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THE USE OF ELECTRONIC MEASURING TECHNIQUES IN AGRICULTURAL RESEARCH

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SUMMARY

This paper describes the general principles of physical measurement using electronic techniques, as applicable to plant and animal research. It gives some examples of the type of transducer units available, and describes some of the means whereby these units may be extended in their applications. Several measuring systems; using these techniques, are described.

INTRODUCTION

To WORKERS in the biological sciences, there must be a certain mystery in the measuring techniques and methods currently used in the physical sciences.

Certain fields such as that of electronics have advanced so rapidly in the past few years that their application to biological sciences have barely begun to be appreciated.

Research workers in these sciences must frequently ask themselves these questions:

(1) What are the principles underlying these new techniques?

(2) What are the most generally useful types of electronic equipment for biological work?

(3) What are their applications in plant and animal research?

(4) What are their advantages?

In this paper an endeavour will be made to answer these questions as clearly and concisely as possible.

GENERAL PRINCIPLES OF PHYSICAL MEASUREMENT USING ELECTRONIC METHODS

The most common measuring technique employed is illustrated schematically in Fig. 1. Such a measuring system consists of three essential parts:

(1) A transducer.

(2) An electronic amplifier.

(3) A display unit or recorder.

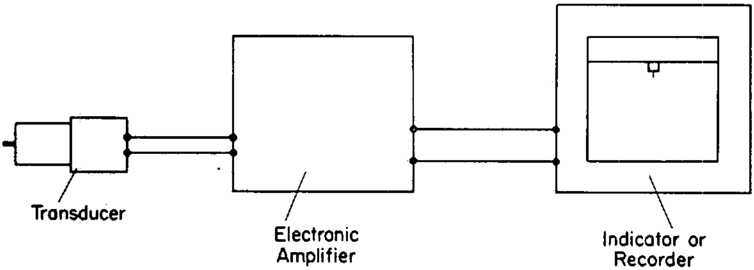

Fig. 1: Schematic diagram showing the three essential components of an electronic measuring system.

The Transducer

The transducer is simply a device which converts one physical variable into another. Most commonly it is an "electrical transducer", which converts a physical variable into a corresponding electrical change.

The advantage in the conversion of a physical variable into a corresponding electrical one lies in the use which can be made of electronic techniques to bring about large amplification of small electrical changes.

The Electronic Amplifier

The electronic amplifier is a device which permits small electrical changes to be amplified to any required level. Even very modest amplifiers can have an amplification of tens of thousands of times. These same techniques can also provide very large power amplification, so that exceedingly small electrical changes can be made to control virtually unlimited power.

The electronic amplifier, then, is a convenient and flexible means of magnifying even very small electrical changes so that they can control robust indicating and recording equipment.

The Indicator or Recorder

This unit, usually with its own amplifiers built in, permits the variable either to be followed visually, or recorded with great accuracy on a moving chart. Many recording techniques are available. The choice depends largely on the recording speed and the sensitivity required. They range from the low-speed chart recorders, running in inches per day, up to high-speed cathode ray oscillographs where times are measured in microseconds. In between these two extremes are those of more general application, operating in inches per minute.

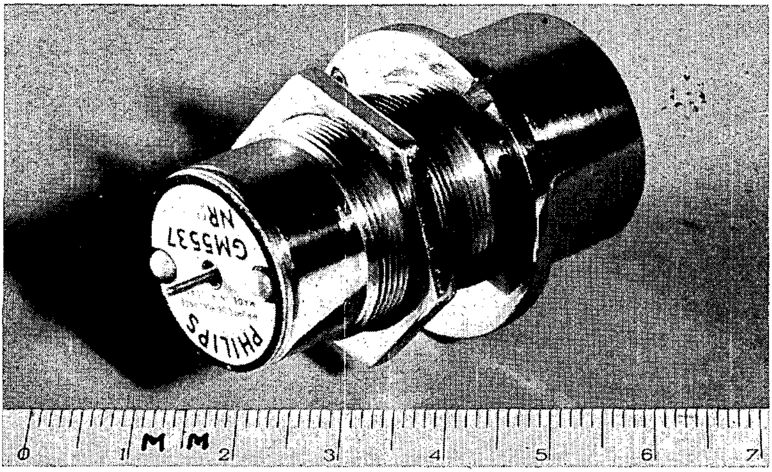

Fig. 2: The Philips Displacement Transducer. This versatile unit is capable of measuring a large number of physical variables.

TYPES OF TRANSDUCER

There are many types of transducer, and new ones are continually being developed as measuring needs arise. Many are in everyday use, although most people may not have thought of them as transducers. They include the microphone which transforms small air pressure changes into equivalent electrical changes, and the gramophone pick-up, which transforms small displacements into electrical changes.

Other less familiar types will be mentioned briefly under the following headings:

Displacement Transducers

These are particularly versatile and have many applications in the measurement of forces, weights, pressures, movements, flow-rates, etc. A unit which has been used very successfully in a number of applications is shown in Fig. 2. This is the Philips Displacement Pick-up. This unit, with its associated amplifier, permits the measurement of displacements or movements in the range from 1 mm to 1/10 micron. The unit consists of a small core of magnetic material carried on a spindle supported on two very light leaf springs. This magnetic core can move along the axis of three small coils which carry a high frequency current. The displacement of the core relative to the coils produces changes in the electrical output from the coils.

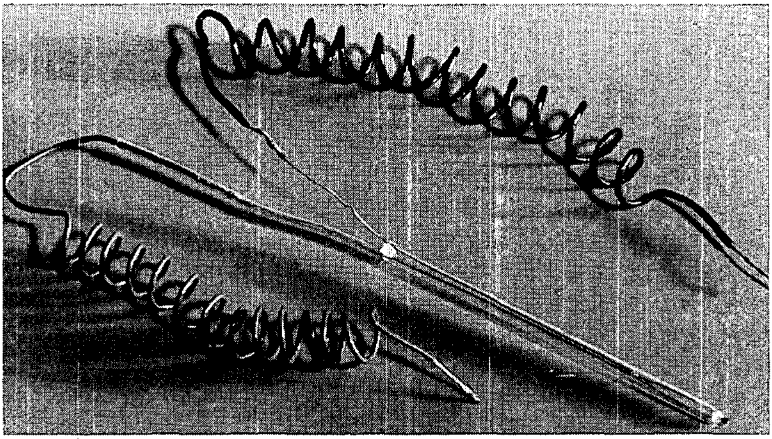

Fig. 3: An example of a heat transducer. A thermistor, showing the sensitive element at the tip of the glass probe.

Heat Transducers

Many types are available in this field, such as resistance thermometers, and thermocouples. More recently the thermistor has been devised, and it provides a large increase in sensitivity. A thermistor is a temperature-sensitive resistance of very small size. An example is shown in Fig. 3. The sensitive element is the small spot at the end of the glass probe.

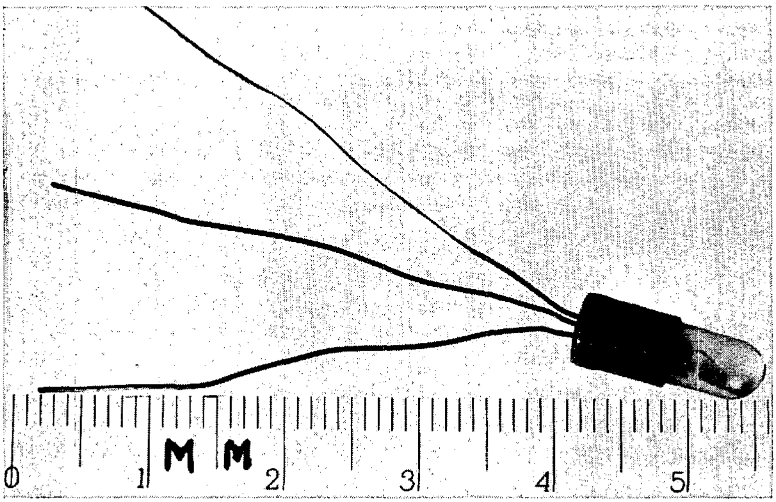

Fig. 4: An example of a photo-transistor, showing its small size. These units are very sensitive and have a variety of uses.

Light Transducers

The photo-electric cell is an example of this type. More recently the photo-transistor has been introduced, following the extensive advances in semi-conductors. The photo-transistor is of high sensitivity and is very small in size as seen in the example in Fig. 4. These units will certainly find many applications in plant and animal measurements where light intensity is of importance.

Transmission by Transducers

One of the advantages of electronics is that the data can be readily transmitted from the measurement site to the recording unit.

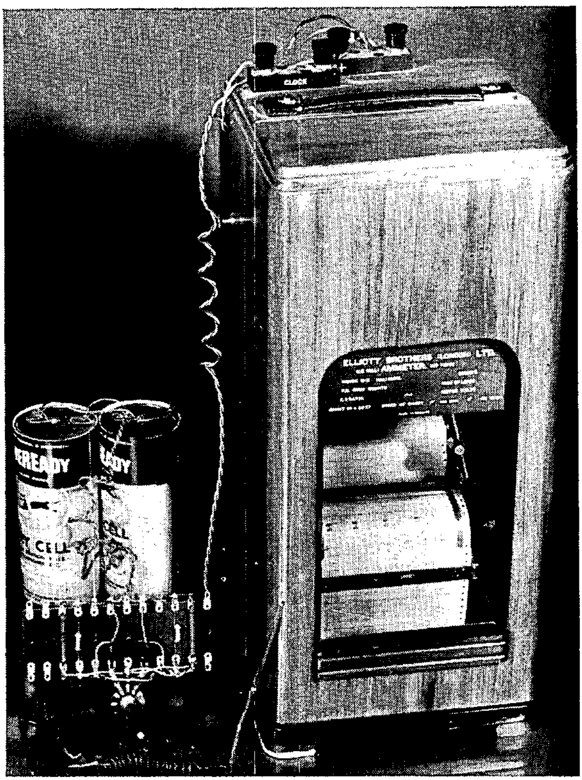

Fig. 5: An example of a measuring system. A thermistor thermometer (bottom, centre) with its associated transistor amplifier and recording milli-amp meter.

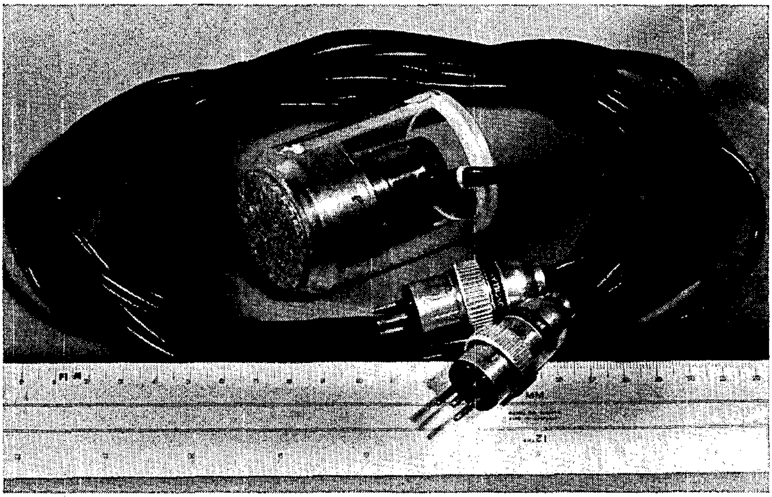

Fig. 6: Intra-mammary pressure measuring transducer unit, based on the displacement transducer shown in Fig. 2. This unit can be connected by the cable to an amplifier and chart recorder similar to those depicted in Fig. 7.

While this is usually done by means of cables, as seen in Fig. 6, it can also be accomplished by means of a radio-frequency transmission as used in telemetry.

A recent addition to the commercially available measuring units uses this principle. This is the Solartron pressure and temperature transducer. This unit, designed to measure internal pressure and temperature in the body, is made in the form of a small capsule no more than an inch long and ⅜ inch wide. The resultant data signal is picked up by a radio receiver placed at some distance. The virtues of such a unit will be apparent to researchers in both plant and animal sciences.

EXAMPLES OF PRACTICAL APPLICATIONS

The following are a few examples of measuring systems taken from equipment used in the Ruakura laboratory.

A thermistor thermometer is shown in Fig. 5, together with a transistor amplifier and recording milli-amp meter. A system of this type is very versatile and sensitive. The small size of the measuring element permits localized temperature changes to be followed readily.

Frequently it is necessary to use a transducer to measure some factor for which it is not specifically designed. An ex-

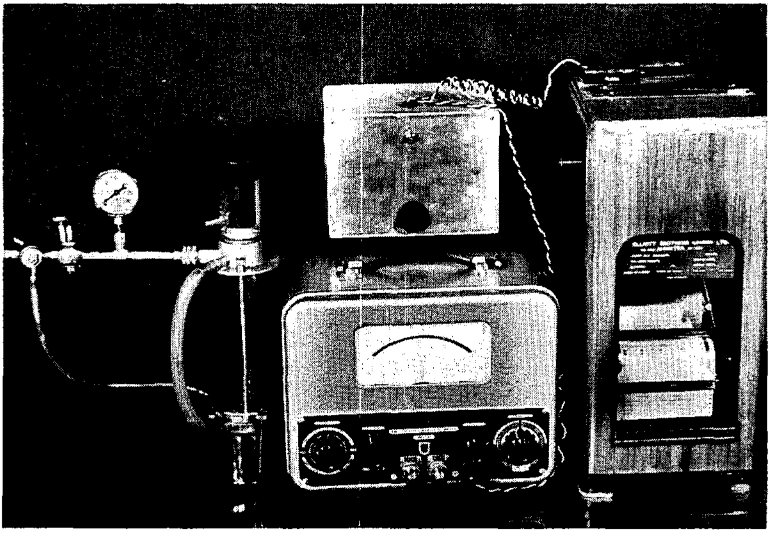

Fig. 7: A milk-flow measuring unit with the measuring head connected to the amplifier system and the recording milli-amp meter. With a medium speed chart drive, this system can follow the milking rate from a single teat through a single cycle of pulsation. The displacement pick-up is in the base of the modified teat cup.

ample of this is the measurement of pressures by means of a displacement pick-up. In this case the pressure is first transformed into a movement by the use of a leaf spring or a metal diaphragm. An example of this is seen in Fig. 6 which shows a pressure transducer unit recently designed in the Ruakura laboratory. This unit is being used to study intramammary pressure changes during letdown and milking. The sensitivity of the unit can be adjusted to measure from two inches of water pressure full scale, up to over 20 ft of water pressure full scale. The change of sensitivity range is accomplished simply by changing the range selector switch on the electronic amplifier.

It is interesting to note that the power amplification in this instrument is of the order of several millions.

Figure 7 shows a high-speed milk-flow recording unit with its associated amplifier and chart recorder designed for milk-flow measurements from a single teat. This unit employs a displacement pick-up, this time as a highly sensitive weigh bridge, and it can follow the flow of milk during individual milking strokes, which occur at rates of over 40 per minute. Using a chart speed of 18 inches per minute, it is possible to measure the changes in the rate of milk-flow during a single cycle of pulsation.

ADVANTAGES OF THESE TECHNIQUES

Physical electronic measuring techniques have the following advantages:

(1) They have extremely high sensitivity, allowing accurate measurement and recording of variables of very small magnitude.

(2) They permit the measurement of variables in remote or inaccessible places.

(3) The transducer unit can be of very small size so that its presence has very little effect on the object under study.

(4) The high sensitivity and power amplification possible permit the use of transducer units requiring very little operating force so that they do not load the source of the variable under study appreciably.

(5) These techniques permit the continuous, accurate, recording of physical variables. The measurement system can be virtually frictionless and therefore extremely smooth in operation.

(6) With the use of power amplification the rate of change of a variable presents no problem, and even heavy pen carriages on recorders can be moved the width of a 10 in. chart in a fraction of a second.

(7) A small physical variable can be used to control a large amount of power, thus permitting accurate control of factors such as temperature, and flow-rate.

(8) The measured data can be readily transmitted from the site of measurement to any convenient site for recording or indication without loss of sensitivity or accuracy.

CONCLUSIONS

In plant and animal research, the investigator very frequently encounters conditions which make conventional methods of physical measurement almost impossible to apply. The advent of a range of miniature, sensitive transducers, and the associated electronic amplifying and recording equipment can make it possible to carry out these measurements with great precision and under very difficult conditions.

The flexibility of these instruments permits their use in a variety of applications and their use generally is so simple that even untrained persons can use them with ease.

In the initial design of a measuring technique it is frequently necessary to employ the services of an instrument engineer, but, once the equipment is in operation, the application usually requires no particular knowledge of electronics.

The animal and plant scientist could undoubtedly benefit greatly from a knowledge of the scope and application of these techniques, and a consultant instrument engineer attached to a research establishment could be extremely useful in many fields of investigation.

DISCUSSION

Q: *Does the tremendous amplification used in these techniques introduce a possible source of error—e.g., through variations in cables joining transducers to amplifiers and to recorders, and in other ways?*

A: The length of cables can affect the speed of response of the recording equipment unless care is taken to use cables and terminations suitable for the purpose.

Q: *The simplicity of these techniques may lead to the amassing of very large amounts of recorded data. Is it possible to use the recording apparatus to prepare the data for analysis by electronic computors?*

A: Electronic evaluation of recordings can sometimes be carried out at the time of recording, to advantage. An example is the use of differentiating circuits to measure the rate of change of the variable under study.

More often, however, it is advisable to study the complete recording and evaluate the particular factor under study before processing is commenced. Many other possibly important aspects of the problem can then be considered.

Q: *In the measurement of intra-mammary pressure, how is the transducer held on to the udder at a constant pressure?*

A: The transducer unit is held against the udder by hand. This does not cause serious error unless the pressure applied is sufficient to deform the lower udder and thus alter the milk pressure. If the face of the measuring unit is kept in firm contact with the udder wall, the errors due to hand pressure are much less than those arising from casual body movements of respiration, etc. It would be possible, of course, to hold the unit in position by means of a vacuum ring, a technique which has in fact been used.