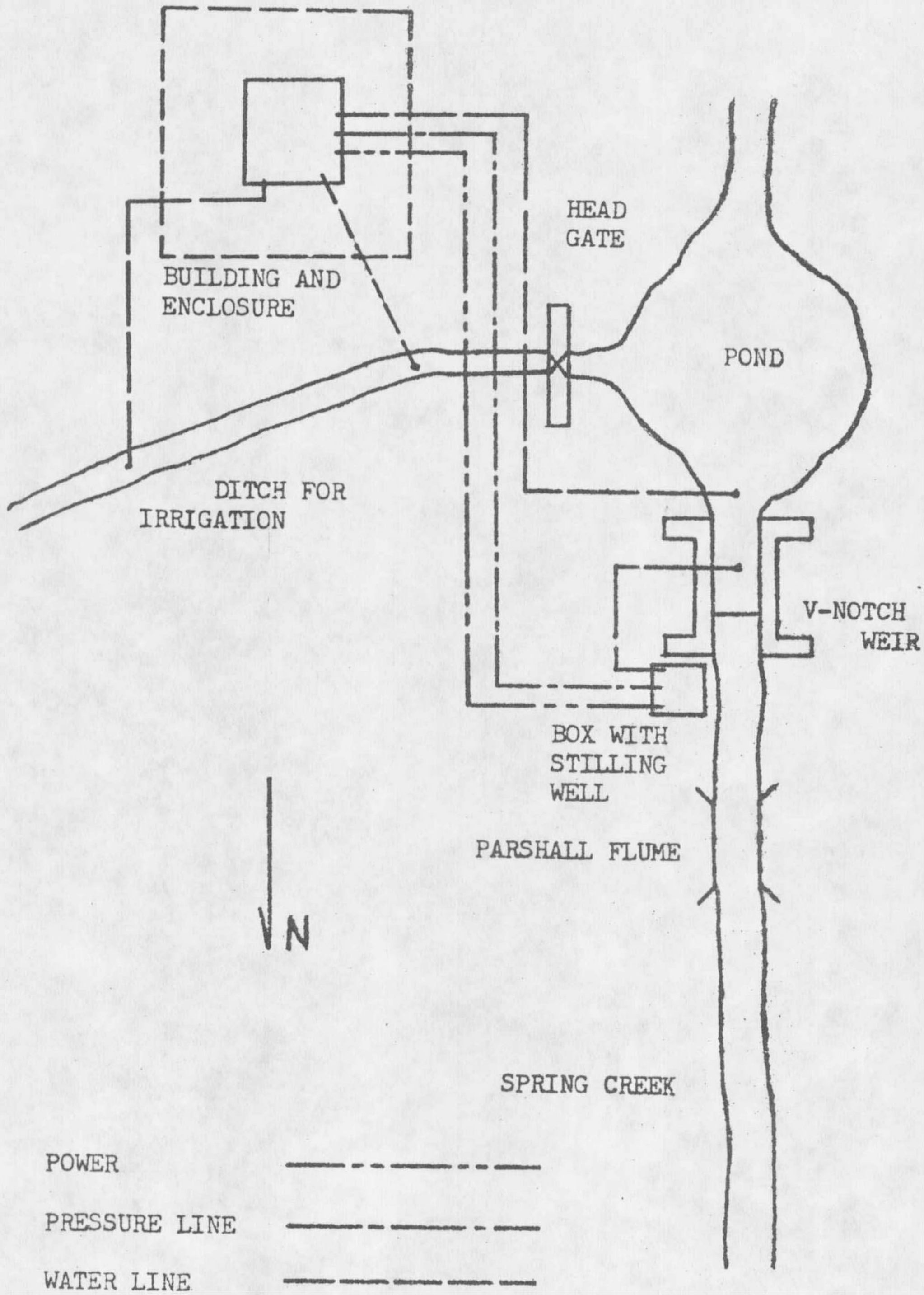

Figure 1. Present Layout of Spring Creek Station

to the concrete walls a four foot square wooden box was installed in the ground for the purpose of placing valves, stilling well, power outlet and pump for summer irrigation of the city park. There are instrument cables, a water pipe and a pressure transmitting line buried from this box to the instrument shelter. Water is pumped from an inlet located above the dam to the shelter so that various water parameters may be measured in the building. The instrument cables connect temporary instruments near the stream to recorders or data acquisition system located in the building. The pressure transmitting line is part of the flow measurement system and will be covered in a later chapter.

A 1/2 horsepower Jacuzzi centrifugal pump was purchased for the project. After making lab tests on the pump, it was determined that the pump would work successfully in the building where it is sheltered and protected. There is a three foot elevation difference between the pump in the building and pond. Losses in the one inch 150 foot plastic pipe increases the total head loss to about six feet. A foot valve had to be placed at the intake to keep the pump primed. It is suggested that the pipe be completely drained in the fall to avoid damage from freezing. The pipe has a slight dip in it so that water can stay frozen in it for some time in the spring. The irrigation pump is used to initially prime the system. After the air bubbles have cleared the building, the pump valve in the building is closed, the valve in the box is then closed and the pump can be turned on and its valve opened slowly. The water drainage pipe is buried to the irrigation ditch about fifty feet north of the building. The surface-scatter turbidimeter located in the building has a separate drain behind the building. Water had a tendency to spray the inside of the building when the drainage pipe to the irrigation ditch was used for the turbidimeter. Since the turbidimeter is open ended, care must be taken when opening the valve to the turbidimeter in order to keep the drain from overflowing. There are two ten amp circuit breakers for the power coming into the building. A third breaker switch controls power to the box. One outlet is thermostatically controlled to operate a portable heater in the winter. Another set of circuit breakers are located on a utility pole 200 feet west of the station.

DESCRIPTION OF COMPUTER AND TERMINAL FACILITIES

The computer and terminal are located in room 502 Cobleigh Hall at Montana State University. There is sufficient space to store unused equipment and to provide lab space for students working on the project. The Hewlett Packard 2115A is a small general purpose 8K word memory, 16 bit computer with a 2 microsecond memory cycle. Peripheral devices used are a photo tape reader, ASR33 teletype, and a MU391 originate/auto-answer modem. Plug-in I/O interface boards for the computer consist of a time base generator, teletype board with one control bit, photo tape reader board, and a communication interface board (WTC-300 Model 101) made by Western Telecomputing of Bozeman. This last board has two control lines and two status bits and operates full-duplex in bit-serial mode. The board is being used in conjunction with the automatic modem. The two control lines are for dial control (CX) and terminal busy (CN) signals. Status bits are for the ring indicator (CE) and clear to send (CB) signals. Input and output of data over the phone is also interfaced through this board. The teletype and photo reader boards are operated normally with the exception that the control bit on the teletype board is used for motor control on the local teletype. This allows the teletype to remain on standby without running.

DESCRIPTION OF DATA COMMUNICATIONS SYSTEM

The MU391 automatic modem is capable of originating and answering a call. It is used with the general purpose board described previously. Specifications on procedure for originating and answering a call are found in the manual on MU391 and MU294 Automatic Modems Specification by Anderson Jacobson, Inc., 1971. A 1001B data coupler is required to provide the electrical connection between the automatic modem and the Bell System. Its purpose is mainly to provide protection to the customer equipment and telephone personnel.

A complete description may be found in 1001B Data Coupler-Description, Installation, Maintenance, and Tests by American Telephone and Telegraph Company, 1970. At the Spring Creek station, a MU294 modem and 1001B data coupler are in use. The only difference between the MU294 and the MU391 is that the MU294 is auto-answer only and cannot originate calls. The signals from the data acquisition system are open collector and so an open collector to EIA interface is used between the data acquisition system and modem. The EIA (Electronic Industries Association) standard is used in most data communication equipment. EIA Standard (RS-232-B) manual published by the Electronic Industries Association, 1965, gives further detail on the types of signals used by the data communication equipment in use for the Spring Creek data acquisition system. The phone number for the Spring Creek station is 994-2041 and the number for the computer at Montana State is 994-3382.

Chapter III

HARDWARE DEVELOPMENT

The Spring Creek data acquisition system is essentially a hardware modification of the Bridger system described in Chapter I. The system was built by the Electronic Research Laboratory of Montana State University with the exception of a Honeywell 620B digital voltmeter used to digitize the analog signals coming from the instruments and transducers. Basically, the system included the digital voltmeter, digital translator, mechanical event counters, and analog scanners.

HARDWARE MODIFICATION

Beginning winter quarter 1973, Steve Luther and the author set out to adapt the system to the Spring Creek requirements. After obtaining manuals on the various components of the system, it was possible to get the scanners and translator working. However, the digital voltmeter never worked properly even after hours of maintenance work. Then it was decided to purchase a Zeltex ZD461 A to D converter ($69) to replace the voltmeter. The converter is smaller, more reliable and more accurate than the Honeywell digital voltmeter. Its input range is zero to ten volts with ten bits resolution for binary serial or parallel output. Consequently, the ten-volt range is divided into 1024 parts encoded by the ten bits in binary fashion. The analog input can be represented to within .01 volt by the output bits.

Originally the digital translator encoded five digits from the voltmeter. Each digit was represented in binary coded decimal form. With the A to D converter, this was not possible so each digit was interfaced to three of the ten output bits of the converter. Thus the digits are octal rather than decimal. Three octal digits could thus be implemented with a fourth digit resulting from the tenth A to D bit.

In December, 1973, it was decided to replace the mechanical event counters by a new electronic counter also designed by Electronic Research Lab. The mechanical counters were unreliable due to heavy current drains resulting in pitted contacts. The replacement included four digital counters, one with five digits and the other three with three digits. The original electronic counters module had reset buttons on the back for each channel. However, with the back inaccessible, a single reset button was mounted on the front along with a logic reset button to be pressed whenver the power is disrupted. This resets logic that originally was controlled by a logic controller and translator not used now. A twelve volt battery and charger was installed in June of 1974 to avoid losing count when power interruptions occur.

The final modification was made to the data acquisition system using a regulated power supply (WTC-120 made by Western Telecomputing Corp. of Bozeman). Previously, each component of the system had its own power supply or no supply at all. The new power supply puts out

+13.5, -13.5 and +5 volts. The 5 volts operate the TTL logic presently in the system while the +13.5 and -13.5 volts are for the A to D converter, analog scanner, and most interface dircuits for the various instruments.

The digital translator has complete control over the rest of the data acquisition system. When an initiate signal is received, the translator makes a reading. An initiate signal can occur two ways, by physically pressing the initiate button on the front panel of the system or by receiving any ASCII character from the communications system. Normally, the second mode is used whereby the computer is the originator of the received character. A reading is the transmission of a code in ASCII form giving an indication of the present voltage value for each instrument.

There are four analog scanners for gating the output voltage of each instrument one at a time to the A to D converter. The first three scanners each have twelve magnetic relays. The first relay enables a read-only memory that contains a number code associated with that particular scanner. This is placed on a data bus and read for identification purposes. This code is know as the scanner address. The next ten relays are gated to ten different interface circuits each of which is associated with an instrument. The last relay allows the value of one of the four counters in the event counter module to be placed on the data bus. The fourth scanner has only two relays, the first associated with the address and the other to the fourth counter. In all, up to thirty analog channels can be used along with four event counters.

Each line of transmitted output contains the data from one scanner. Each channel within a scanner has an identifying alphabetical letter associated with it and is transmitted after each channel output which is in the form of five digits. Figure 2 shows a printout of a sample reading made. The first set of digits is the scanner address code. Analog inputs for channels A through J of each scanner is gated to and converted by the A to D converter discussed previously; hence that data is in octal form with 00000 representing zero volts, 00777 for five volts, and 01777 for ten volts. Output of the A to D converter is placed on the data bus three bits at a time for octal digits. The data for the K channels or counters is placed a digit at a time on the data bus. The counter with #4800@ address has five digits and can count to 99999 before resetting to 0 while the other three can count only to 999.

The digital translator also encodes the data from the data bus into ASCII form and transmits the bits at the standard 110 baud rate. It also supplies line feeds, carriage returns, and identifying letters with the output.

INSTRUMENTATION

Many of the instruments used are connected to the data acquisition

```
#4800@00302A00367B00053C00274D00374E00213F00715G00215H00355I01335J
73442K

#4801@00631A01000B00777C00777D00777E00777F00777G00777H00777I00777J
00000K

#4802@00777A00777B00777C00777D00777E00777F00777G00777H00777I00777J
00000K

#48032@00022K
```

Figure 2. A Sample Data Acquisition Reading

system using similar analog interface circuits. Generally these instruments output a voltage that is not in the 0 to 10 volt range. Also, the low 10K input impedance to the A to D converter requires a low source impedance of about three ohms for accurage conversions. These requirements for an interface circuit can be met by using a simple operational amplifier circuit. Such a circuit is shown in Figure 3. The input impedance of the amplifier is 1M ohms. Hence, an instrument can have an output impedance up to 10K ohms for 1% error. If impedances can not be held to these tolerances, the gain may be adjusted to compensate. Open loop output impedance of the 741 operational amplifier is given as 75 ohms. Closed loop output impedance is found from the equation Z = 75G/(K-G-(75/Rs)) where K is the open loop gain and G is the closed loop gain (1+Rf/Rs). For low frequency operation, the open loop gain is 10^5 so that the maximum closed loop gain with the 3 ohm impedance requirement met is 4000. The largest gain any of the present instruments require is 640 for the solar radiation measurement. All of the operational amplifier interface circuits have been built in one 4" x 4" x 6" box. There is room for nine circuits with three being used now. All circuits also make use of 10K trimming resistors to offset the output. This is adjusted so that a reading of zero volts output is obtained with a zero input. Calibration is easy and better use of the 0 to 10 volt range is made.