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NEW HYBRID ANALOG DATA ACQUISITION SYSTEM FOR ATMOSPHERIC TURBULENCE (HYSAT)

By

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Abstract

A new hybrid analog data acquisition system (HYSAT) for the purpose of data processing of vertical turbulent transports and related quantities in the atmospheric boundary layer is proposed. This system is a combination of an analog and a digital computing parts. The analog part is used in pre-processing to calculate the mean values and standard deviations of physical entities, and cross correlations and covariances of them in analog form. The digital part is to sample the pre-processed data and to integrate for the whole sampling duration in digital form. However this part is not completed and the calculation to obtain the final results has been made manually by a desk top electronic calculator.

A final test of the system shows that the results are as satisfactory as expected and can be used in field experiments.

1. Introduction

In the study of the turbulence in the atmospheric boundary layer, one of the most interesting and important works is to estimate the amount of vertical turbulent transports of meteorological entities and to find its dependency on the mean profile and other parameters which are measured relatively easily. For the evaluation of the vertical turbulent transports, the eddy correlation method has been the most reliable method, especially since the appearance of the sonic anemometer by which the accuracy and reliability of the vertical velocity component measurement has been remarkably improved. However, since the data processing by the eddy correlation method has been time-consuming and costly undertaking, and the development of the new system on-site of the data analysis in simple and quick way has been requested for a long time. For this purpose, new hybrid analog data acquisition system for atmospheric turbulence, abbreviated as HYSAT is proposed by the present author (Hanafusa [1971]), the details of which are described in this paper.

2. Basic design of the system

In the study of turbulent transports in the atmospheric boundary layer, such quantities as the means, standard deviations of physical entities and cross correlations and covariances between them are, at least, necessary.

To obtain the mean value of a parameter over an arbitrary sampling duration, the most accurate method is to sample the signal, digitize and accumulate it in digital form with high enough sampling speed. However, to use a high speed A–D converter and an electronic computer in the field experiment is not practical. Nevertheless, for a short sampling duration it is easy to obtain mean value with enough accuracy by a low pass filter. Therefore, to process the data on-site, it is the simplest and easiest way to obtain the mean value by making the signal smooth with a low pass filter and then sampling and converting into digital form and integrating in slow sampling rate. This is the fundamental idea of hybrid analog processing of data which is used in this system.

In this system the following method is adopted. The input signals are pre-processed by component analog computing circuit with a low pass filter of cutoff frequency of 0.01 cps in the output side. Then the signals are sampled by slow speed scanner in the sampling rate of one or two times per minute per channel and converted into digital form, and finally then integrated by a simple desk top electronic calculator.

The computation of standard deviation of the fluctuating component can also processed by the analog method. Jones and Pasquill [1959] has reported the attempt to have standard deviation from the mean deviation obtained by an electronic filtering and detecting under some assumptions. However, the reliability of this electronic circuit is not completely satisfactory and its field application has not been progressed. While the combination of the thermocouple and hotwire sealed in a vacuum tube has been used to measure r.m.s. value of high frequency signal. By this method standard deviation is directly obtained. The same method can be used even in low frequency range, in which meteorologists are interested, with some changes in the design of the hotwire. To eliminate the DC component, the input must be filtered by a high pass filter with the cutoff frequency as low as possible. It is found from the experimental results of power spectra of wind velocity, temperature and water vapor in the atmospheric boundary layer (Mitsuta, et al. [1970]) that the normalized energy peak frequency is about 5×10^{-2}. Accordingly, the cutoff frequency of the high pass filter must be lower enough than $5 \times 10^{-2} U/Z$ (cps)(where U is wind speed and Z, the height of observation) if one wants to measure the standard deviation without serious error. However, this difficulty can be overcome by application of the following procedure. The contribution from the part of frequency lower than the cutoff frequency can be easily estimated from the output of the mean-meter if the time constant of sigma-meter and mean-meter are equal, as discussed in another paper (Hanafusa [1971]). In this system, cutoff frequency of 0.01 cps was adopted from technical point of view restricted by the reliabilities of circuit components. The low frequency limit of the inertial subrange of the spectra of vertical velocity is larger than about 1 in nondimensional frequency (Monin [1962]). In the lower atmospheric boundary, the contribution by the variance of fluctuations higher than 10 cps is considered to be small and, then, the low pass filter whose cutoff frequency is 10 cps is placed at the input side to keep away from noise. The r.m.s. value obtained by this system is the contribution of the fluctuations between 10 cps and 0.01 cps.

The development of the multiplying circuit has made it easy to estimate cross correlation and covariance between two signals. The upper limit of the frequency should be the one at which transports of the physical entities become negligibly small, that is inertial subrange. This limit of the frequency has not been determined uniquely partly because it may depend on the height of measurement, mean wind speed and atmospheric stability. Again it is quite satisfactory to place the limit at 10 cps, as the case of computation of the standard deviation. On the low frequency side, as the mean value of the physical entities cannot be known precisely in advance in a field measurement, the one similar to Dyer's one which has been used in Evapotron (Dyer, et al. [1965]) is adopted in this system.

3. The details of the analog part

The analog computing part of the HYSAT consists of component computing circuits which are eight mean-meters, six sigma-meters and four flux-meters. They are mounted in one case as shown in Photo. 1. The range of all the input and output signals is ± 1.0V. The power supply of 100V$\pm$10 AC is required. The details of each component computing circuit are as follows.

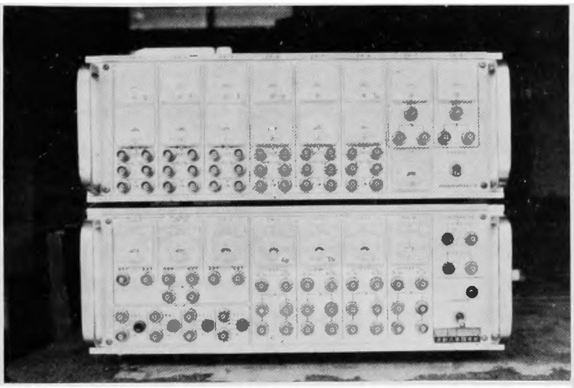

Photo. 1. The outlook of the analog part of HYSAT.

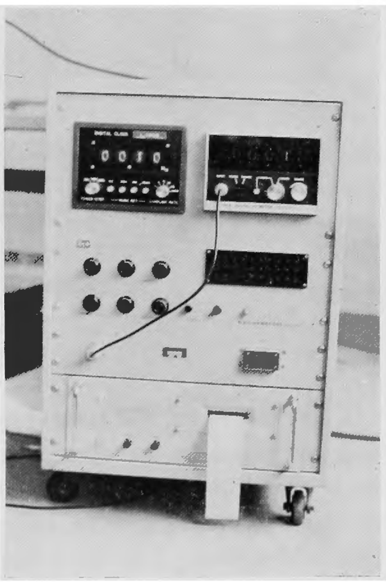

Photo. 2. The outlook of the digital part of HYSAT.

a) Mean-meter

The mean-meter is an active low pass filter, whose cutoff frequency (f_c: the amplitude is decreased by -3dB at this frequency) is 0.01 cps, the circuit of which is shown in Fig. 1. It is, of course, possible to make the low pass filter in an ordinary RC or LC circuit, especially the LC filter which has a special good feature in the frequency characteristics and stability. However, to make the LC filter in low frequency range requires large component parts which increase the weight and volume of the circuit, and therefore it is not suitable in field experiments. The traditional RC filter on the other hand has technical difficulties as pointed out by Jones and Pasquill [1959], moreover the frequency character is not so good as the filter with LC. To avoid these faults, an active filter, which is a combination of an operational amplifier and an RC circuit, is adopted as shown in Fig. 1.

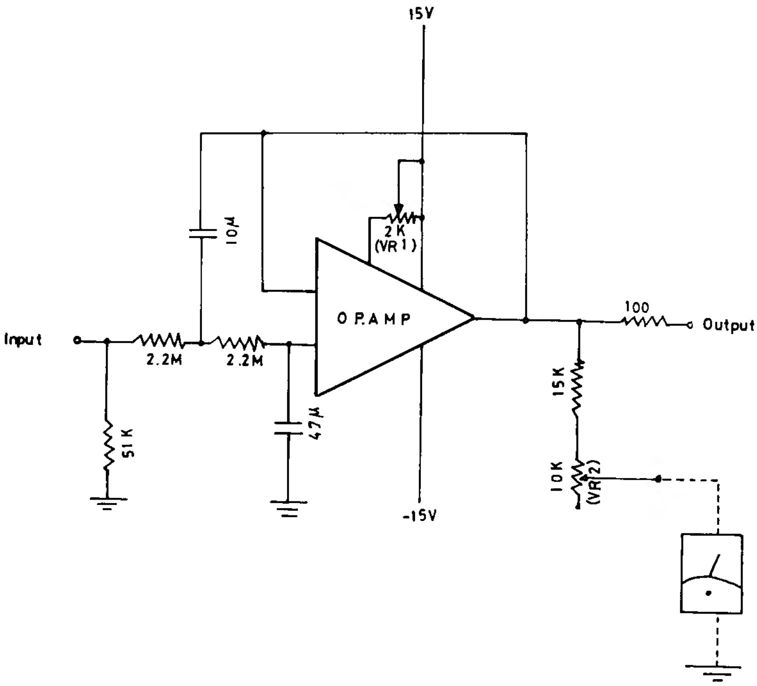

Fig. 1. The circuit of the mean-meter.

The computed and tested frequency response characteristics of the mean-meter as a low pass filter is shown in Fig. 2, in which the gain is shown in amplitude gain. As is clear from this figure the falling response curve around the cutoff frequency is enough sharp compared to ordinary RC filter, and the slope in the high frequency side is 12 dB/oct. The cutoff frequency is chosen at point where the amplitude gain decreases by 3 dB, and the characteristics of a numerical filter of moving average fitted at this point following Pasquill's method (Pasquill [1962]) is equivalent to 45 sec moving average as shown by dotted line in Fig. 2. Therefore, we can say that filtering by this mean-meter corresponds approximately to moving average of 45 sec

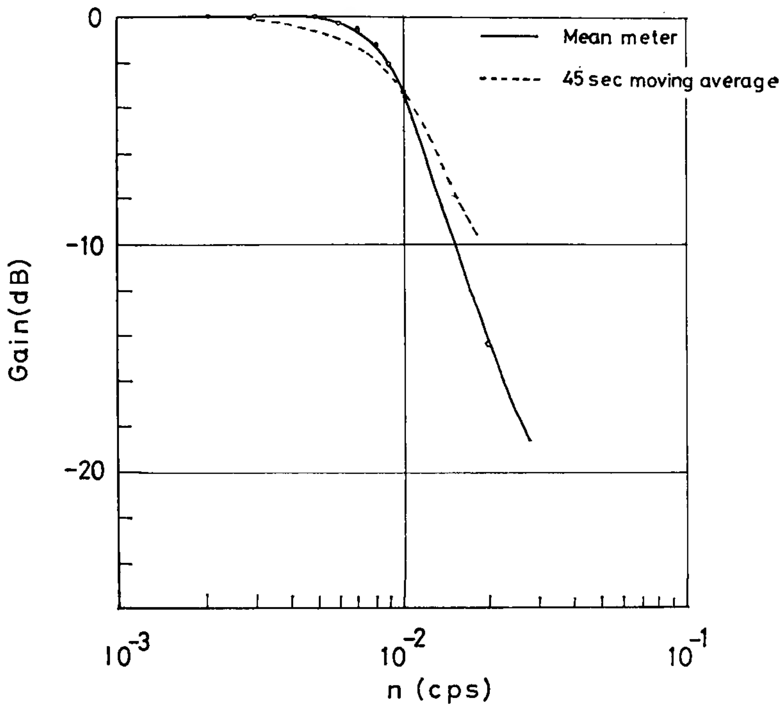

Fig. 2. The computed and tested frequency response characteristics of the mean-meter.

in the meaning of Pasquill's.

The component parts of this mean-meter are selected as being free from temperature effects and leakage. The resisters are metal film ones and their temperature coefficient is less than $10^{-4}/°C$. And the leak resistance of the condensors is larger than 10,000 MΩ at 20°C. The change of the offset voltage of the operational amplifiers (QFT–5 P/N) from ambient temperature change is smaller than 50 μv/°C. Therefore the drifting of the output is negligible. The overall absolute errors in mean-meter is estimated to be less than 1 mv in any conditions.

b) Sigma-meter

This circuit is to compute the mean square value of the fluctuating component in the frequency range from 0.01 to 10 cps of the input signal. The details are shown in Fig. 3.

The input signal is amplified 10 times in the Operational Amplifier 1 (PA 72709L) and filtered by the low pass filter with $f_c=10$ cps (Op. Amp 2) and by the high pass filter with $f_c=0.01$ cps (Op. Amp 3). The output of the low pass filter, which is the fluctuating component in the range from 0.01 to 10 cps, is supplied to the left side hotwire of the thermocouple unit shown as TC. The heating current is proportional to the input voltage of the fluctuating component and the production rate of heat of the hot wire is proportional to the square of the input voltage. As the heat exchange rate is constant, the temperature of the hot wire is the function of the square of the input voltage. The temperature difference between the two hotwires is detected as the electromotive force of the thermocouple, which is amplified by Op. Amps. 4 and 5 (Op. Amp 4 is a chopper amplifier (148 ZELTEX Co.)) and fed back to the reference hot wire on the right hand side. Therefore the output voltage of Op. Amp 5 or the current of the right hand side hotwire is proportional to the root mean square value of input fluctuation. The use of paired hot wire has increased the accuracy and the stability of the circuit. The output of r.m.s. circuit is filtered by a low pass filter with f_c of 0.005 cps to have the smoothed value of r.m.s. The cutoff frequency is chosen low enough not to distort the input high pass filter characteristics. Here, it must be pointed out that the phase relation is ignored in the course of processing. Accordingly, the standard deviation of the fluctuation in the frequency range of the input signal from 0.01 to 10 cps can be attained by the aid of the outputs of the mean-meter as explained in the separate paper (Hanafusa [1971]).

Besides the type shown above, one of the sigma-meters in this HYSAT has different characteristics for research purpose. It has three channels of input band pass filters of 0.01–0.08, 0.08–0.64 and 0.64–5.12 cps respectively, and three r.m.s, and low pass circuits for each of them. Therefore, we can obtain spectral contribution of fluctuating component in three channels by this unit.

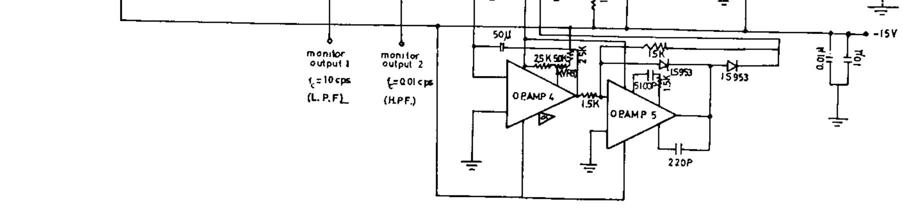

Fig. 3. The circuit of the sigma-meter.

Fig. 4 shows an example of the calibration curve of a sigma-meter unit. The abscissa is scaled in voltage of the half amplitude of the input signal (sinusoidal wave in 1 cps) and the ordinate shows the output and is scaled in the voltage of r.m.s. value of the input. The measured points deviate a little from the expected value shown in solid line. However, the maximum deviation is less than 3 % of the expected value.

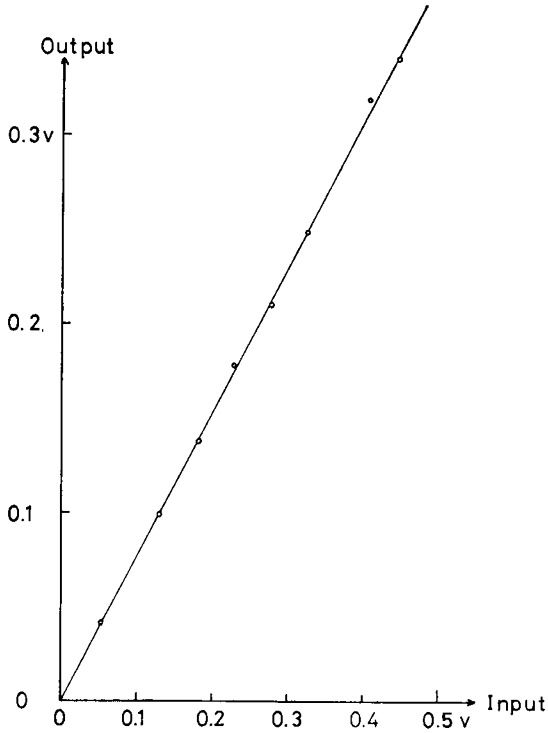

Fig. 4. An example of the calibration curve of the sigma-meter.

c) Flux-meter

This unit is to measure the covariance of two input signals, and the detailed circuit of which is shown in Fig. 5. The two input signals are filtered with low pass filters with cutoff frequency of 10 cps to eliminate undesirable signals and amplified by 10 times by the input stage operational amplifiers (Op. Amps 1 & 2 [SN 72709L TI]). Then the product of two signals is made by the multiplier (SPM-1A P/N), whose output is filtered by the low pass filter with cutoff frequency of 0.005 cps and divided in the last stage (Op. Amp. 3) in order to have 1.0 V output out of two 1.0 V input signals.

The circuit parts are of the same kind as those of other units and their temperature coefficients are small enough. The accuracy and stability of this unit is mainly dependent on the multiplier which is, according to the maker's manual, good enough for the present instrument.

d) Auxiliary components

Besides three kinds of computing units mentioned above, four DC amplifiers to adjust the input signal level to the standard value of ± 1.0V, the DC and AC calibration signals outputs and the main power supply are built in this analog part.

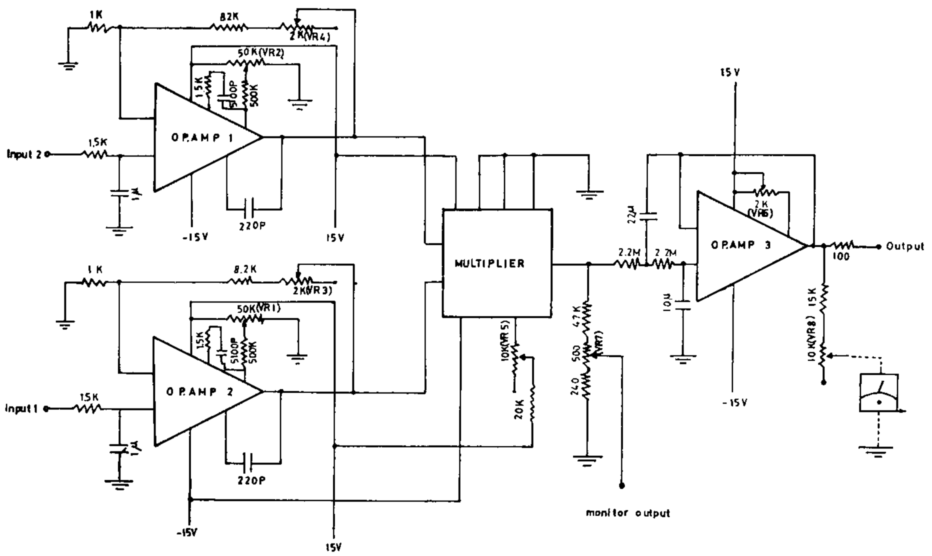

Fig. 5. The circuit of the flux-meter.

4. The details of the digital part

The digital part consists of an input scanner, an A–D converter, a monitoring line printer, a calculator and a digital clock. The calculator is to be a small desk top electronic computer to store the all channels of input signals and accumulate the input to the stored value in each channel. However, this is not completed at present stage and the calculations to have the final results are made manually by a desk top electronic calculator. The rest parts are built in one rack as shown in Photo. 2.

The input scanner is a 30 channel input scanner, MS–30 (supplied by Eto Denki Co.), which is controlled by the digital clock (Eto). The A–D converter is a small four digit digital voltometer (Eto EO–9). The line printer prints out the channel number, time and the output voltage (Eto DP–2). The sampling rate can be controlled by the digital clock.

5. The test of the system

After the completion of the system, it was tested in detail. The results were satisfactory as expected from the test of each unit described in the previous sections. The most serious deficiency for the system of this type is the drifting of the zero points of the units. The test of the zero point drifting of all units is made for about twelve hours in the laboratory without air conditioning. The results show that, after a few hours from switching on, driftings are very small and the averaged value of all channels is almost zero and the maximum difference of zero point of any two channels was less than 2 mV. This may be tolerable in field measurements.

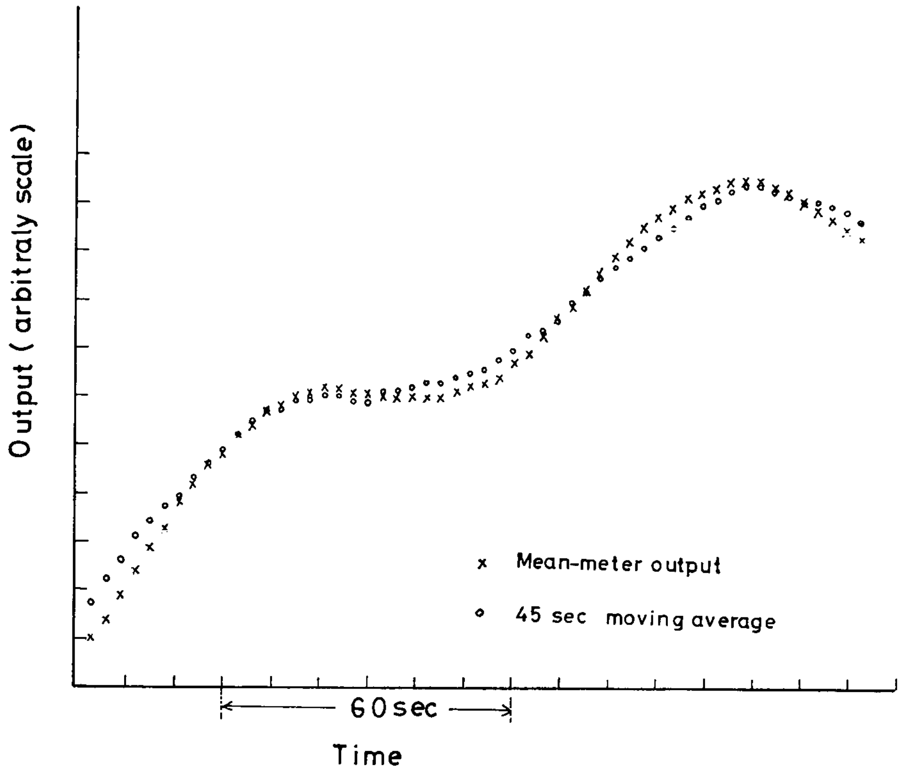

Fig. 6. Comparison of the outputs of a mean-meter with the 45 sec moving average values.

The outputs of a mean-meter for a signal of natural wind fluctuation was compared with the 45 sec moving average value of the same signal, which was estimated to be compatible with the output of a mean-meter from the frequency response characteristics. The results are shown in Fig. 6. The moving average was plotted at the end of the averaging interval and the filtered output is plotted at the time of sampling. This figure shows good agreement between the two curves and the compatibility is certified.

6. Conclusion

A new hybrid analog data acquisition system for atmospheric turbulence (HYSAT) designed by the present author is described. The performance of the completed system is satisfactory. Hereafter the experimental studies on the turbulent transport processes near the ground can be performed very easily on-site in real time by the use of this system with the aid of the sensors already developed.

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