A WATER QUALITY MONITORING ROBOT

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Abstract

The electronics package for a new Water Quality Monitoring system is described. Designed for use in rivers, lakes and estuaries, this versatile automaton can replace costly manual methods with automated in situ measurements and water samples. Eight selectable sensors and a 16 cell water sampler are programmable for unattended operation. Underwater communications to a surface Control Station permit collection of data and rescheduling of measurements without the need to retrieve the submerged Buoy. The automated in situ measurements provided by this robot-like system can provide early warnings of water pollution, quantitative results for regulatory action and capabilities for scientific studies heretofore unavailable.

Introduction

The increasing importance of water quality and the need to provide scientists with repeatable and error-free measurements have spurred the development of this new Water Quality Monitoring system. It has long been recognized that manual methods of measurement are expensive and prone to human error. Moreover, manual data collection around the clock is not practical in many situations. Yet, continuous monitoring is essential to pinpoint the causes and effects of isolated events. Based on the cost of manual data collection in the past the Water Quality Monitoring robot could pay for itself during its first launch period.

The advent of microprocessors and of non-volatile magnetic bubble memories has permitted the development of this automaton. The system may be left unattended for two weeks or longer. Up to 12,000 measurements may be stored in the system. Remote underwater communications are available to gather data, to reprogram the automaton and to command the submerged Buoy to surface. Programming of the measurement schedule and all commands originate at the surface Control Station. The measurement of each parameter is programmable in terms of time of day, intervals during the day, bursts of measurements within a specified interval, or on the basis of an alert triggered by another parameter. An alert example is the collection of a water sample when the level of dissolved oxygen drops below a threshold value.

It was the goal of this development to use commercially available sensors. These were adapted to in situ measurements. Flexibility to incorporate additional sensors to effect different measurements is built into the Water Quality Monitoring system.

A block diagram of the system is shown in Figure 1. When launched, the robot-like Buoy releases itself to a preset height off the bottom. While the Buoy is at work performing its appointed tasks, this condition is signaled acoustically through the water. Upon interrogation from the surface Control Station, the Buoy transmits the results collected to-date. Once transmission is completed without errors, the Buoy returns to its appointed tasks.Rescheduling of measurements may be accomplished from the Control Station via the acoustic or cable command link. Upon completion of its work, the Control Station commands the Buoy to float to the surface for recovery. An automatic self-test routine allows the system to check its calibration daily.

In the Control Station, complete flexibility for data organization and presentation of results is provided. A liquid crystal display and a printer are incorporated.

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OVERALL SPECIFICATIONS

Operating Depth:	Submerged to 100 ft max.
Sensors:	Temperature Pressure Conductivity pH ORP(Redox) Dissolved Oxygen Fluoride Turbidity plus 16-cell water sampler
Length of Operation:	14 days
Data Points:	12,081
Data Retrieval:	Via acoustic link inside a cone of approximately 45 deg. in open waters or via a direct cable link.
Data Identification:	Buoy (Station) Identification, Parameter name, Units of measurement, Time of event in days since launch, hours and minutes of day. Calendar date and time of launch are also shown.
Buoy	
Size:	20 in dia. x 5 ft. height
Weight:	130 pounds total with anchor
Control Station	
Size:	21 in. x 13 in. x 6½ in. attache case
Weight:	20 pounds

Description of Subsurface Buoy

A block diagram of the Buoy electronics is shown in Figure 2. The Buoy controls eight sensors, a 16-cell water sampler and a Release mechanism.

The Buoy receives the schedule of measurements and all commands over the acoustic or the direct cable command link. The Data Link block decodes the received digital bit stream. After checking for errors, the housekeeping bits are stripped and the remaining information bits are presented to the CPU. The CPU is an 1802 microprocessor based system. The 1802 is of CMOS construction; the low power consumption of CMOS permits long term battery operation.

The CPU subsystem consists of the 1802, two 512 x 8 RAMs, twenty 512 x 8 EPROMs to hold the software program, a timer, and Input/ Output circuits to handshake with the rest of the Buoy electronics. The twenty EPROMs hold a 10,000 step software package. When a command is received in the Data Link, the CPU interrupts its schedule and turns its attention to the received command which originated at the surface Control Station. The CPU has a hierarchy of priorities and will allow the Buoy to perform only one task at a time.

When a measurement is desired, the corresponding sensor is activated by a signal from the CPU to its interface circuit. The measurement is performed by the sensor, as well as other sensors, such as temperature, used for secondary corrections. The output of each sensor is buffered in the signal conditioning circuit and isolated from the sensor interface by floating supplies and optoisolators. The sensor interface translates the analog voltage into a serial digital stream and presents it to the CPU.

The CPU computes the true value of the measurement using the secondary parameters

LIST OF SENSORS				
Parameter	Manufacturer	Units	Range Measured	Resolution
Temperature	YSI Thermistor probe 710	Degrees C	-2 to +35	$.2^{\circ}$ C
Pressure	Bell & Howell CEC 1000	kg/cm^2	0 to 5 ABS	2 %
Conductivity	Neil Brown-4 Electrode	umho/cm	0 to 100,000	3 %
pH	Great Lakes pH 60	pH	2 to 12	.1
ORP (Redox)	Great Lakes ORP 60	mV	-1000 to +1000	5 mV
Dissolved O_2	Beckman Fieldlab 39552	mg/l	0 to 20	2 %
Fluoride	Beckman Fieldlab 39600	mg/l	Activity to 10^{+3}	10 %
Turbidity	Ecologic 204A	NTU	0 to 100	.2 NTU

and equation specified by the sensor interface. The CPU compresses the sensor identification, true measured value and time of measurement into a 29 bit word for each data point. The data is sent from the CPU to the storage unit, which is the magnetic bubble memory, or MBM.

The bulk of the MBM is used to store data points. Data is organized in blocks and pages in the MBM. The measurement schedule, which amounts to only 1% of total MBM capacity, is stored in the non-volatile memory with redundancy. The MBM uses a separate, smaller CPU subsystem of its own. The 1802 microprocessor is used here also. A 1000 step software package supports the MBM.

When the surface Control Station requests data from the Buoy, the CPU in the Buoy first gets the data from its MBM. Formatting and housekeeping bits are added in the Data Link under supervision of the CPU and the information is transmitted to the Control Station serially. The stream is of FSK modulation over the acoustic link and is binary digital over the direct cable link.

The water sampler is activated by an interface circuit controlled by the CPU. Sequencing is performed in accordance with the schedule stored in the MBM. The time of each sample is stored among the data points in the MBM.

The release mechanism is triggered upon command from the Control Station. One of the commands is issued shortly after the initial deployment of the Buoy. This command causes the Buoy to be released from the bottom to its operating height. The command to release the Buoy completely from its anchor is given at the end of the deployment period. At this time, the Buoy floats to the surface for recovery.

The locator pinger operates off its own internal battery and emits a coded tone burst. Its function is to help relocate the subsurface Buoy. A standard commercial acoustic listening device will indicate the direction of the Buoy.

The emergency pinger is turned on when the Buoy is not performing any tasks. This may occur under several different circumstances with the effect of stopping the CPU in the Buoy: the power pack of the Buoy has been used up, a water leak in the enclosure has been detected, the MBM is full of data, or a malfunction in the system. When the emergency pinger is on, the Buoy will not respond to commands or perform any measurements.

Description of Control Station

The Control Station allows presentation of results in organized format, remote communications with the Buoy, scheduling of measurements, and calibration of sensors in the Buoy. A user interactive keyboard and display is provided. Entries and prompting are in English. Thus, the user is provided with a stand-alone system having the power of a minicomputer.

A block diagram of the Surface Control Station is shown in Figure 3. The 64 character ASCII keyboard is supplemented by six special purpose keys. The CPU scans the keyboard for entries. The 16 character alphanumeric LCD display shows all entries line by line. The special purpose "print" key activates the self-contained printer. All program entries and schedules are entered from the keyboard. The supporting software package resident in the CPU prompts the operator on a line by line basis. Full editing capabilities are also included.

Data is retrieved from the Buoy and stored in the MBM. As in the Buoy, the storage capacity is obtained in four 92 Kbit chips. The measurement data received from the Buoy is preceded by heading information. This includes a Buoy identification number, a roster of sensors the Buoy carries, and the latest measurement schedule. This format permits one Surface Control Station to service many Buoys. By means of operator instructions from the keyboard, data is selectively retrievable for display, printout and transmission over the RS 232 link. Selection is made on the basis of station number assigned to the Buoy, parameter measured, and time interval desired. An example of typical data is shown in the printout of Figure 4.

For acoustic communications with the Buoy, a hydrophone is lowered in the water. The hydrophone cable is plugged into the Control Station attache case. The data is transmitted in FSK format. Carrier frequencies of 230 Khz and 153 Khz are used. Modulation rate is 2.88 Kbit/sec. Parity checks are used to detect errors in measurement data. Commands transmitted from the Control Station to the Buoy are repeated by the Buoy. This confirmation is received and displayed on the LCD display.

Automation of sensor calibration is achieved.No internal screwdriver adjustment or potentiometer trimming is needed. A standard solution is presented to each sensor. The true value of the sample is entered from the keyboard. Calibration is then performed internally by the software in the Buoy.

Conclusions

Several tests were run in 1980 in lakes and reservoirs in Virginia and also in Lake Huron. Results on this prototype system indicate that automated measurements provide important scientific and cost advantages over manual methods. The fine structure of the data, the ready correlation of parameter to parameter plots, the repeatability of measurements, and the flexibility in the schedule programming demonstrate capabilities not provided by methods currently in use.

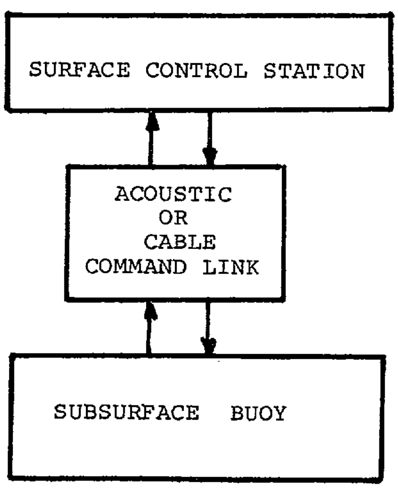

Figure 1
System Block Diagram

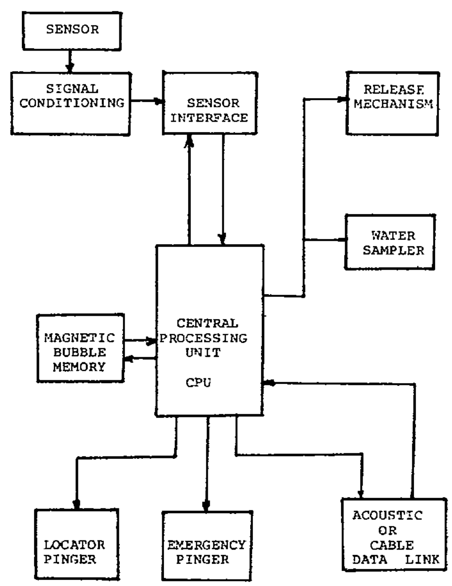

Figure 2
Block Diagram of Subsurface Buoy

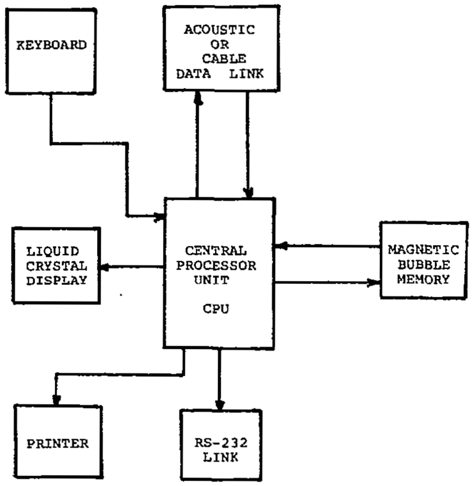

Figure 3
Block Diagram of Surface Control Station

```
01 10:45 + 2.8
01 11:00 + 2.9
LIST SAMPLER 1
FROM 00 11:00
TO 01 12:00
1, DATE 01 31 30
SAMPLER SAMPLE #
01 00:00 +  1.
LIST PRESS 1
SELF TEST
1, DATE 01 31 90
PRESS KG/CM2 ABS
CAL. S/T +3.552
00 23:59 +3.552
LIST PRESS 1
FROM 00 11:00
TO 01 12:00
1, DATE 01 31 90
PRESS KG/CM2 ABS
00012:15 +1.399
00 12:20 +1.399
00 12:40 +1.399
00 13:00 +1.399
00 13:20 +1.399
00 13:40 +1.399
00 14:00 +1.399
00 14:20 +1.399
00 14:40 +1.399
00 15:00 +1.399
```

Figure 4
Typical data from Buoy No 1

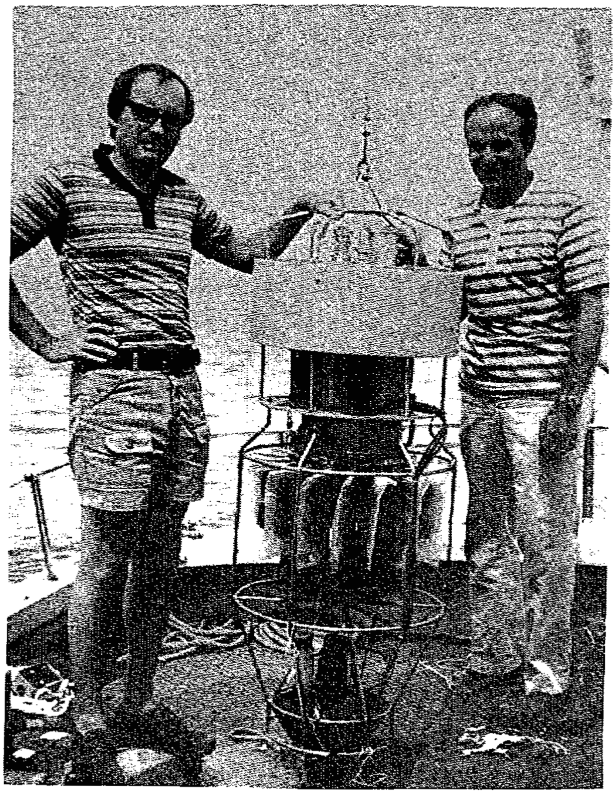

Figure 5
Subsurface Buoy set for launch

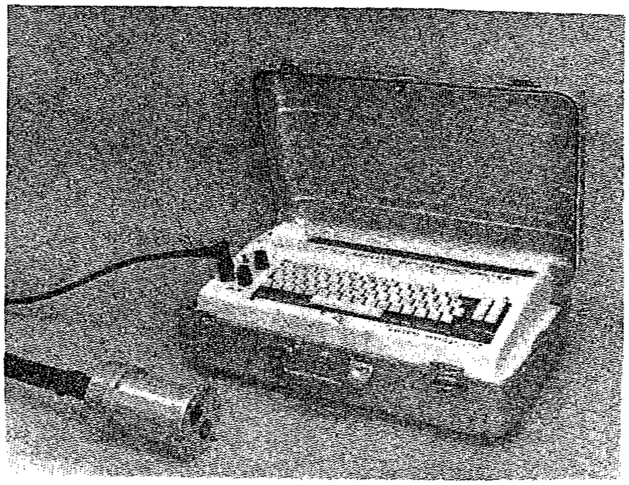

Figure 6
Photograph of Surface Control Station