THE BRIDGER DATA ACQUISITION SYSTEM
at
MONTANA STATE UNIVERSITY

BOZEMAN, MONTANA 1/

By

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Introduction

The Office of Water Resources Research and the State of Montana established the Montana Water Resources Research Center at Montana State University, Bozeman, Montana early in 1965. The mountainous surroundings of Bozeman have attracted "out-of-door" experimental researchers for many years. Therefore, it was a natural step for the University and the new Water Resources Research Center to tie a number of these programs together in an efficiently instrumented outdoor laboratory. The Bridger Hydrometeorlogical Research Area was established in the summer of 1965 as a cooperative effort by the U. S. Forest Service, the Bridger Bowl Ski Association, the WRRC and the University. The research area includes and surrounds the Bridger ski area and was selected because of a combination of convenience and possibilities of interesting experiments in snow and avalanche research, meterology and weather modification, and hydrology. The location is about 20 miles from the campus by a good road.

In the spring of 1965, the University made the decision to provide a general purpose data acquisition system at Bridger as a support facility for the experimenters. The system design goals required continuous unmanned operation, servicing a wide variety of instruments at the various research sites. All data were to be converted to digital form and transmitted by a telemetry system to the MSU campus. A machine readable record was to be made on the campus which could be used as input data to the IBM 1620 II computer (the present MSU computing facility). This paper describes the resulting system and some of the operating experience.

Buildings and Utilities

The Bridger Data Center building was constructed during the summer of 1965. This 16 by 24 foot two room building serves as the "nerve center" for the entire research area. Commercial power, telephone and data-phone are connected. The building is insulated and electrically heated. All the electrical communication cables to the various research sites terminate in this building, which also houses the main electronic components of the data acquisition system. The building is located near the Bridger Ski Lodge and the ski area parking lots. A voice radio communication system is installed providing communications to all research sites and areas from the Data Center.

A small A-frame building, the Bridger Ridge Station, was constructed on the top of the Bridger Ridge at an elevation of 8500 feet. This building has commercial power and is insulated and electrically heated. In the winter, this building is reached using the chair lift and a rope tow. In the summer, the ridge is reached by trail from the top of the chair lift. A 100 conductor communication cable connects the Bridger Ridge Station with the Data Center (1¼ miles). This building also contains a voice radio system covering the entire area.

At present, there are about a dozen research sites located in the six square mile research area. Some of these have small buildings and shelters. All the research sites are connected together with a system of electrical communication cables. The cable system to

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the sites is maintained as a part of the central facility. However, each experimenter is responsible for the installation and operation of his instruments connected to the system.

The Data Acquisition System

The Bridger Data Acquisition System was designed to handle electrical analog signals and discrete event signals. In the analog system, the parameter to be measured (Temperature, stream flow, snow depth, etc.) is converted into some electrical quantity (current, voltage or resistance). This electrical quantity is connected to the Data Center using the communication cable system. Discrete event signals (tipping-bucket rain gauge, wind flow anomometer, etc.) take the form of an electrical contact closure. This open or short circuit condition is also transmitted to the Data Center using the cable system. These contact closures cause electro-mechanical counters to advance. Figure 1 shows the data flow from the remote instruments at the research sites into the Data Center. In the Data Center these signals are scanned in sequence and converted to digital code form (ASCII code). The digital telemetry system transmits the data record from Bridger to the Data Recording Center on the MSU campus.

Greater detail is shown in Figure 2. The system controller is initiated by a periodic control signal (C) from the Clock. The present system handles up to 99 channels (separate instruments) and these are identified by channel numbers 101 through 199. A channel is activated by plugging its control line into one of the periodic control circuits (a variety of periods from every five minutes to once a day are available). If a channel control line is plugged into the 5 minute control circuit, it will be read each five minutes. Once the clock has initiated the system controller action, the controller will sequentially read all connected channels. The controller operates the analog scanner to connect the appropriate signal to the analog-to-digital converter (data signal indicated by D). If the channel is a "discrete-event" instrument, the system controller will read the counter reading. In either case, a digital representation of the instrument reading is read into the controller (D). The controller also reads the time from the clock (D).

When the system controller is activated it sends a control signal to the digital communication system which turns on the communication system. This will turn on the ASR33 teletype (located in the Data Center) if its manual control is on (this teletype is used for local recording required in system calibration and maintenance or when the communication system fails).

The digital data output (D) from the controller is in the form sequence of serial ASCII characters. These characters are organized into standard format records. Each record starts with a line feed character. Next is a four digit time field giving hours and minutes in Mountain Standard Time (0000 through 2355). This is followed by up to eight data fields of eight characters each. Each data field contains a three digit channel number and a three digit data reading plus sign. Each data field starts with a space as a separator. The record terminates with a carriage return character. A typical data record is as follows: 1025 101+025 125+733 176+000 189+100
The controller generates characters at the rate of 10 per second (standard speed for ASR33 teletype).

Radio Telemetry System

Figure 3 shows a block diagram of the radio telemetry system. The radio transmitter is located in the Bridger Ridge Station which provides an approximate line-of-sight path to the campus. A commercial FM voice radio was modified to transmit binary data using audio-frequency-shift modulation. The audio frequency is shifted between 1700 Hz and 2550 Hz. Approximately 2 watts of power is radiated from a quarter wave vertical antenna. The frequency is in the hydrologic telemetry band (approximately 170 mhz). The transmitter is remote-controlled from the Data Center. Both control and data are transmitted to the Bridger Ridge Station using the communication cable. Control is transmitted to the campus by turning the carrier on and off. Data is transmitted using frequency modulation of the carrier.

The telemetry signal is received using a vertically-polarized Yagi antenna mounted on the roof of Roberts Hall (the engineering building on the MSU campus). A commercial FM receiver has been modified to demodulate the telemetry signal and operate an ASR33 teletype. A carrier detector has been added which is used to turn the teletype motor on and

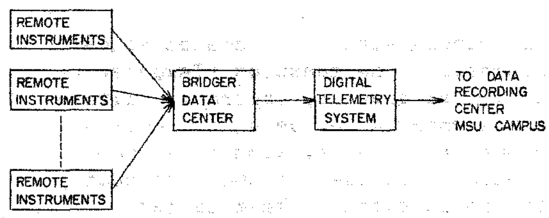

FIGURE 1

THE BRIDGER DATA ACQUISITION SYSTEM

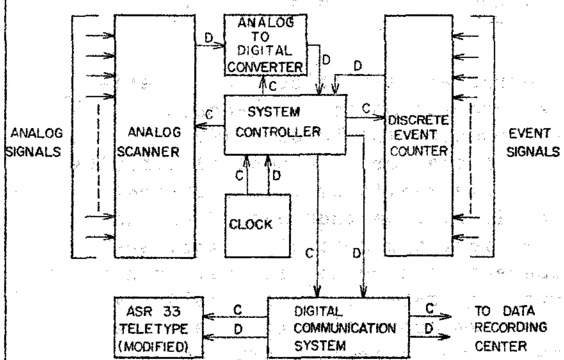

FIGURE 2

SYSTEM COMPONENTS

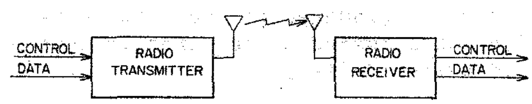

FIGURE 3

RADIO TELEMETRY SYSTEM

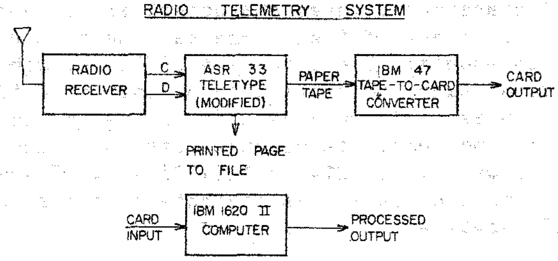

FIGURE 4

DATA RECORDING CENTER SYSTEM TO NOV. 15, 1966

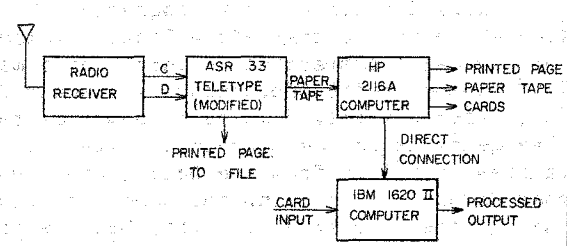

FIGURE 5

DATA RECORDING CENTER SYSTEM SPRING 1967 off. Both teletype machines have been modified to allow this type of operation. The teletype produces both a printed page and punched paper tape record. The printed page record is filed and the paper tape is used in data processing.

The Data Recording Center

The digital telemetry receiver and recording teletype are located in the Data Recording Center on the MSU campus. System operations up to November 15, 1966 utilized an IBM model 47 tape-to-card converter. This machine was wired to convert the code records on the paper tape to a card record. In addition, the first data field on the card format contained the date. The first card in a run would have the date punched by hand. The IBM model 47 was wired to reproduce this field on each card which followed and then to punch the next tape record on the remainder of the card. The cards were organized into a data file for each day. A date card is the first card of the file and a card with 2400 in the time field is used as the end-of-file indicator.

The data file for each day was run through the IBM 1620 II computer using a program (written in Fortran) called "Sort and Punch". This program edits the data by elimination of entire records or data readings when the time, channel number or data falls outside the allowable limits. The program sorts the data by channel number and punches the channel number, the date and up to six time-reading pairs on a card. The cards were then sorted by channel number with a card sorting machine and filed by channel numbers. Second pass processing depends on the particular experimenter's data processing needs and on the particular instruments and their calibration tables. The Data Recording Center keeps a log of all instruments connected to the system at any given time. Also, a file is kept on all calibration tables and graphs.

It became obvious early in 1966 that the time-consuming task of converting tape to cards was unnecessary. The system shown in Figure 4 is gradually being changed to the system shown in Figure 5. A Hewlett-Packard 2116A instrumentation computer was added to the Data Recording Center facilities in January 1967. The paper tape data file from the Bridger Data Acquisition System is fed directly to the HP 2116A computer using a 300 character per second paper tape recorder. The "Sort and Punch" program is now done on the HP 2116A with the paper tape output as the sorted file. When cards are required, this second tape is fed to the computer and the cards for the desired channels are punched. A direct electrical connection is being established between the HP 2116A and the IBM 1620 II. In this way, the Bridger data can be fed directly into the 1620 II without using cards.

Plans for the future are aimed towards a direct connection of the Bridger Data Acquisition System (plus other data sources) to the HP 2116A computer. System control and real-time on-line processing will be tasks assigned to the computer. Dynamic control of the instrumentation system will replace the wired-schedule system. The IBM 1620 II is to be replaced by an SDS Sigma 7 within the next year. A high speed (25,000 cps) two way communication channel is planned between the HP 2116A and the Sigma 7. Time-share computer operation will allow anyone with access to the Sigma 7 (teletype and data phone required) to read Bridger instruments using the data acquisition system provided a few code words are known.

Operating Experience

In 1966, over 2 million readings were made. The operating cost including data processing on the 1620 II computer was well under one cent per reading. The basic instruments at Bridger result in approximately 5000 readings per day. The peak load on the system has been as high as 35,000 readings per day during some experiments. As efficiency improves and the data volume grows, the cost per reading should be less than 1/10 cent.

The major source of errors resulted from clock time errors following commercial power failure. The system is self starting after a power failure but the clock has lost time. The time of power failure can be determined from the record. When the clock is reset, the change is put in the log. A new clock (using a new time format) is being built for the Data Recording Center. This clock operates from storage batteries and provides the time for data recording by giving the year, the day number and the decimal fraction of the day. January 1st is day zero and the day starts at midnight GMT.

Most system failures and lost data resulted from teletype failure. Tape frequently jammed in the punch and occasionally someone forgot to keep the punch supplied with paper.

The biggest problem by far is the general distrust that the experimenters have in instrumentation that is not under their full control. Also, few of the experimenters have any data processing experience. They are generally oriented to chart recordings. The time delay between taking the data automatically and giving the experimenters processed results has been too long. Most experimenters have learned to use the printed page copy at Bridger but the rest of the system (including Fortran) remains a mystery to them. Most of these problems will slowly disappear as the experimenter becomes familiar with data processing and programming and as the Data Recording Center provides better service. Most of the hardware problems are solved except for the financial support necessary to expand the facilities. Much needs to be done in software (standard computer programs for system control and data processing) and much needs to be done in improving the standard operating procedures of the Data Recording Center.

References

This brief paper provides only a superficial description of the Bridger Data Acquisition System. Several technical reports have been prepared covering the system in detail. These reports can be obtained by writing to: Dr. Roy Huffman, Director, Montana Water Resources Research Center, Montana State University, Bozeman, Montana 59715.

LIST OF REPORTS

1. Instrumentation and Operation of Meteorological and Stream Gauging Stations. By T. T. Williams - February 1967. WRRC Report No. 7.

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