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使用微机的自动气象站

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提　　要

本文综述了应用微型计算机作为自动气象站的核心部分应考虑的要点。阅读本文并不要求读者掌握微机的基本知识。本文所描述的原理涉及来自气象感应元件的信号处理、计算机硬件性能的选择、编制程序的语言和技术、最终结果的输出方法等。作为一个实例，本文介绍了一个用于向公众展示当天气象要素及气候统计资料的自动气象站。

Abstract

A review is presented of the important points to consider when using a microcomputer as the central part of an automatic weather station. No previous knowledge of microcomputers is assumed. The principles described include the treatment of signals from meteorological sensors, the choice of computer hardware options, programming languages and techniques, and methods of producing output. An example is given of automatic weather station used to provide a public display of current weather parameters.

AUTOMATIC WEATHER STATIONS USING MICROCOMPUTERS

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Introduction

Automatic weather stations are normally used in hazardous or remote

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locations such as in mountains or at sea. Their purpose is to make routine meteorological observations at regular intervals and to report them to some central station or record them for later use. With the advent of microcomputers it has become reasonably inexpensive to design automatic weather stations which are very versatile. The real versatility of the microcomputer is due to the ability of one piece of equipment to do a multitude of different tasks simply by changing the program.

A general definition of an automatic weather station is a device which accepts a number of analogue signals from different meteorological sensors and processes these signals to produce some form of permanent record. The fact that this is done automatically makes this different from what is done at a manned weather station. Another difference is that only those parameters which can be objectively determined (eg temperature, pressure, rainfall or wind speed) can be processed by automatic weather stations. Subjective parameters (eg cloud amount, present weather, or cloud type) cannot presently be measured automatically, but as the development of "machine vision" continues these should also be recordable. A few parameters exist for which objective instruments are available but for reasons of cost subjective estimates are more often used (eg visibility or height of cloud base).

It is convenient to separate the functions of an automatic weather station into Input, Processing, and Output. Each of these will now be discussed separately before an example of a microcomputer-controlled weather station is given.

Input

Meteorological sensors exist in various forms, but the ones which are usually used in automatic stations are those which produce electrical signals. A list of typical sensors and their signals is given in table 1. There is quite a variety of different signals but it is necessary to convert all signals to some standard range before presenting them to the computer. The computer also expects to receive all signals in digital form which necessitates analogue to digital (A/D) conversion. The signal processing is carried out by first converting all signals to be voltages, normally in the range 0 5V, then passing these signals to the A/D converter which is controlled by the computer. For instruments which produce a voltage or current it is simply a matter of amplifying the signals when necessary but the instruments which produce pulses or frequencies require other forms of processing. The pulse signals can be processed by a "ramp" or "staircase" circuit which will add a small analogue voltage to the output for every pulse at the input. When some predetermined level is reached (5V in this case) the output voltage is reset to 0V and the process starts again. Of course this system is satisfactory only when the time taken for the signal to cycle from 0V to 5V is much longer than the rate at which the computer is sampling the signal. The frequency generating instruments must have their output processed by a "tachometer" circuit which converts frequency to voltage. After this signal conditioning, all signals are in the range 0-5V and they are connected to the input of the A/D converter. One of the design constraints on an automatic weather station is the number of input channels which the A/D converter possesses. For meteorological purposes sixteen channels is likely to be more than adequate, but simple weather stations could be constructed with as few as four channels. The other constraint which is imposed by the A/D converter is the digital resolution of the incoming signals. In general 8 bits (0-255) may be sufficient but 12 bits (0-4095) is preferred. The digital resolution available from a number of meteorological instruments is shown in Table 1. Usually the A/D converter must be connected to the computer by 12 data lines (for 12 bits) and also by lines with which the computer can control which of the A/D input channels will appear on the output data lines. Determining which channel

TABLE 1 TYPICAL SENSOR SIGNALS AND RESOLUTION

Parameter	Sensor	Typical signal	Meteorological range	Digital resolution 8 bits	12 bits
Temperature	Thermistor Thermocouple	KOhms mV	-50 to 50C	0.4C	0.02C
Wind speed	Optical tachometer Generator	KHz mV	0-60m/s	0.2m/s	0.02m/s
Wind direction	Potentiometer Coded disc	KOhms digital	0-540 deg	2deg	0.1deg
Pressure	Monolithic transducer Aneroid	V mA	950-1050hPa	0.4hPa	0.02hPa
Rainfall	Tipping-bucket Syphon	pulses(V) V	0-50mm	0.2mm	0.01mm
Radiation	Pyranometer	mV	0-1200 Wm^{-2}	$5Wm^{-2}$	$0.3Wm^{-2}$

is to be used can be done in one of two ways: a pulse can be sent which simply requests the A/D converter to send data for the next channel; or a number can be sent from the computer to the A/D converter to identify one channel. The former method requires only two lines, one to carry the pulses to increment the A/D to the next channel and one which is used initially to set the A/D to the first channel. The latter method requires a number of lines determined by the number of possible channels (4 lines for 16 channels). Additionally, a line which sends a signal from the A/D converter to the computer to indicate when the converted data is ready may be included, but as the time taken is always constant the computer can delay reading the A/D for the appropriate time after requesting the data from a particular channel. Finally, it must be recognised that most microcomputers use an 8 bit data bus which makes it necessary to read 12 bits of data from the A/D converter in two parts.

Computer hardware and software

Microcomputers exist in a large variety of shapes and sizes, from single-board computers with only a few integrated circuits, to complete systems with keyboard, disc drives, and high resolution graphics screen. The type of computer used for controlling an automatic weather station depends on whether only one station is to be produced or whether a commercial product is being developed which would require costs to be minimized. In either case the development work would be done on a machine which had a keyboard, disc drives and monitor, but in the case of commercial production this would be the "development system" and the final product, which might be a single-board machine, would be the "target system".

All microcomputers (in fact, all computers) must have at least three basic functions: input, processing and output. Input was considered in the last section where the primary input is the meteorological measurements, but we may also want secondary input from a keyboard, for example to instruct the automatic station to operate in a different way. Output will be discussed in the next section. The part of a microcomputer in which the processing power resides is the central processing unit (CPU) of which a number of different types are available. For most meteorological purposes processing power is not a very important factor. Most programs will be doing nothing for long periods between short bursts of activity when they read the instruments and act on the readings. For the development of software it is necessary to save information or programs and it is therefore essential for the development system to have some type of easily accessible storage medium; usually floppy disc.

When purchasing a microcomputer for use as an automatic weather station (or as a development system) the important things to consider are:

* The CPU is unimportant, almost any microcomputer has sufficient power.
* In addition to a keyboard it must be possible for the machine to read input from other sources.
* Input from external sources should be as parallel data which would allow an A/D converter to be connected directly. If the external input is restricted to serial data then additional electronics is required to convert the A/D output to a serial signal. This also slows down the rate at which the instruments may be read.
* Storage on disc is essential for rapid program development.
* Battery back-up in event of power cuts is an advantage.
* The inclusion of a "real-time" clock or interval timer in the computer hardware is essential for most automatic weather station applications where time dependent actions are needed.
* The memory available in most microcomputers is adequate, although the Random Access Memory (RAM) required may exceed 32Kbytes it rarely exceeds 64Kbytes.

Once the appropriate computer hardware has been identified it is necessary to ensure that it will also support the desired software. The choice of software is just as important as hardware since it can greatly affect the time taken for program development. Before discussing particular software considerations for automatic weather stations some general points can be made. The language chosen for programming should be a high-level language (ie one in which it is possible to write structured programs, including procedures and functions). It is also very useful to be able to produce libraries of procedures and functions. Usually such library facilities are provided for languages which are compiled rather than interpreted. It may sometimes be necessary to use assembly code programming for time dependent operations which makes a good assembler a valuable software tool.

A clock is nearly always necessary in an automatic weather station. It may be used to record observations every hour, to define a period over which to calculate the average wind speed, to measure the time between increments of a tipping-bucket rain-gauge, or to sample wind speed and direction at short, regular intervals for turbulence studies. Operations which are time dependent can use two techniques for finding the time, polling and interrupting. Polling is used for operations where the timing is not crucial (compared to the time taken for the program to complete a cycle of its main loop). It involves reading the time from a variable which contains the clock time at the appropriate part of the program and performing actions depending on the time read. This is suitable for recording data every hour and possibly for most of the examples given above if the time for a major program cycle is short, eg a few seconds. Interrupting is essential when operations require very accurate timing, eg finding the wind speed and direction every 100 milliseconds (Of course, this requires an anemometer with a response time very much less than a standard anemometer.) When an interrupt is generated the main program leaves what it is doing and performs the action required by the interrupt. Usually the first action must be to set the interval timer counting again (to produce another interrupt after the required time interval), then the time dependent action can be taken, and finally control is passed back to the program at the stage it was interrupted. The main program will then continue to run until the next interrupt is generated. In general the ability to produce interrupts after a time interval is more versatile than simply polling a clock built into the microcomputer. It is simple to use interrupts to simulate a clock, but they also have many other capabilities. The part of a program which deals with interrupts when they occur usually has to be written in assembly code.

Some suggestions concerning software techniques which are particularly useful for automatic weather stations will now be described. When readings are obtained from instruments it is advisable to store them in data buffers in the program, ie regions of memory (perhaps an array) in which the most recent instrument readings will always be found. The values read from the A/D converter will be in the range 0 to 255 (for 8 bits) or 0 to 4095 (for 12 bits) and can be stored in a buffer of integer numbers. At this stage it is often a good idea to read each instrument several times and place the average of, say, eight readings in the integer buffer. This reduces any noise which may exist on the cables to the instruments or in the A/D converter and can usually be accomplished in a few tens of milliseconds. The program needs to have the readings in meteorological units which requires some conversion to real numbers. This is easily performed if the conversion is linear. A real number buffer is then set up which will always contain the most recent observations in meteorological units. To convert from the integer buffer to the real buffer requires a slope and origin for the linear calibration line. It is particularly convenient to be able to change these values when necessary, eg when replacing an aged instrument with a new one which might have a different calibration. In this way all calibration of instruments can be done entirely within the software and need not involve electronic circuitry. It may be desirable for the real buffer to be larger than the integer buffer. The integer buffer will only contain values for the number of instruments connected, but the real buffer may contain quantities derived from the instrument readings, eg dew point temperature or relative humidity derived from wet- and dry-bulb temperatures.

Since meteorology often requires time-averaged quantities, eg wind speed, it may be necessary to accumulate large numbers of observations. If the wind speed is measured every second we would need 600 values to find a ten-minute average. Such calculations would be very space-consuming and a much more attractive approach is to use a time filter with a suitable time constant. This is achieved with a program statement such as:

$$F = (1 - a) F + aR$$

where R is the observed value in the real number buffer and F is the filtered value. The amount by which each new value of R affects the filtered value F is determined by 'a'. If 'a' is close to zero then each new value 'R' has little effect and the filter effectively has a large time constant. The time filter is exponential with a time constant of 1/a where 'a' lies in the range 0 to 1 and the units are the sampling interval for the new readings 'R'. This method may also be applied to finding time derivatives such as pressure tendency. If pressure measurements are made every minute (with an accuracy of, say, 0.2 hPa) then to find the pressure change in three hours would require excessive amounts of memory to store all the pressure values. If the pressure change in one minute is calculated it could be expressed as a pressure change in three hours, but since the expected pressure change in one minute is very much less than the accuracy of the measurement the calculated tendency, by itself, is of no value. However, if the tendency based on a calculation over one minute is considered to be a "raw" tendency then a "filtered" tendency can be calculated. If a large time constant is chosen for the filter then a large number of inaccurate tendency measurements are accumulated to produce an accurate and slowly changing value for the pressure tendency. A similar procedure may be used to calculate rainfall rate.

The type of computer chosen will determine how the system is implemented when program development is completed. If a complete microcomputer system is employed then operating the automatic weather station is equivalent to running the program, although it is desirable to arrange for the program to be started automatically when power is switched to the computer, thus providing automatic restart in case of power failure. If, however, the program development was aimed at a single-board "target" computer then it will be necessary to transfer the program onto Read Only Memory(ROM)which can be inserted in the target machines. This can be done from a microcomputer if an EPROM programmer is one of the available accessories. (EPROM is Erasable Programmable ROM which allows the ROM to be changed several times.)

Output

How should an automatic weather station produce output which reflects the observations made? There are many different possibilities and the choice is determined by what the purpose of the station is. If the weather station is operating in a building where many people might want to see the current readings, then a video display, relayed to several monitors, is a good form of output. However, this leaves no permanent record of the observations which might be useful for more detailed analysis at a later date. This could be overcome by adding a printer to give a hard copy of the observations but subsequent analysis is most likely to be done by computer and it would be better to store the data in a machine readable form, eg paper tape, floppy disc or magnetic tape.

If the weather station is to be located in a remote site then it is most likely that data will have to be logged in some machine readable form. Although this can be managed adequately using a cassette-tape data-logger, these usually require enough power that battery changes are needed every few weeks. Another possibility, which requires less power, is to store the data in a "memory module": a section of RAM which is accessible to the microcomputer but is also detachable and replaceable. It must have its own power supply to keep the data intact when the "module" is removed from the station. Magnetic bubble memory is now becoming available which will not require its own power and which has a capacity of about 1 million bits. The use of a "memory module" is most beneficial in cases where power requirements must be kept to a minimum. Sometimes automatic weather stations are placed in locations where it is not possible to retrieve data which has been logged for very long periods, eg mountain stations in winter. In this case it is best to fit the automatic weather station with a radio transmitter which will transmit data from the buffer at regular intervals. A receiving station can then record and store data from one or more such remote station.

An example

An example of a microcomputer-based automatic weather station is METDADS (Meteorological Data Acquisition and Display System) which was developed at the Department of Meteorology, University of Edinburgh. Its purpose is to provide a continuous display of current and recent weather statistics in various parts of a large University building. It is also able to save hourly observations on floppy disc which can subsequently be transmitted to the University mainframe computer for analysis. The system is based on an Apple IIe microcomputer. It has eleven meteorological sensors: wet- and dry-bulb thermometers, soil thermometers at depths of 2cm and 20cm, anemometer and wind vane, barometer, raingauge, shaded and unshaded pyranometers, and a net radiometer. The main program is written in PASCAL and is approximately 1300 statements. The flow diagram in figure 1 shows the structure of the program. The heavy lines show the part of the program which is executed continuously. This only stops when someone interrupts it to change the display or the calibration data, or to switch the archiving facility on or off. This station produces a display on TV monitors which are placed at three locations in the building, up to 100m away from the computer. The display consists of four "pages" of information (figures 2 to 5) which change every 20 seconds showing the most recent observations. A complete description of this weather station is given in Duncan, 1985.

References

Duncan, C.N., "A microcomputer-controlled automatic weather station", Weather, 1985.

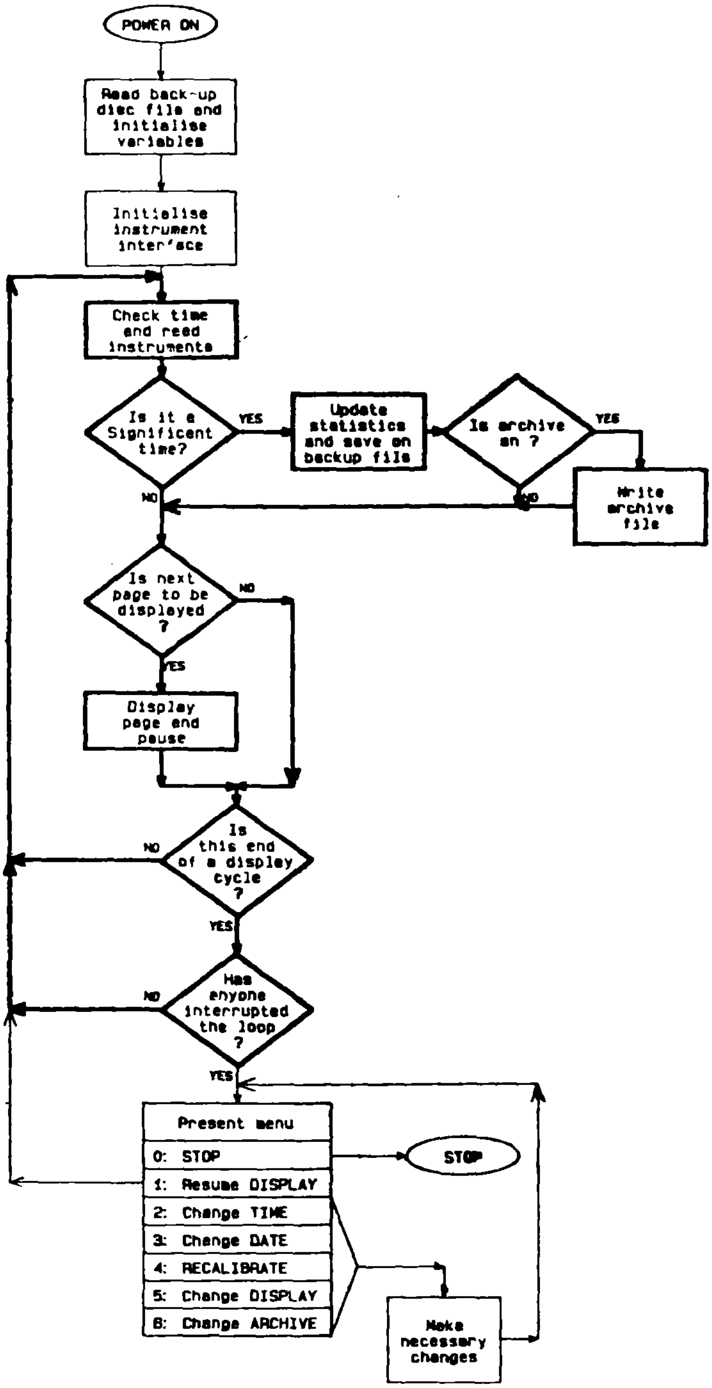

Figure 1. Flow diagram showing the structure of the program used in the METDADS station. The heavy black lines indicate the continuous loop which is executed by the computer.

METDADS 3 27/2/84 10:23 **GMTE**

DRY BULB TEMPERATURE	2.6 C
WET BULB TEMPERATURE	1.7 C
SOIL TEMPERATURE(2CM)	4.5 C
SOIL TEMPERATURE(20CM)	3.6 C
RELATIVE HUMIDITY	83 %
MAX TEMP SINCE 09 GMT	2.7 C
MIN TEMP SINCE 21 GMT	1.8 C
WIND SPEED	1.8 M/S
WIND DIRECTION	240 DEG
BEAUFORT FORCE AND DIRN	2 SW
MAX GUST SINCE 00 GMT	4.3 M/S
WINDCHILL	875 W/SQ M

Figure 2: The first "page" of information which is displayed on the monitor screens of the METDADS station. This screen shows current observations of temperature and wind.

METDADS 3 27/2/84 10:34 **GMTE**

PRESSURE	1024 HPA
PRESSURE TENDENCY	-1.7 HPA/3HR
RAINFALL SINCE 09 GMT	0.0 MM
RAINFALL RATE	0.0 MM/HR
RAINFALL THIS MONTH	50 MM
NORMAL MONTHLY RAINFALL	43 MM
RAINDAYS THIS MONTH	17
NORMAL MONTHLY RAINDAYS	16
TOTAL SOLAR RADIATION	130 W/SQ M
DIFFUSE SOLAR RADIATION	127 W/SQ M
SOLAR TOTAL THIS MONTH	18 KWHR/SQM
NORMAL MONTHLY SOLAR	34 KWHR/SQM
NET RADIATION	41 W/SQ M

Figure 3: The second "page" of information, showing current information on pressure, rainfall and radiation.

METDADS 3 27/2/84 10:27 **GMTE**

RECENT STATISTICS

MAX TEMP YESTERDAY	4.0	C
MIN TEMP YESTERDAY	1.3	C
MAX TEMP THIS MONTH	9.1	C
MIN TEMP THIS MONTH	-0.2	C
RAINFALL YESTERDAY	0.0	MM
MAX WIND GUST YESTERDAY	6.1	M/S
MAX MEAN WIND YESTERDAY	5.8	M/S
MAX WINDCHILL YESTERDAY	956	W/SQ M
MAX GUST THIS MONTH	21.5	M/S
MAX MEAN WIND THIS MONTH	21.2	M/S
MAX WINDCHILL THIS MONTH	1091	W/SQ M

Figure 4: The third "page" of information, showing statistics from the previous day and the current month.

METDADS 3 27/2/84 10:31 **GMTE**

LAST MONTH'S STATISTICS

MAX TEMPERATURE	11.0	C
MIN TEMPERATURE	-6.9	C
AVERAGE TEMPERATURE	2.1	C
NORMAL AVE TEMPERATURE	3.2	C
RAINFALL	138.5	MM
NORMAL RAINFALL	63	MM
NUMBER OF RAINDAYS	11	
NORMAL RAINDAYS	19	
INTEGRATED SOLAR RAD	14	KWHR/SQM
NORMAL INT SOLAR RAD	16	KWHR/SQM
MAXIMUM WIND GUST	43.7	M/S
MAXIMUM MEAN WIND	32.8	M/S
MAXIMUM WINDCHILL	1386	W/SQ M

WIND ROSE(%)	NE	E	SE	S	SW	W	NW	N
LAST MONTH	3	16	17	5	4	27	24	4
ANNUAL MEAN	4	15	13	4	6	30	24	4

Figure 5: The fourth "page" of information, showing statistics from the previous month.