EQUIPMENT DEVELOPMENT FOR AUTOMATIC COLLECTION OF GREENHOUSE ENVIRONMENTAL DATA USING MOVING SENSORS

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INTRODUCTION

There are many variables in the design of a greenhouse that affect plant growth and development, such as building orientation, design, shape, and construction materials (1, 8). The effects of these variables on the environment in a greenhouse are readily measured at a single location and can be used for the control of the environment within preset limits. However, the conditions at one location are not truly representative of the conditions encountered by the plants throughout the house.

In evaluating any new concepts in greenhouse design, or structural material, it is necessary to theoretically analyze the possible effects of the change as well as to support the calculations with data collected from prototypes and finished structures (3, 7, 9, 11, 12, 14). Present methods for measuring and recording environmental conditions are either very time-consuming or require many costly sensors. For these reasons it is believed that many publications report only a minimum amount of environmental data, such as inlet and outlet air temperatures and humidities, with little information about light distribution (9, 12). Some papers report several light intensities and little about temperature and humidity variations (4) or an author assumes that measurements at a single location can adequately represent the overall conditions. Usually, the control of the greenhouse environment is based on this assumption (1, 2, 5, 6, 13).

A system has been designed to allow several locations in a greenhouse to be sampled for temperature, humidity, light, or other environmental variables that should prove useful for those researchers who were previously limited because of the high cost of "better" data logging systems. The purpose of the system being described is:

(1) To provide a relatively inexpensive method of measuring a fixed number of environmental variables at several locations.
(2) To collect the information from station to station automatically; and
(3) To employ commonly found sensors and instruments, without the need of a complete data logging system.

The design specifications selected for this prototype were the abilities to measure from 1 to 15 environmental parameters (some combination of light, temperature, and humidity) at each of 10 locations in about 10 min. The actual number of locations encountered in the 10 min will vary with the number of measurements taken per location, the distance between locations, and the equilibration time required by the sensors.

THE SYSTEM

Overview

The data-collecting system consists of a module, or mobile transmitting station, and a stationary data recording station, or receiver station, remote from the module. The module travels along a fixed two-railed track, independent of cables or other connections to the receiver station. Besides carrying sensors, the module contains its own propulsion system and electronic circuits that control its operation. The receiver station consists of one sensor amplifier per type of sensor carried by the module, a recorder, as well as electronic circuitry similar to that on the module. The track, approximately 7 cm wide, is constructed of two rails (the type used for large sliding doors) bolted together and is suspended from the roof structure of the greenhouse to form a closed loop. A fixed electrically shielded cable (transmission cable) runs midway between the rails. At the locations along the track where sampling is to take place (sampling sites), small mercury troughs mounted between the rails enable an electrical connection to be made between the module and receiver station via the cable. The troughs are machined into a piece of Plexiglas and each is partly filled with mercury. Each trough is connected to its own wire in the transmission cable. The sensor that requires the most wires for data transmission (N wires) determines the number of wires that must be in the cable (N + 1). The additional wire is required to carry a signal for synchronizing the operations of the module and receiving station.

The module (Figure 1) travels along the track until it reaches a sampling site. Upon being stopped by a wedge on the track, the module's fork connector (Figure 2) drops into the mercury troughs and completes the module-to-receiver connection via the transmission cable. The sensors equilibrate to their new environment for the length of time (a variable) preset in the module circuit. After equilibration, the sensors are sequentially connected to their respective amplifiers at the recording station and the data are recorded. On completion of the recording, the fork is lifted from the troughs, and the module advances to the next sampling site.

THE MODULE

The basic components of the module are shown in Figure 1. At a sampling site, microswitch MS1 (A) is tripped by a wedge on the track, and stops the motor (B), which propels the module. An automobile windshield-wiper motor is

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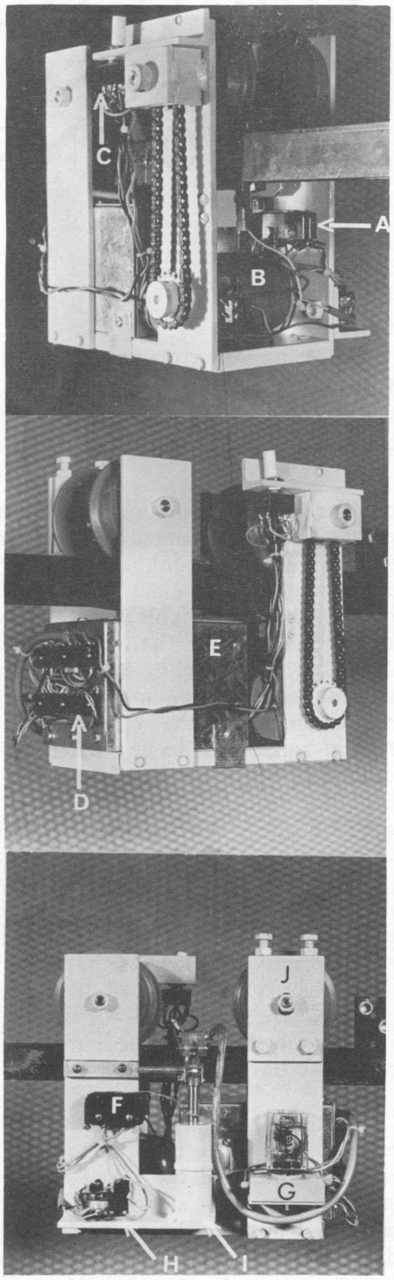

Figure 1. Transmitting module. *Legend:* A, microswitch MS1; B, motor; C, motor-reversing switch (test model only); D, sensor connector strip; E, electronic circuit box; F, microswitch MS2; G, timer relay; H, relay 16; I, fork lifter solenoid; J, spring suspension assembly.

used to drive one of the four wheels. The motor reversing switch (C) was used only on the prototype, as a short straight track was used in preliminary testing.

The cables from the sensors, which are supported by a rigid plastic tube at different elevations under the module, are connected to the sensor connector strip (D). The electronic circuit box (E) electronically connects each sensor sequentially to the fork connector used to transfer the sensor signals via the transmission cable to the sensor amplifiers.

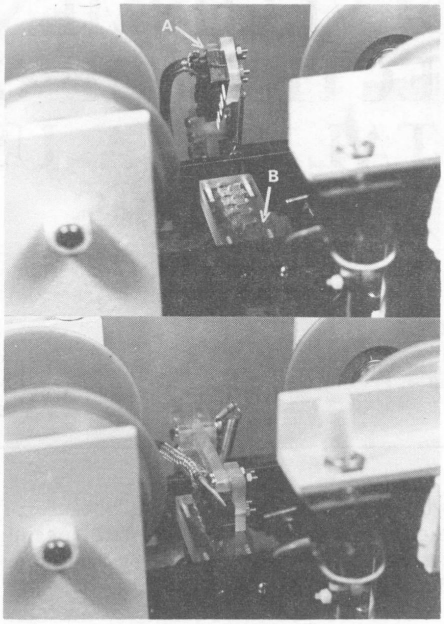

Figure 2. Fork connector. *Top*, fork connector A about to drop into mercury trough B; *bottom*, connection completed.

Microswitch MS2 (F) is used to start the motor and advance the module to the next sampling site. The timer relay (G) closes after the preset sensor equilibration time has elapsed. The connection of the sensors to their amplifiers then takes place, and the connecting sequence is terminated by the closing of relay 16 (H). This relay activates the lifter solenoid (I), which removes the fork connector from the mercury troughs. The lifting of the fork results in the closing of MS2 and the advancement of the module.

Three of the four wheels that support the module are idlers, one of which is mounted in a spring suspension assembly (J), which assures that all four wheels are always in contact with the track.

The module obtains its electrical power from the main direct-current power supply located at the recording station. The track acts as the negative (and ground) connection and a power-conducting strip adjacent to one of the rails is the positive connection. Electric motor brushes are used to transfer the current from these conductors to the module. A small voltage regulator mounted on the module supplies the current for the module's circuitry.

The block diagram of the module's circuit is shown in Figure 3. The module would be moving when the switches are in the positions shown. A more detailed description of the circuitry has been reported previously (10).

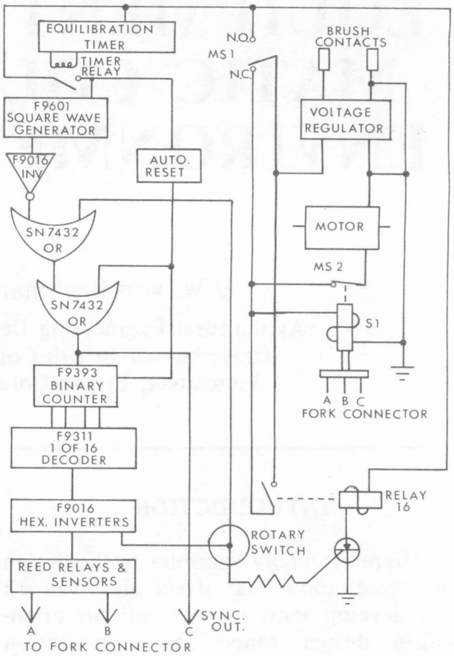

Figure 3. Module circuit block diagram: circuitry for module propulsion and sequential connection of sensors to common cable.

THE RECORDING STATION RECEIVER

The switching of a sensor to its proper amplifier is controlled by the integrated circuits of the module. However, because the 15 sensor signals have been converted into one signal path, the wires of the transmission cable, they must be diverted again to their respective amplifiers at the recording station. For this reason, a similar circuit to the module circuit is required at the recording station, and this is the recording station receiver. The 15 sensor signals are received sequentially via the cable and are routed to their proper amplifiers. To simplify the receiver circuit, it was arbitrarily decided to divert the first three sensor signals to one amplifier, the next three to another, and so on up to the 15th.

In order for the sensors and amplifiers to be connected at the right time, it is essential that the module's switching circuits are synchronized with those of the receiver's. A synchronizing signal that is transmitted via its own wire in the transmission cable from the module to the receiver assures that this will occur.

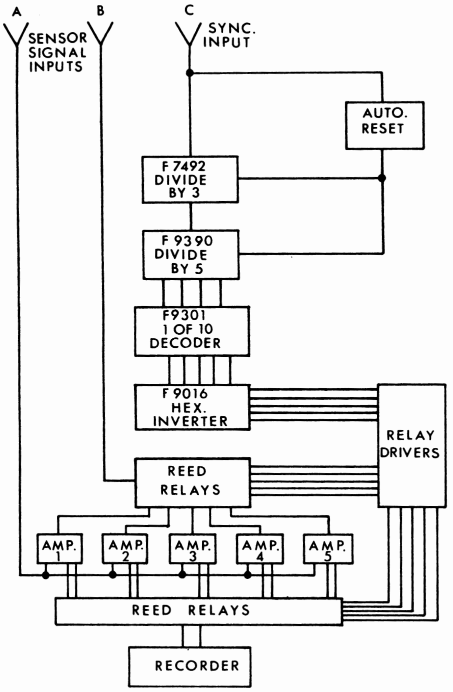

Figure 4. Record station block diagram: circuitry for the sequential connection of the sensor signals from the cable to their respective amplifiers and recorder.

As well as connecting the sensors and amplifiers, the receiver connects the individual amplifiers to the recording unit one at a time. This eliminates the interference between amplifier outputs. If a pen recorder is used as the recording device, a straight horizontal line will be obtained for the length of time that a sensor is connected to its amplifier. This time may be varied by an adjustment in the module circuit. A digital print-out or magnetic recording device that may be triggered to take a reading at a given instant would be much more convenient, because transferring of data from the chart paper would be unnecessary.

The block diagram of the recording station receiver is shown in Figure 4 and has been reported in more detail previously (10).

Preliminary Tests

The only errors that might be encountered in the output data of this system that cannot be corrected by calibration of the sensors are those that might occur as a result of a bad connection between the sensor and its amplifier. Because the mercury connector is the only place where a variation of contact resistance should be found, a test was made on the reproducibility of the resistance of a sensor-to-amplifier connection. A digital ohm meter (Weston 1240) was connected at the receiver station where normally the sensor's amplifier would be. The module was allowed to go through its normal procedure of approaching the mercury connector and dropping the prongs into the troughs, switching in the sensors, and advancing. The resistance of the dummy sensor was measured through the switching system every time the module stopped at the sampling station.

The test was repeated 15 times. The resistance varied ±0.5 ohms over the 15 readings. This does not imply that the variation obtained from station to station will be as small as the variation at a single station. But, any variation in readings due to change in transmission cable length from station to station can be readily corrected mathematically. Sensors connected to the module, and suspended under it, showed that results from a given sampling station were obtainable in their proper sequence and were reproducible. Calibration of the sensors was omitted in the trial and consequently the results are not reported.

Due to the toxic effect that mercury vapors have on some plants, it was proposed that a thin layer of lubrication oil covering each mercury trough should substantially reduce evaporation of mercury. It was necessary, then, to study the effect of the oil layer addition to the mercury trough resistance reproducibility. A dummy sensor having a 105.5-ohm resistance out of circuit was placed on the module as in the previous experiment. Ten trials were performed using no oil and repeated with the oil covering the troughs. The lack of reproducibility of the resistances due to the added oil is evident by comparing the results listed in Table I.

The results of this experiment indicate that the addition of oil to the mercury produced random increases in the conductor resistance, and for that reason should not be used.

DISCUSSION

Probably the most controversial design aspect of the system is the mercury trough connector. The use of the solid-liquid-solid connection was chosen over sliding contacts due to the variability of electrical contact resistance of the latter, resulting from dust collection and corrosion. Even with a heavy dust layer on the mercury, electrical connection using this technique was unaffected. Great care in handling mercury in the greenhouse is required, but it is felt that with adequate ventilation, the accumulation of mercury vapors in the atmosphere will be negligible, as the surface area of the troughs is small.

TABLE I EFFECT OF OIL LAYER ON MERCURY TROUGH RESISTANCE

	Resistance (ohms) of dummy sensor in circuit	
Trial	No oil	Lub. oil
1	105.8	106.3
2	105.6	117.4
3	105.7	107.5
4	105.6	111.1
5	105.6	127.1
6	105.6	105.9
7	105.6	106.8
8	105.8	106.0
9	105.6	108.9
10	105.6	110.7
	Mean = 105.6	Mean = 110.8
	SD = 0.0850	SD = 6.726
	SE of mean = 0.0269	SE of mean = 2.127

The total cost of the complete system cannot be accurately estimated, as it will vary with sensors, amplifiers, recording devices, and length of track used. However, the material cost of the transmitter, receiver, and carrier is approximately $500. The cost of the two-railed track is about $1.00 per foot, not including the transmission cable.

SUMMARY

One of the major problems encountered in collecting data for use in analyzing the internal environment of a greenhouse is the time required to read and record the many environmental parameters. This problem severely restricts the analysis of factors affecting the environment by limiting the number of locations that can be conveniently sampled and the frequency with which each location can be sampled. The time and cost factors also limit the number of parameters that can be measured at each location.

A sensor-carrying module has been designed and developed that will automatically measure environmental parameters at any number of predetermined points along a fixed track. The module is capable of sampling 15 variables at a single location and transmitting via one cable all 15 signals for interpretation by a main decoding and recording station remote from the module.

The sampling rate for 15 parameters per location is approximately one location per minute, which is considerably faster and less expensive than other methods.

Originally the design was intended for use in the greenhouse, but there is no reason why it may not be incorporated into other agricultural buildings such as poultry barns, where environmental gradients exist that could be monitored.

ACKNOWLEDGMENTS

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