Introduction

Profiles of temperature and dissolved oxygen concentration are routinely taken in three lakes in the English Lake District as part of the Freshwater Biological Association's long term research programmes. These measurements are normally taken every week during summer months and every fortnight during winter months. This has given the FBA valuable long-term data sets which, when combined with meteorological, chemical and/or biological data, can be used to test models and provide evidence of trends and cycles (e.g. George & Harris 1985; Heaney et al. 1988). Profiles of these and other parameters are also required as basic data for a whole range of short term field studies. Until recently, these data sets have been gathered by scientists using a number of commercially available instruments, each independently powered and with its own probe system and meter (e.g. Heaney & Talling 1980; Jewson et al. 1984). This method is cumbersome and requires great discipline by the scientist. Talling (1981) has discussed some of the problems in the context of the advantages of an earlier type of profiling instrument. In adverse weather conditions, there is a temptation to record readings before the probes have equilibrated and the analogue meters are always difficult to read in a rocking boat.

It was clear that such data could be gathered more easily if measurements could be made using a single instrument and with at least a degree of automation. The design of such an instrument should permit the addition of further transducers when required. A completely unmanned, fully automatic...
system was considered, but there are several reasons why this is not the best solution:

1. A scientist may notice scientifically interesting aberrations from a normal data set and take extra readings or notes as required;
2. Water samples for later biological and chemical analysis are usually collected at the same time as these measurements;
3. Dissolved oxygen electrodes require a daily calibration check. This would require a costly and elaborate field set up.

The Profiler Concept

Developments in microelectronics and computing in recent years have made hand-held microcomputers available at quite modest cost. At least two models (the Husky Hunter and the Microscribe) are available in environmentally sealed housings. It was realised that an instrument based on such a microcomputer could provide a solution. The electronics requirement for such an instrument could be kept relatively simple, since a computer program could not only store the profile data, but also perform the calibration and temperature compensation functions. This would dispense with the need for any adjustment of the circuitry. Through the use of software it would be possible to advise the operator whether the probes have equilibrated, graph the data on the microcomputer screen and recall earlier data sets in the field. The 'Profiler' concept was born.

Requirements of a Profiling Instrument

The immediate requirement was for an instrument that could measure temperature, electrical conductivity, dissolved oxygen concentration, light attenuation and the sampling depth. The instrument should preferably require one person to operate and be suitable for deployment from small craft. Any power requirement must be met entirely by internal batteries. The instrument should be easy to use and at least match the accuracy of available commercial instruments. It should be capable of being used in any lake in the Lake District and therefore be able to withstand submersion to 90 m. For convenient use in shallow lakes and rivers, it is desirable that the cable from the probes to the surface is interchangeable with shorter cables. The unit should operate under the complete range of environmental conditions occurring in the Lake District (including extremely heavy rain!) and not be significantly affected by variations in ambient temperature in the range -10°C to +40°C.

Traditionally, the Electronics department of the FBA has designed specific instruments to meet specific tasks. However, in 1986, it was decided that an alternative approach be adopted to design a flexible system. It would then be possible to adapt the circuitry (and large sections of the computer program) to suit a wide range of tasks, reducing the design effort needed for a range of related instruments. Thus, the design of the profiling instrument should not only meet the requirements of its potential users, but also incorporate the following ideas:

1. Modularity – to allow easy expansion and alternative sensor configurations;
2. High resolution – even if not immediately required, a high basic resolution would give greater flexibility in accommodating any further measurements;
3. Switching – the computer software should be able to control power to the instrument, allowing future development of a data logger based on the same technology;
4. Control – capability to switch external circuits (such as a dissolved oxygen probe stirrer) under computer control.

The final design met all of these criteria. In particular, the modular approach allowed the bulk of the circuitry to be committed to printed circuit boards which can be used whatever sensor configuration is required for a particular unit.

Design Considerations

At the outset, we had to decide whether to locate the electronic circuitry (which converts the probe signals to a digital form for communication to the microcomputer) at the lake surface or near the probes at depth. Keeping the electronics at the surface has the advantage that it would be cheap and easy to house. However, an important design requirement was to allow interchangeable cables to the probes at depth. If the electronics were located entirely at the surface, an expensive multi-core cable and underwater connector pair would be required. Each probe would require recalibration whenever cables were changed due to the change in electrical characteristics (principally resistance) of the cable. The use of long cables to carry low level analogue signals is also poor design practice as such a design will be inherently susceptible to electrical noise and interference.

For these reasons, it was decided to locate the electronics in an underwater housing and mount the probes on this housing with short lengths of cable. Serial digital communications would be used to provide the link to the surface. This simplified the cabling to a 4-core cable and the connector requirements to a 4-pole underwater connector pair, irrespective of the number of probes attached. As the signals were in digital form, there would be no effect on calibration if an alternative length cable were used to connect from the surface to the deep water unit.

This electronic circuitry has to be protected from the ingress of water under pressure from a head of up to 90 m of water. It should be accessible, to allow
serving, if this is ever required. These two needs are met by housing the circuitry in a stainless steel case, which is filled with petroleum jelly. The external pressure is transmitted to the jelly through a neoprene gasket. To gain access to the circuitry for servicing, the gasket is removed, the unit is heated and the jelly poured out.

In some circumstances, such as the calculation of light attenuation coefficients, it is necessary to take simultaneous measurements at the surface and at depth. It may also be desirable to provide a socket at the surface suitable for connection of any other instrument's chart recorder output. This feature can be used to integrate a commercial instrument into the system. A unit containing the electronics required to digitise the measurements at the surface, to communicate with the hand-held computer and to relay communications between the microcomputer and the deep water unit is sited at the surface. This also contains the battery for the entire system. The deep water unit contains the electronics required to communicate with the surface unit and digitise the measurements taken at depth. Fig. 1 shows the complete system, comprising the hand-held microcomputer, the surface unit and the deep water unit. Although the profiling instrument only requires two probe interface units (the surface unit and the deep water unit), the design permits any number between one and sixteen probe interface units to connect to a single microcomputer linked, one unit to the next, by just a four-core cable. This could have applications for logging data from a number of sites 100 m or more apart.

The Electronic Circuitry

The electronic circuitry is assembled using specially designed printed circuit boards. All components used in the system are rated for use over the temperature range \(-10^\circ C\) to \(+65^\circ C\) and most exceed this. The circuitry used in the final design separates functionally into four sections:

1. Digital communications;
2. Analogue to digital conversion;
3. Analogue signal processing (prior to digitisation);
4. Power supply.

The digital communications use the RS232 standard and this allows the electronics to interface with almost any commercially available computer. This digital communications link is extremely insensitive to electrical noise and interference. The microcomputer sends coded instructions via the communications link to the probe interfaces (that is the surface and deep water units). This instruction might be a command, such as digitise all channels, or it might be a question requiring a response from a probe interface, such as what was the result of the last digitisation of a particular channel?
The digitisation is performed by a device called an integrating analogue to
digital converter. One of these devices is used for each channel. This
integrates the applied analogue signal for 200 ms before digitising, which
substantially reduces the effect of any high frequency noise in the system. It
also virtually eliminates the effect of interference from any nearby mains
supplies, since a whole number of mains cycles are contained in the
integration period. The basic resolution of the conversion is better than 1 part
in 30,000. This is more than adequate for environmental measurements. By
exceeding the requirement for any conceivable channel, all channels can use
identical conversion circuitry. The system is virtually free of drift caused by
changes in ambient temperature. The main factor determining the tem-
perature stability of the system is the stability of a voltage used as a reference
by the integrating converters. The design ensures that this voltage is stable to
within 3 ppm per °C. Thus, a 10°C change in ambient temperature is required
before any effect is detectable. In practice this causes no problems and is
significantly better than most commercial instruments. The use of one
converter per channel guarantees true simultaneity of readings and no
possibility of interaction between channels.

The design of the signal processing electronics has been kept as simple as
possible. Software is used to perform calibration, linearisation and tem-
perature compensation functions, so component costs can be kept to a
minimum.

Power for the system is supplied by a single 12 V sealed lead-acid battery
housed in the surface unit. This allows more than 20 hours of profiling
between recharges. (A 12 V pack of ‘C’ or ‘D’ cells can be optionally used).
From this +10 V, +5 V, -5 V and -10 V supplies are derived for the rest
of the circuitry. The microcomputer memory used to store the profile data
has a separate battery back-up which will ensure that data is retained for
many months.

The Computer Program

Much of the design effort concerned the computer software which runs on
the hand-held microcomputer. The program was designed to be as far as
possible intuitive to use.

The two commercially available, environmentally sealed, hand-held micro-
computers which have been used as part of the profiling instrument are
functionally very similar. They are based on the CP/M operating system and
thus the program can be developed using a full-size microcomputer and
transferred to the hand-held microcomputer in the later stages for testing.
They each possess a screen capable of displaying 8 rows of 40 characters
using liquid crystal display (LCD) technology and a full, but miniature,
keyboard. Both hand-held microcomputers dispense with the idea of
removable floppy diskettes by using a silicon disk. This is a low power,
semiconductor memory (with its own battery back-up) which is designed to
operate as if it were a floppy diskette. Various capacities of silicon disk are
available, but a typical system includes capacity for storing about 20 profile
data sets, with a limit of 5000 readings for any particular profile.

The software is designed so that the scientist using the instrument selects
operations from a list of possibilities (the ‘menus’). Once an operation is
selected, the scientist may be asked to respond to questions with simple ‘yes’
or ‘no’ answers or to provide and type in, for example, a name for a particular
data set. Since every option is displayed on the computer screen, the scientist
does not have to remember the operating sequence in order to use the
instrument.

In addition to the ability to store data, a major benefit of basing the
instrument on a hand-held microcomputer is that the computer program can
monitor successive readings on each channel and advise the operator when
each of these becomes steady (and hence whether the corresponding probe
has equilibrated). The software deems a channel steady when the most recent
reading lies inclusively between the previous two. A channel remains steady
until a subsequent reading falls outside an error band. A further useful feature
is that an error band appropriate for the conditions at the time readings are
being taken can be set automatically in the field. To do this the operator
holds the probes at a fixed depth for a period until it is certain that they will
have equilibrated. The microcomputer monitors the readings on each channel
for a while. By analysing these readings, it fixes suitable error bands for each
channel. These can be optionally overridden and values for the error band
associated with each channel entered manually.

The program is written in Digital Research MT Plus Pascal. This is a ‘native
code’ compiler and so can be used to produce programs which run rapidly,
while allowing the programmer to use software engineering techniques to
produce a relatively easily maintained piece of software.

The Operation of the Computer Software

In the field, the instrument can be set to operate in one of three basic
modes:

1. Display Mode

In this mode, the microcomputer simply continuously reads all selected
probes and displays the readings on its screen. The operator is advised
whether each reading is steady. This is shown in Fig. 2. Steady readings are
indicated by the letter ‘S’. Readings are updated two times per second.

2. Profile Mode

Profile mode is used in the field to take and store a sequence of readings
and sort them into depth order (this is what is meant by the term ‘Profile’). It
involves a series of steps. The operator is asked to enter a title for the profile

3. Data Transfer Mode

In this mode, the microcomputer transfers the stored data to a
hand-held microcomputer. The program was designed to be as far as
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(to distinguish this data set from any others stored). He or she next selects his or her name from a menu of names (optionally adding a name to the menu). The date and time are automatically stored. The program operates as if in display mode, but with the following extra facilities: store the current set of readings; list all of the readings stored in this profile so far; list the rate of change of one parameter against depth and graph one parameter against depth on the microcomputer screen. Once all of the readings are stored, a memo can be entered and is stored along with the data set.

3. Review Mode

The user may retrieve any stored data set in the field with options to: list readings; graph a parameter against depth; display the rate of change of any parameter with respect to depth; transfer a particular data set to a printer or laboratory based computer and delete a particular data set.

Two additional modes would normally only be used in the laboratory:

1. Calibration Mode

A full calibration is only normally required before the first ever use of the instrument or following the replacement of a probe. The probe to be calibrated is placed in a controlled environment (such as a water bath for a temperature probe). The hand-held microcomputer reads the directly digitised value from the probe interface. The operator enters the known value corresponding to the conditions under which the probe is held. This procedure is repeated for several values in the range over which the operator wishes to measure in the field. The hand-held microcomputer will use this table of calibration points and automatically interpolate between the nearest two points.

Special arrangements are made to allow a single point calibration of the dissolved oxygen cell. This provides compensation for day to day changes in sensitivity of the cell. (Commercial versions of both the Mackereth and Clark dissolved oxygen sensors are susceptible to these sensitivity changes. See e.g. Dawson & Henville, 1985.)

The depth sensor actually measures the sum of the atmospheric pressure and the water pressure. Since atmospheric pressure can vary even on the same day, a zero depth calibration is normally performed just before recording a profile.

2. Transfer Mode

All stored data sets can be transferred to a printer or laboratory based computer for further processing.

The 'Windermere Profiler' in use

As can be seen from Fig. 3, only one person is required to operate the 'Windermere Profiler'. In addition to the two units in use at the FBA's Windermere Laboratory, five instruments have been sold to UK water authorities, with further instruments sold or hired by a university, an environmental consultancy company and a research institute. The 'Windermere Profiler' has been used for estuarine studies of the River Mersey and River Thames and for lake work in Zimbabwe, Turkey and the Antarctic. Some typical profile results are shown in Fig. 4.
WINDERMERE NORTH BASIN (Slope Scar)
15 August 1988 13:16 hrs

Temperature (°C)  Dissolved Oxygen Concentration (% saturation)  Conductivity (µS cm⁻¹) corrected to 20°C

DEPTH (m)

FIG. 4. Some typical results, taken using the ‘Windermere Profiler’ instrument.
Future Developments

Although the 'Windermere Profiler' is generally well liked by operators and is proven in the field (e.g., George, 1988), development of the profiling and related instruments continues. Enhancements are being considered, following comments from those using the instrument, and to take advantage of newly available technological advancements in the fields of electronics and computing.

The use of a cylindrical plastic housing for the deep water unit is being investigated. This would be cheaper and lighter than the stainless steel housing used at present. The physical size of the deep water unit would be reduced through the use of Surface Mount Technology. This is a construction technique allowing the use of smaller electronic components and offering improved reliability.

A prototype low cost multi-spectral light sensor for underwater use (shown in Fig. 5) has been constructed. This can be used to measure the relative transmission of four specific wavelengths of light, as recommended for primary production studies (e.g., Talling 1971; Jewson et al., 1984; Westlake 1986). It is also intended to add pH and turbidity measurement to the 'Windermere Profiler'. A problem in adding the measurement of pH is the selection of a probe that is rugged, suitable for environmental freshwaters and operates correctly when exposed to the pressure shock of being submerged to depths of 90 m or more. This is being pursued at present. A commercial turbidity probe has been successfully used with the system, although we hope to produce a novel turbidity sensor for field trials this summer.

Much of the technology used in the 'Windermere Profiler' was designed with a view to wider applications. Recently the FBA has had a number of in-house needs for specialist data logging equipment, which have been met using variants of the profiling instrument. It is hoped that, subject to satisfactory field trials, a versatile data logging system will be made available for sale later this year. The 'Coniston Logger' will include such features as different data capture rates on different channels and support for up to 56 channels. It is hoped to include a facility to vary data collection rates depending on the data being read. The operator could describe using quite complicated rules, what would constitute an interesting event. The logger would monitor the channels, perhaps storing data at a low capture rate, but would switch to a faster capture rate during the interesting event.

Further details

The Electronics Department produces a range of equipment from a Magnetic Stirrer to the 'Windermere Profiler'. If you would like a price list and further details of the 'Windermere Profiler' and the full range of electronic products available from the Freshwater Biological Association, please contact:

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REFERENCES


