A Digital Recording System for Tipping Bucket Raingages: Description and Field Testing

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ABSTRACT

A system for recording data from a large network of tipping bucket raingages on digital tape cassettes has been developed for the Florida Area Cumulus Experiment (FACE). This system is substantially less expensive than those previously available when large members of gages are needed. Field tests during June, July and August 1978 in South Florida showed the system to be accurate and reliable.

1. Introduction

The Florida Area Cumulus Experiment (FACE) is a weather modification project which has been described in detail by Woodley *et al.* (1977). A requirement of FACE is that rainfall be measured accurately throughout the target area. The FACE target area occupies $\sim 1.3\times 10^4$ km^2. Within the FACE target area is a dense inner network of raingages encompasing $\sim$ 500 km^2 with raingages on a 3.22 km grid. In the remainder of the target area is a network of raingages on an approximate 11 km grid. The nominal gage locations for both spacings are shown in Fig. 1. There were about 135 gages in the FACE target area at any time during the 1978 experiment, 48 of which were in the inner network.

In previous years, only the inner network was used. Rainfall was recorded on 24 h strip charts and read manually. Twenty-four hour charts were used to get the time resolution needed for the experiment. This required each raingage to be serviced every 2 days to insure readability of the charts. With the number of gages doubled and the area covered more than 10 times larger in 1978 than in previous years, the labor and cost involved in using this manual system became prohibitive. A system that was capable of recording the data in digital form on cassette tape for automatic data processing and that would need less frequent servicing and did not require a special shelter in the field was required, but systems commercially available at the time were too costly. As a result, a preliminary design was generated for a digital system that would meet these criteria at reasonable cost. The final detailed design and manufacture was contracted to Kinetic Research, Inc., of Madison, Wisconsin.[1] In this report we describe this system and present field operations results from FACE 1978 when it was in use.

[1] Mention of a proprietary product or corporation does not constitute an endorsement thereof by the authors or by the National Hurricane and Experimental Meteorology Laboratory.

2. Digital recording system

The digital raingage recording system comprises two kinds of devices: field units (FU) and recording and control units (RCU). Data from a tipping bucket raingage are stored in a field unit until transferred to permanent storage on a magnetic tape cassette through the use of a portable recording and control unit. A block diagram of the system is presented in Fig. 2.

Each field unit is housed in an aluminum case measuring 206×130×76 mm (including connectors), which fits inside the housing of Weather Measure's P501-1 tipping bucket raingage[1] along with a 6 V rechargeable battery. The FU contains two 121×152 mm circuit boards. The memory board contains random access memory circuits for data storage, a counter for addressing the memory and an address decoder. The control board contains a voltage regulator, raingage contact debounce circuitry, a precision real-time clock (RTC) with an elapsed days counter, and the logic necessary to respond to RCU commands and to transfer data to and from the memory board. CMOS[2] is used throughout for low power consumption. In this configuration each FU can store up to 512 5-min count totals or about 42 h of rainfall. A maximum of 256 counts can be stored in a 5 min period.

Each recording and control unit is housed in a portable case measuring 318×337×248 mm containing switches and controls, a 7-digit display, a cassette tape drive, a clock board, a microprocessor board, two 6 V rechargeable batteries, and a battery charger/voltage regulator. The RCU's will operate for several days on a single charge. The clock board supplies crystal oscillator derived timing signals and RTC data to the micro-

[2] CMOS: Complimentary metal oxide semiconductor technology.

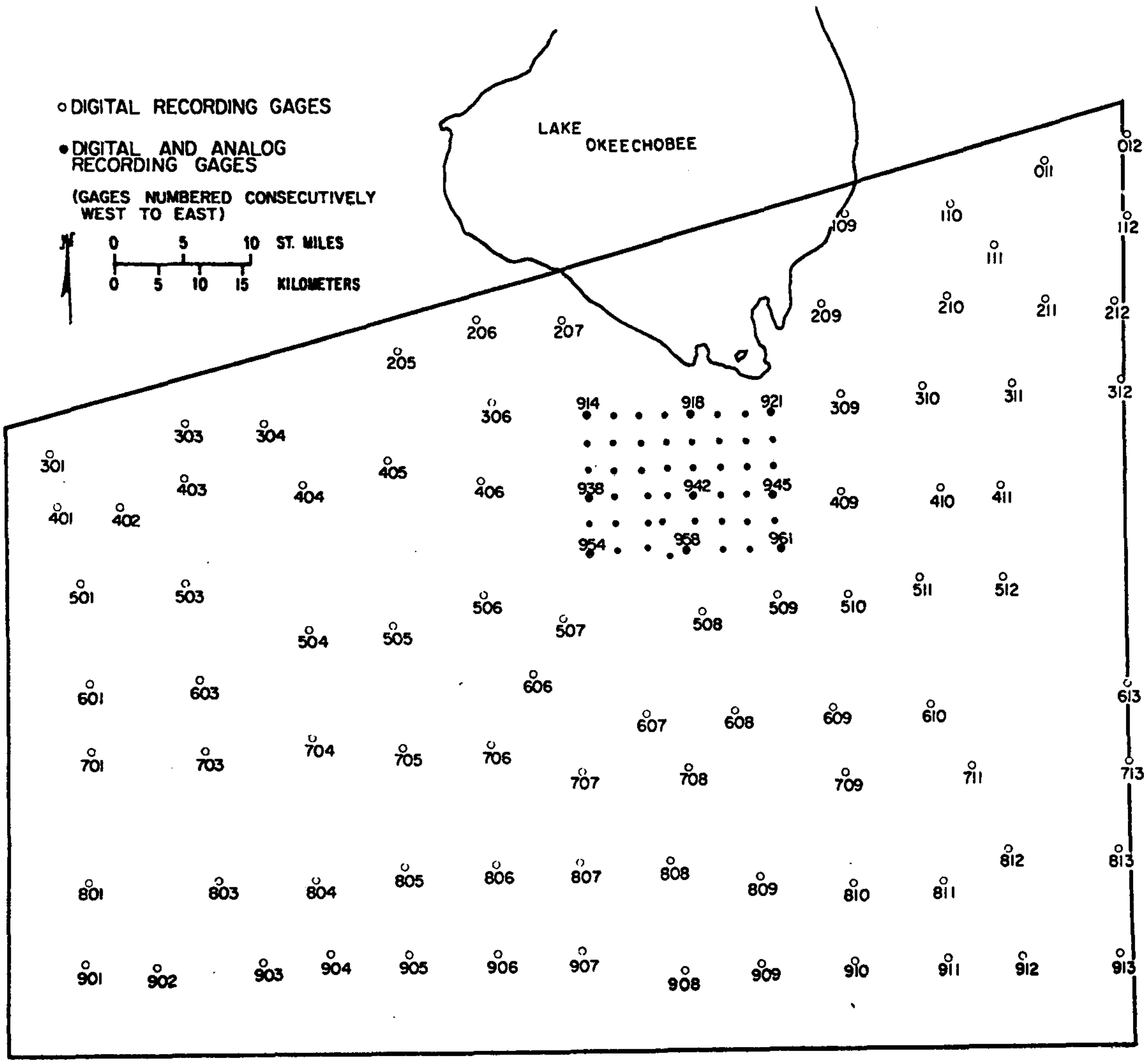

Fig. 1. FACE 1978 target area. Dense raingage cluster is in upper center part of area.

processor board. It also handles data transfer from an A/D converter used to monitor RCU and FU battery voltages. The microprocessor board contains an 8-bit microcomputer (CPU), with its program memory (EPROM), and I/O expander, a display driver, interface circuitry for the controls and switches, and data bus logic.

When the RCU logic circuitry is activated by the operator (the RTC is always on) a test code is displayed confirming proper functioning of the CPU and EPROM. The operator may display the FU or RCU battery voltage, or the RCU RTC on the 7-digit display. The RCU RTC may be manually present with thumbwheel data entry switches. The operator may initiate subroutines to transfer FU memory data to the cassette tape or to initialize the FU. All operations are activated with switches on the RCU.

Data and control signals are transferred between the RCU and the field units through a connecting cable. A FU is initialized when the RCU clears the FU memory and elapsed day counter and sets the field unit RTC. Thereafter, at each tip of the raingage bucket a tip counter on the FU control board is incremented. Each tip indicates 0.254 mm of rainfall. Every 5 min the control logic examines the tip counter. If the count is zero, nothing is done. If it is nonzero, its value is transferred to memory along with the value of the FU RTC and elapsed days counter. This lengthens the service cycle since none of the 42 h memory capacity is used to record zeros. Memory is only used if nonzero rainfall occurs. The tip counter is then reset to zero for the next interval. When a FU is to be read, the RCU instructs the FU to transfer its memory contents to the RCU for recording. After the data transfer has been accomplished, the RCU is used to reinitialize the FU as described above and the cable is then disconnected.

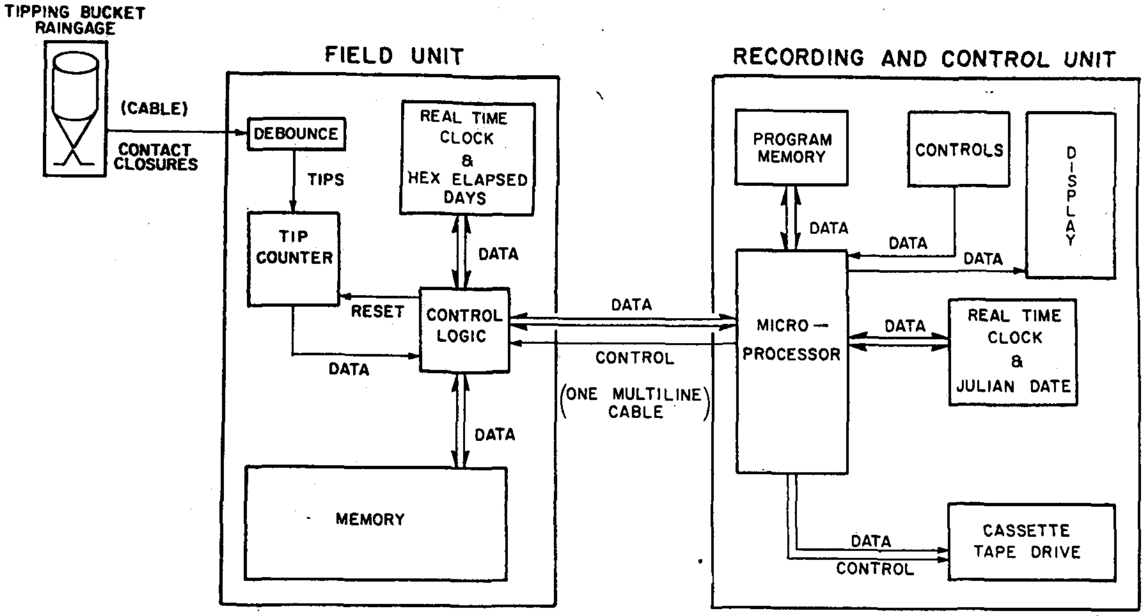

FIG. 2. Block diagram of raingage electronics (excluding power circuits).

3. Field operations

Approximately 10 days were required to install the recording raingages as shown in Fig. 1. All systems were activated in a 2-day period just preceding the beginning of the 1978 FACE program.

Optimally, one person working a normal work schedule could service all of the digital systems within the designed service cycle of the FU, but the nature of the terrain, accessibility and the practical requirements of the FACE experiment such as safety and quality control dictated that four people be used. The majority of the digital systems were accessible by ground vehicles, but nine units were accessed by helicopter. For quality control purposes most digital units were initially planned to be serviced once a week with the extremely remote units (those accessible only by helicopter) accessed about every 3 weeks. Normally the entire digital network or raingages (excluding the nine remote units) was serviced in a 3-day period by two field crew members, with an additional working day for delivery of the data cassettes to Miami for processing. The average service cycle was an 8-day cycle, with an occasional 14-day cycle for some of the units. This does not include the nine remote units that were planned to have a longer service cycle. The longest service cycle for the remote units was 30 days. This limit was determined by battery life and could be extended by use of larger capacity batteries. The batteries used in the experiment reported here have a capacity of 2.5 ampere hours (Ah).

The outer network units require ~20 min service time, which included travel time between raingages. The inner network units required about half this time. A complete recording and erasing process for a field unit required about 5.5 min. About 2.5 min was normally required to record just the nonzero data from memory and reinitialize the FU. A typical working day for the field crew was 7 h with about 20 units serviced.

TABLE 1. Intercomparison between digital and strip chart raingage records.

Number of counts (0.254 mm) difference between digital and strip chart records	Number of comparisons	Percent of total
0	369	83
1	59	13
2	17	4
>2	2	<½

4. Intercomparison data and results

To evaluate the accuracy of the field units, the inner network was dual-instrumented. Each raingage was connected to both a digital recording package and to a strip chart. Both data sets from each gage were analyzed for daily rainfall totals and the digital data were compared with the strip chart data for each gage on each day over a 12-day period during which a representative sample of all known problems occurred. Data from one gage on one day will hereafter be called data from one gage day. There were 447 such comparisons. Table 1 presents the results.

The average daily rainfall at each gage was 5.69 mm (22.4 counts) with a standard deviation of 4.42 mm

(17.4 counts). The largest value was over 50 mm and the smallest was zero. The errors were not correlated with the magnitude of the reading.

All of the errors were of the same sign—the field units always recorded the same reading as the strip chart system or a count (or 2) higher. This may mean that many of these errors were induced by vibration or motion of the raingages during the more frequent servicing of the strip chart system. Such motions would register on the FU, but not on the strip chart system. Other possible reasons could be counting errors, mechanical linkage problems, spurious magnetic fields, and/or rain rate recording capability. A comparison for a 5 or 15 min period would most likely reveal the "when" and "why" for these 1 or 2 count differences; however, they were infrequent and of little consequence considering the volume of data recorded.

5. Reliability of the system

During the 1978 FACE experiment there were 3017 gage days for the digital recorders in the inner network. The data recorded appear valid for 2700 gage days. Of the gage days lost, 19 were caused by vandalism, 39 by malfunction of FU's, and the rest (259) by problems associated with the RCU's and their cables. Another factor, human error, is incorporated in the latter figure. Typical errors of this type were improper switch selection (e.g., erasing before recording) and improper battery replacement (e.g., allowing battery cables to interfere with bucket movement or installing the battery backward). These errors were infrequent. The largest number of gage days lost can be directly attributed to a construction fault in the RCU data cables. Very little information was lost from component failure in the RCU's. A minor factor in loss of gage days may be data loss caused by lightning; however, no visible lightning damage was noticed. Any data loss due to induced voltage generated by lightning is difficult to assess. In any case, it is certainly small. The overall inner network digital failure rate was 11%.

Similar problems affected the outer network digital units. Again, the largest number of lost gage days (411) can be attributed to the RCU data cables. For a total of 6426 gage days the outer network digital units recorded data that appeared valid for 5625 gage days. Vandalism and FU malfunctions accounted for 139 and 221 lost gage days, respectively. This 12% data loss for the 85 digital recorders in the outer network is approximately the same as that in the inner network.

For comparison, the strip chart recorders in the inner network lost 311 gage days out of 3435 possible gage days. This is about a 9% data loss compared to the 11% data loss described above for the digital recorders in the inner network. Since the strip chart recorders were checked every 2 days versus an 8-day cycle for the digital recorders, it would appear that this digital system is as reliable or more reliable than the strip chart system. An 8-day cycle for the strip chart would have resulted in a considerable data loss. this conclusion is reinforced when we consider that the digital failure rate includes gage days on which cable failures occurred, a major problem which has since been corrected. No detailed comparison was made after the cables were repaired. A comparison during the period after the cable problems were corrected would not be representative of the initial reliability of the system. Also certain portions of the inner network raingages were degraded from the dual capability to replace units in the outer network because of vandalism or malfunction during the latter half of the experiment. Data loss from all causes was significantly reduced during the latter half of the experiment.

6. Conclusion

The major limitations of this digital system are battery life and storage capacity. With 2.5 Ah batteries, the system will run for at least 30 days. With larger capacity batteries, the lifetime is proportionally larger. The memory size limits storage to 512 5-min rainfall intervals. For convective tropical rainfall, this has been adequate for at least 30 days of operation. In other environments it may be necessary to expand the memory size to achieve similar duration. For our application, this digital recording system has proved accurate and reliable. No special shelter is required since the FU and its battery fit inside the raingage housing. The cost is comparable with that of commercial analog systems and lower than that of commercial digital systems. The time and manpower savings become evident when we note that 2160 strip charts requiring about 350 man-hours contain the same data as 19 cassets requiring less than 2 man-hours to process. The combination of high performance and low cost makes this approach quite attractive for remote and long-term monitoring of convective rainfall.

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