Machine Reduction of Anemometer-Bivane Data[1,2]

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(Manuscript received 10 April 1963, in revised form 3 June 1963)

ABSTRACT

An analog computer has been programmed to process anemometer-bivane data recorded on magnetic tape. The recorded data were the wind vector in spherical coordinates, azimuth angle, elevation angle and wind speed. The computer resolved this vector into rectangular coordinates and computed continuous averages of the means and standard deviations of each of the three components in one pass. Over 1600 hours of data were processed at 64 times real time. This time compression was achieved by recording the data at 15/16 inches per second and playing it back at 60 inches per second.

1. Introduction

A task group was sent to a rain forest by the Bendix Systems Division and The University of Michigan. The purpose of this task group was to study diffusion through a typical forest canopy. One parameter of interest, in addition to many others, was the structure of the turbulent wind below, in, and immediately above the canopy. The sensing instruments used were eight anemometer-bivanes and two wind vane and cup anemometer systems; the outputs were recorded on two 14-channel magnetic tape recorders. The purpose of this paper is to describe the machine processing of the magnetic tape records.

Briefly, the pertinent features of the experimental site were two 200-ft towers with four anemometer-bivanes and one wind vane and one cup anemometer on each tower. The four bivanes were located at 6.5, 56, 74 and 146 ft. The average top of the canopy was about 140 ft. The cup anemometers and wind vanes were at the top of the 200-ft towers.

The anemometer-bivane[3] is comprised of a propeller type anemometer that is positioned into the wind by a bi-directional vane. The three outputs, speed, azimuth and elevation indicate the total wind vector expressed in spherical coordinates. The speed signal is pulse frequency modulated while the azimuth and elevation signals are voltage analogs. These signals were recorded on magnetic tape using frequency modulation (FM).

[1] Paper No. 76 from the Department of Meteorology and Oceanography, The University of Michigan.

[2] Work conducted under contract with the Bendix Systems Division, Ann Arbor, Mich., as part of the Canopy Penetration Study under contract DA 42-007-CML-530, U. S. Army.

[3] Gill, Gerald C., E. Wendell Hewson and Alan L. Cole, 1962: A sensitive anemometer bivane. Paper presented at the Fourth Conference on Applied Meteorology of the Amer. Meteor. Soc., September 1962, at Hampton Va.

A pulse frequency modulated signal and a voltage analog signal are the outputs of the cup anemometer and wind vane sensors, respectively. The speed signal was demodulated on site so that two voltage analog signals were available to be recorded on magnetic tape using FM.

One 14-channel tape recorder was used at each tower to record the outputs of four bivanes, the direction signal from the wind vane, and a 60-cycle timing signal. In some cases the speed signal from the cup anemometer was recorded in place of the timing signal. The recording speed of the tape recorders was 15/16 inches per sec.

There were 13 test runs each of 10-hr duration and one run of 72-hr duration which involved only one tower. Thus a total of 1328 hr of anemometer-bivane data and 332 hr of wind vane data were generated. The standard operating procedure was to record calibrations during the first half hour of each 10-hr run.

The objectives of the analysis were to obtain the average of the mean and standard deviations of the three wind components in rectangular coordinates at each bivane location. A five-min sampling period was used for the computation of the means and standard deviations and 30 min for the averaging of the means and standard deviations. For the wind vane, the average of the mean and standard deviation of the azimuth was wanted.

An analog computer was used to perform these computations since it is more efficient for this job and because an adequate computer is available in The University of Michigan. The advantage of the analog computer in this case arises from the fact that it is fast and inexpensive. Further, the computations required are easily performed on an analog computer and typical analog accuracy is more than adequate.

2. Computational procedure

The computational procedure may be conveniently divided into five parts: signal conditioning, vector resolution, mean value and standard deviation computation, final averaging, and output sampling. These procedures cover all the steps from accepting the output of the magnetic tape unit to producing the final averaged means and standard deviations.

Three channels of the tape, corresponding to the three outputs of one bivane, were read simultaneously and operated on as described below. For the wind vane sensors, one channel was read. The procedure used for a bivane is described below. The procedure used for handling the wind vane is a specialization of that used for the bivane, and is likewise described below.

The first step, called signal conditioning, is to take the azimuth, elevation and speed signals read from the magnetic tape and prepare them for analog computation. Azimuth, elevation and speed as read from the magnetic tape were designated AZ, EL and SP, respectively, while the corresponding computer variables were designated θ, ϕ and U. Conversion included removal of noise, demodulation of the speed, bias and amplification. The values of gain and bias were determined for each anemometer-bivane for each run. This computation had to be performed by hand due to the extreme variability of the amplitude and appearance of the calibration data.

Next the wind vector represented as θ, ϕ and U was resolved into its rectangular components u, v, and w using the following relations

$$u = U\cos\theta\cos\phi$$
$$v = U\sin\theta\cos\phi$$
$$w = U\sin\phi,$$

where θ is the angular deviation of the vector from the north and ϕ is the angular deviation from the horizontal. Positive values of u, v, and w represent flow from the north, east and up directions, respectively. It is this conversion which requires that three channels be read simultaneously.

The mean values and standard deviations of u, v, and w are computed continuously and simultaneously. The standard deviation is not computed directly but is taken to be 1.25 times the mean absolute deviation. This approximation, and the circuits actually used, are discussed by Brock and Provine (1962). Five minutes of data was the sampling interval used.

The quantities $\bar{u}$, $\bar{v}$, $\bar{w}$, σ_u, σ_v, and σ_w were further averaged over 30 min, designated as $\bar{\bar{u}}$, $\bar{\bar{v}}$, $\bar{\bar{w}}$, and $\bar{\sigma}_u$, $\bar{\sigma}_v$, $\bar{\sigma}_w$, and printed out.

When the wind vane data were processed, the speed and elevation inputs were set to zero and the vector resolution circuits were bypassed for the azimuth. The output in this case would be $\bar{\bar{\theta}}$ and σ_θ.

It is evidently impractical to process 1660 hr (1328 hr of bivane and 332 hr of wind vane) of data in real time and there was not enough equipment available to enable processing of more than one bivane at a time. Therefore some sort of compressed time scale was needed. This was achieved by reading the magnetic tape faster than it was recorded. Since the data were recorded at a tape speed of 15/16 inches per sec, a time compression of 64 times was possible by reading the tape at 60 inches per sec. In compressed time, the quantity of data becomes only 25.9 hr which was quite reasonable. At this speed, one reel containing 10 hr of data plays back in about 10 min. The 5-min sampling interval becomes 4.68 sec and the 30-min interval becomes 28.1 sec.

3. Computer circuits

The signal conditioning circuits are represented by the three boxes on the left of Fig. 1. The points labeled AZ, EL and SP are the entry points for the signals read from the magnetic tape. The circuits that operate on AZ and EL are similar and each has two controls for setting the amplification and bias. This conversion is given in Table 1.

TABLE 1. Transformation from magnetic tape output to computer variables.

Parameter range		Tape output	Range volts	Computer variable	Range volts
Azimuth	+180 deg	AZ	$+e_1$	θ	+90
	−180 deg		$+e_2$		−90
Elevation	+ 50 deg	EL	$+e_3$	ϕ	+50
	− 50 deg		$+e_4$		−50
Speed	25.2 ft sec^{-1}	SP	pulse freq.	U	100
	0				0

Operations performed on SP include demodulation, amplification and filtering. The pulse frequency demodulator shown in Fig. 2 was the only piece of non-standard equipment used. A correction for the nonlinearity of the demodulator was included by using a function generator. In the same way, a correction for the small nonlinearity of the bivane anemometer could be made.

The vector resolution circuit was composed of diode function generators and diode multipliers to provide the necessary high frequency response. It was expected that the upper limit of the signal frequency would be about 100 cycles per second (corresponding to an upper limit of bivane fluctuations of about $1\frac{1}{2}$ cps). This results from the time compression which multiplies all the recorded frequencies by 64. The resolver is designed to generate the components u, v, and w in the range ± 100 volts. This range is also called ± 1 M.U. (machine unit)

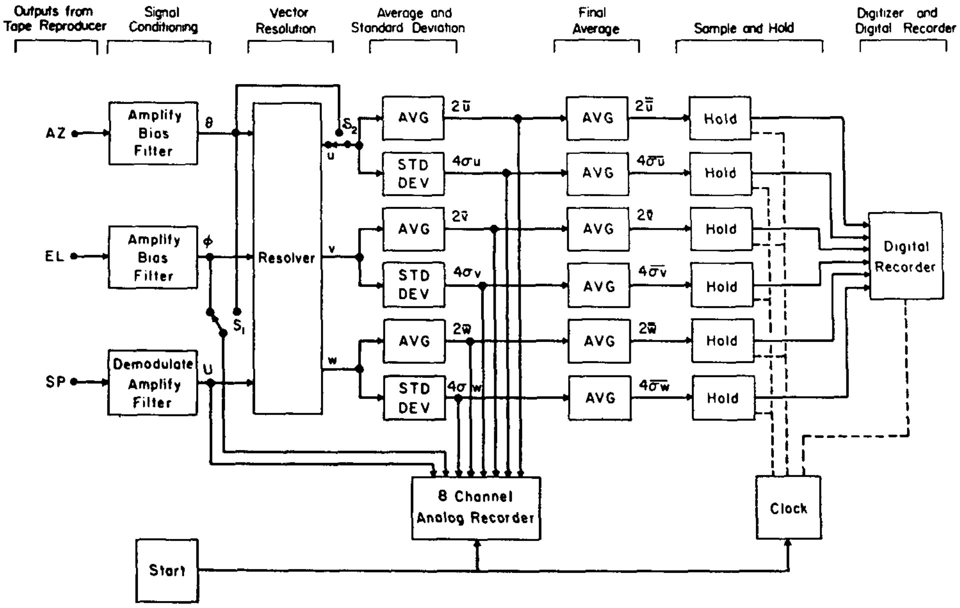

FIG. 1. Schematic of the computer circuits. Each box represents a group of analog computing elements: amplifiers, function generators and multipliers.

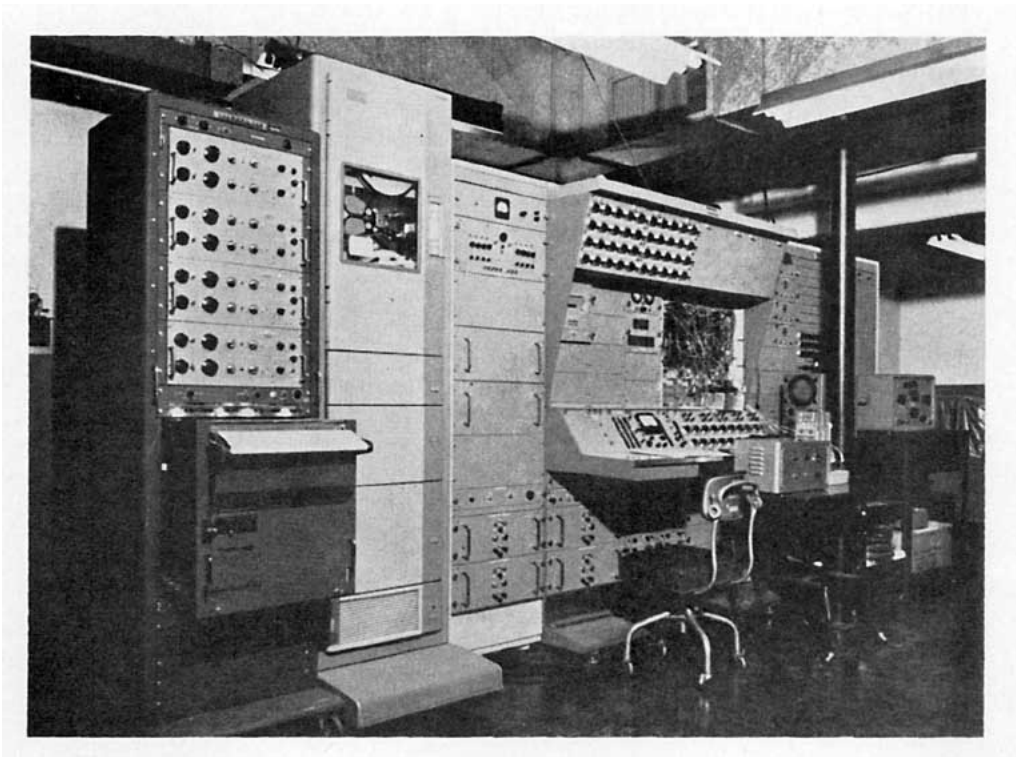

FIG. 2. Picture of the analog computing equipment. From the left; the eight channel analog recorder, magnetic tape transport, computer console, and ancillary equipment. The small box to the right is the pulse-to-dc demodulator.

and is equivalent to ± 25.2 ft sec^{-1}. This value was determined from the calibration of the pulse frequency demodulator and of the bivane anemometer.

The next set of boxes shows the mean value and standard deviation circuits. In order to increase the voltage levels of the output and thereby improve the accuracy and resolution, a gain of 2 was used in the mean value and 4 in the standard deviation so that the outputs were $2\bar{u}$, $2\bar{v}$, $2\bar{w}$, $4\sigma_u$, $4\sigma_v$, and $4\sigma_w$.

The six parallel circuits used for final average are shown next. These are similar to the previous mean value circuits except for the averaging interval which is 28.1 sec or 30 min in real time.

A sample and hold circuit was incorporated to sample the output of the final mean value circuits every 30 min in real time and to hold these values until they could be converted to digital signals and printed out.

The total equipment complement was 83 amplifiers, 7 function generators and 5 multipliers. Two recording media were used: digital recording and analog recording on chart paper.

The digital output was $2\bar{\bar{u}}$, $2\bar{\bar{v}}$, $2\bar{\bar{w}}$, $4\bar{\sigma}_w$, $4\bar{\sigma}_v$ and $4\bar{\sigma}_w$ in terms of machine units. Each of these must subsequently be multiplied by a scale factor to convert from volts to feet per second. For wind vane analysis, the output was $\bar{\bar{\theta}}$ and $\bar{\sigma}_\theta$.

The recording medium used throughout was analog recording on chart paper. An 8-channel recorder was employed to record $\bar{u}$, $\bar{v}$, $\bar{w}$, σ_u, σ_v and σ_w. These values had to be multiplied by a scale factor also to convert to physical units. The digital recording largely eliminates the need for abstracting the chart paper.

4. Conclusions

The analog computer circuits performed satisfactorily in this operation and the only improvements desirable in the overall operation for future use would be in the direction of increased automation. Automatic operation is of particular value when handling so many data since it can reduce the operating time and thereby the costs and because it minimizes operator error. The need for automation was greatest in interpreting the calibration. The best possible situation would be for one set of calibrations to be valid for all of the data. This puts stringent demands upon the field operating techniques and equipment and can be quite difficult to achieve. An equally acceptable solution that is not so demanding is that the field calibrations be put on the tape using a rigidly adhered to, and preferably automatic, procedure. When the tape is read the computer could be instructed to read and interpret the calibration data. It would also be very useful to have one channel of the magnetic tape reserved for a code which could inform the computer when data are being recorded. Then there would be no problem of reading calibration or blank pieces of tape as data.

Automation is also needed in the output stage. As currently operated, the final print out was in terms of machine units instead of physical units such as feet per second.

Ideally the computer would get all necessary instructions from the magnetic tape as it is read and would produce an intelligible output directly.

The drawback to partial or complete automation is that the computer makes no judgment as to the quality of the data but simply prints it out. This is why it was necessary to record the outputs on chart paper. The usual 8-channel recorder produces a record which is detailed enough to enable the observer to make judgments about the data. These records have such a small scale however that they cannot be read directly to more than two significant figures.

This type of computing holds considerable promise for routine processing of wind data. The techniques used here can be readily extended to the computation of auto-correlations and cross correlations.

Acknowledgment. The author wishes to acknowledge his grateful appreciation to Vernon L. Larrowe and Raymond E. Crabtree of the Analog Computer Laboratory of The University of Michigan and to Paul E. Sherr of the Bendix Systems Division for their constant guidance and help.

REFERENCE

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