AUTOMATIC CALIBRATION OF THE SENSORS USED IN A MINIATURE STD INSTRUMENT

TRYGVE GYTRE INST. OF MARINE RESEARCH P.O..BOX 1870 .5024 BERGEN

ABSTRACT.

The paper describes a system for simplified calibration of a new STD instrument.
When measuring, the raw data from the instrument conductivity, temperatue and
pressure sensors are fed into a microprocessor inside the instrument. The
microprocessor computes the calibrated primary data by inserting the raw data into
an equation of the form $Y = A + B.X + C.Xexp2$ where A,B and C are calibration
coefficients.
The new instrument automatically computes and inserts these calibration
coefficients itself when exposed to a temperature bath, a conductivity bath and a
pressure reference with a few known values.

INTRODUCTION

All excact sciences are dependent on quantative measurements.
In order to determine the precicion of these measurements, the instruments that are
used must be calibrated against a known standard or reference.
Many scientific instruments are calibrated too seldom because it is too difficult or
too costly to calibrate them.Simple calibration is therefore important component of
in modern instrument design.
This paper describes an automatic calibration strategy which has been designed into
a new miniature STD- instrument in order to simplify the calibration procedure.

ANATOMY OF A MODERN INSTRUMENT

A modern scientific instrument generally consists of one or several sensors, an
electronic interfacing which standardizes the electric signals from the sensor to a
common voltage or current range, a signal digitizer which makes the information
available for digital processing and a microprocessor .
Fig. 1 shows the basic structure of a modern instrument. The central component in a
modern instrument is the microprocessor.
The microprocessor controls the measurement process, makes necessary
calculations and controls the recording, display or transmission of the results.
To do this the microprocessor must be able to fetch instructions from a program
that is stored in an adressable memory and be able to deliver the results of the
processing to an output device or to a data memory.
Although the microprocessor is credited for its universal functions, it is important

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to realize that the the microprocesor itself is just a slave of its own programs. Since the microprocessor now plays a major role in most measurement functions, modern instrumentation is increasingly becoming dependent on microprocessor programming.

Fig.2 shows a block diagram for the functions of the new instrument. Conductivity, temperature and pressure are detected by individual sensors. The sensor signals are digitized and sequentially scanned by a microprocessor. Each sensor signal is processed according to an individual calibration equation. Each calibration equation has coefficients which have been adapted to the sensor by means of an automated calibration routine.
Finally the measured temperatures, pressures and conductivities are inserted into the "UNESCO"-formula which is resident in the program memory. When the conductivity, temperature and pressure have been calculated according to individual calibration data,
the microprocessor immediately computes the salinity, the temperature and the water depth, Then it records the results in the data memory, displays the data in engineering units, or it transmits the data to a remote terminal via RS-232.

Fig. 3 shows the mechanical design of the new instrument .
The instrument is basically a molded polyurethane cylinder with protruding sensors for temperature ,pressure and conductivity and with a RS-232-plug for communication to the external world.
The specific instrument functions are determined from one of 12 possible sub programs which are selected when the user temporarily connects a programming unit to the RS-232- plug and holds a magnet outside a "START"- position on the instrument.
9 of the possible sub-programs are time interval programs that makes the instrument to measure, process,record, transmit and display one STD-set at repetition rates from one measurement per 5 seconds to one measurement per 3 hours.
One sub program makes the instrument to display unprocessed raw data, one sub program prepares it for slave or master functions when several instruments are working together in a chain, and one sub program is devoted to automatic calibration.

CALIBRATION STRATEGY
The raw data for the instrument are detected by an inductive type conductivity cell,a thermistor and a solid state pressure sensor.
Each time a measurement is made, the data from the sensors are sequentially converted into 3 equivalent numbers N_c, N_t and N_p and then loaded into the microprocessor.
The microprocessor is a 8 bit N-MOS type with a 16 K address space for both external RAM and external ROM.
After the raw data have been loaded into the processor,the processor consults the data memory to receive calibration instructions.

To simplify the calibration process, the primary variables C,T and P are all defined by an equation of the form

$$Y = a_0 + a_1.X + a_2.Xexp2 \qquad (1)$$

This is the general equation for a parabola of second order. Specific curves are obtained by dedicating individul values to the general coefficients a0,a1 and a2.

To determine these coefficients experimentally -which in fact is the nature of calibration- one good way is to collect a set of points (
X1,Y1),(X2,Y2)........(Xi,Yi) and use non -linear regression to find the coefficients for the curve that fits best possible to the observed points.
In the new instrument the least square parabola approximation has been chosen.
If a set a set with n points of (X,Y) observations are made, the following equations may be generated:

$$\sum Y = a_0.n + a_1 \sum X + a_2 \sum Xexp2 \qquad (2)$$
$$\sum X.Y = a_0 \sum X + a_1 \sum Xexp2 + a_2 \sum Xexp3 \qquad (3)$$
$$\sum Xexp2.Y = a_0 \sum Xexp2 + a_1 \sum Xexp3 + a_2 \sum Xexp4 \qquad (4)$$

Where $\sum X, \sum Y, \sum X.Y$ and $\sum Xexp2.Y$ are the respective summed and summed ,multiplied values of X and Y in the chosen data points.
To find a0,a1 and a2, the microprocessor contains a program that solves equations 2-4 generally by matrix algebra.
In order to use the general solution of equations 2-4, to calibrate temperature,conductivity and pressure, these variables are all have been described by 3 coefficient -equations:

The temperature T in degrees K is determined from:
$$1/T = A + B.lnNt + C.(lnNt)exp3 \qquad (5)$$
Rt is the temperature dependent resistance of the thermistor at the moment of measurement.
A,B, and C are the thermistor calibration coeffisients.

The pressure is defined by the equation
$$P = D + E.Np + F.(Np)exp2 \qquad (6)$$
D, E and F are the pressure calibration constants.

The conductivity is defined by :
$$C = G + H.Nc + I.(Nc)exp2 \qquad (7)$$
G,H and I are conductivity calibration constants

A calibration of these variables obviously means a determination of the constants A-I.
In most instruments similar constants must be calciulated externally and inserted by the user. Normally via a terminal. In earlier instrumentation which is still in use the insertion of calibration data must be done by turning potensiometers with a screwdriver. In this new instrument the calibration is controlled and executed by the instrument itself.
Fig.4 shows the instrument setup during calibration.
The user must have acess to at least 3 known pressures,temperatures and conductivities.
He must also have a terminal (f. inst. a PC with a terminal program) which is

connected to the RS-232-plug via a cable.

TEMPERATURE CALIBRATION

After having set the instrument into "sensor calibration" mode ,the microprocessor inside the instrument prints the following messsage on the terminal display:
TEMP CALIBRATION:Y/N
"FORMAT: T=+00.000 T1=?
The user must hold the sensor part of the instrument in a tank of stirred water with a known but arbitary temperature T1.When the reading is stable, he simply keys in the correct bath temperature in the specified format after which he presses the "RETURN" key . The instrument immediately both notes T1 and measures the resistance of the thermistor Rt1. Then it asks for more data.
The user now changes the temperature in his temperature bath and keys in the new temperature.
After having received a wanted number of measurements,the instrument loads the received data sets (Ti,Nti) into equations (2)-(4). Then the microprocessor immediately calculates and prints out the coefficients A,B andC.
The new calibration coefficients are stored in the program memory.

PRESSURE CALIBRATION

The instrument asks for pressure calibration data by printing:
FORMAT :P=+00.000 P1=? , and the user applies a known pressure to the instrument
pressure transducer and keys in its value in bar.
The pressure is measured with an absolute pressure transducer. This means that the atmospheric pressure will always add itself to the measured pressure when the instrument is in the water.
The instrument pressure transducer must be exposed to a number of different pressures in the actual pressure range, after which the instrument immediately calculates and loads in the pressure calibration coefficients D,E and F.
The known pressures are preferrably generated from a "dead weight " tester.
When the instrument is later used for "real" measurements ,it will calculate the best possible "correct" water depth by measuring the ambient atmospheric pressure each time the instrument is started . This "zero"-pressure is later subtracted from all successive pressure measurements until next "START".

CONDUCTIVITY CALIBRATION

Conductivity is calibrated in the same way as the pressure and the temperature. The instrument asks for C1,C2,C3 etc. After having received a convenient number of "points"(typically 5-6) the microprocessor immediately calculates and stores the calibration constants G,H and I.

TIME NEEDED FOR CALIBRATION

The instrument itself performs all necessary operations within a few seconds. The time needed for calibration is basically used to move the instrument beteween different baths or to key the information into the terminal.
If several buckets of water with different temperature and conductivity are prepared in advance and if good pressure reference, thermometer and conductivity meter are available, a complete CTD-calibration can be made in less than 1/2 hour.

Fig 6 shows a printout from the terminal showing the actual dialogue between instrument and user when the user makes a 3 point calibration of the conductivity.

RESULTS.
At the time of writing an extensive testing of the instrument functions is being carried out. The tests include both the instrument functions and the calibration system.
The automatic calibration procedure which has been presented seems to work satisfactorily within the restrictions that have been designed into it.
Over the temperature range -2-+40 degrees C preliminary testings indicate that the temperature errors are within +/- 1/100 degree.
In the conductivity range 10-47 mmho the errors are within +/- 1/100 mmho.
In the pressure range 0-500 meters the errors are within +/- 3 cm of water depth.
If necessary the calibration equations may be extended to equations of higher order than those presently used.

CONCLUSION
The new instrument which has been described represents an excample of a modern trend in oceanographic instrumentation..
The instruments are becoming smaller and more intelligent .
This instrument weighs only 2 kg. It can handle complex mathemathical operations by itself,and it can communicate with external computers.
When automatic calibration routines like those described here have become more common, future intercalibration problems beween groups in different parts of the world may be simply solved by just mailing calibrated reference instruments to each other prior to the experiments.
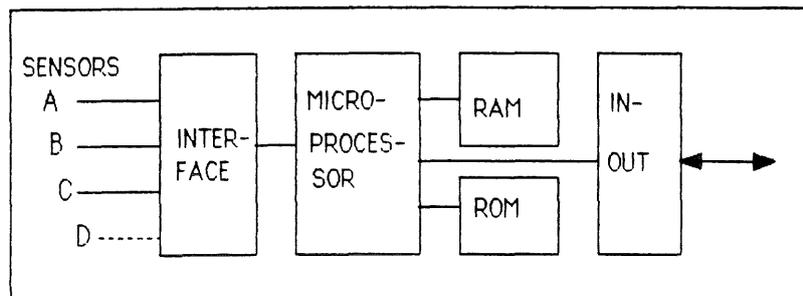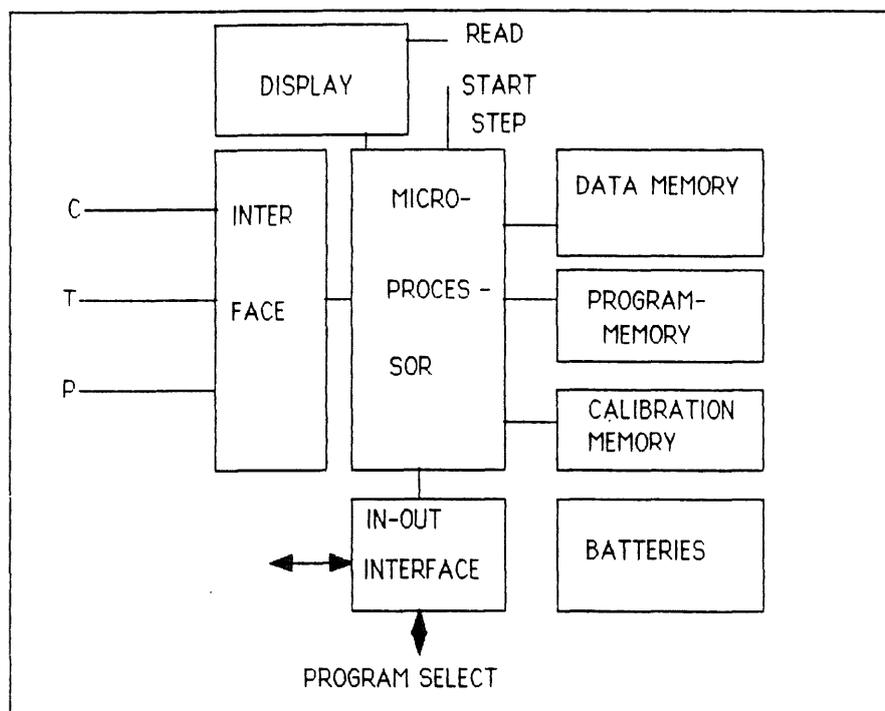
FIG.1 . ANATOMY OF A MODERN INSTRUMENT

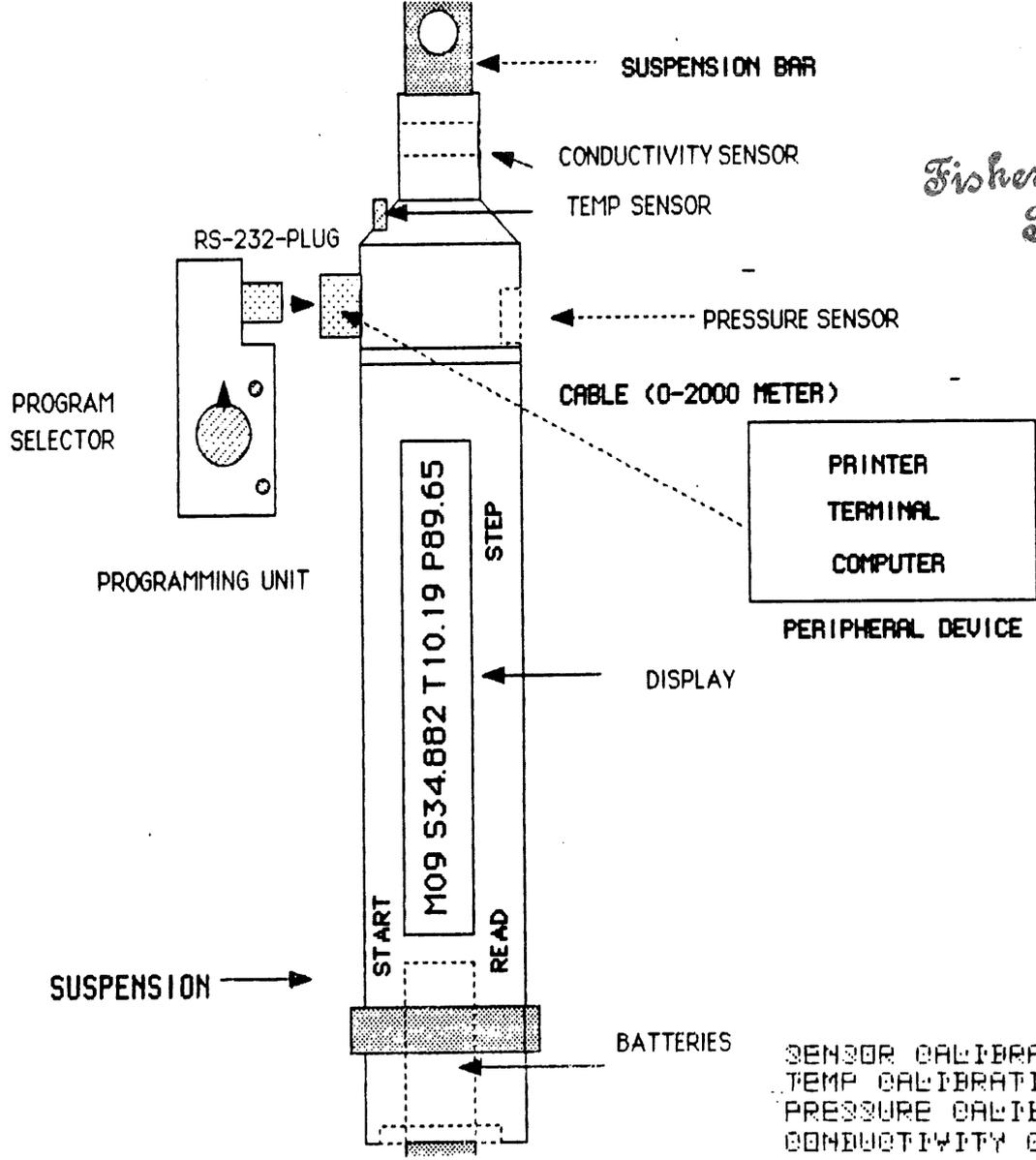FIG.2 FUNCTIONAL BLOCK DIAGRAM FOR NEW INSTRUMENT

SUSPENSION BAR

CONDUCTIVITY SENSOR

TEMP SENSOR

RS-232-PLUG

PRESSURE SENSOR

PROGRAM
SELECTOR

CABLE (0-2000 METER)

PROGRAMMING UNIT

PRINTER
TERMINAL
COMPUTER

PERIPHERAL DEVICE

DISPLAY

M09 S34.882 T10.19 P89.65

STEP

START   READ

SUSPENSION →

BATTERIES

FIG. 3 MECHANICAL INSTRUMENT DESIGN

TERMINAL
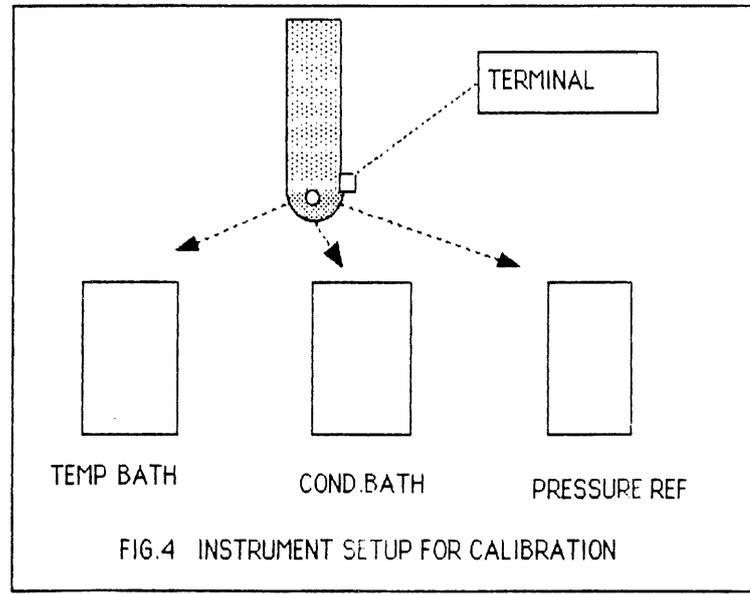
TEMP BATH   COND.BATH   PRESSURE REF

FIG.4 INSTRUMENT SETUP FOR CALIBRATION

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SENSOR CALIBRATION
TEMP CALIBRATION> Y/N EXIT><G>
PRESSURE CALIBRATION> Y/N EXIT><G>
CONDUCTIVITY CALIBRATION> Y/N EXIT><G
INSERT CONDUCTIVITY 01,02,--08 IN MMH
FORMAT>0>+00,000
01>+44,000
02>+20,000
03>+10,000
MORE POINTS> Y/N
CONDUCTIVITY COEFFICIENTS>
G   NAN0000E-00
H   NAN0670E-02
I   NAN0000E+00
STRIKE ANY KEY TO GET MENY
MENY>
SET REAL-TIME CLOCK              <S
SET COEFFICIENT                  <M
DO SELF-TEST                     <T
SENSOR CALIBRATION               <O
ERASE STORAGE MEMORY             <E
DISPLAY DATE & TIME              <D
DUMP DATA>D01>START D03>STOP G>MENY<P
SELECT MASTER/STANDAR MODE       <I
LIST CAL/COEFFICIENTS            <L
LIST PRESSURE MATHEM./COMP./COEFF.  <C
EXIT                             <G
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Fig. 6 TYPICAL CALIBRATION DIALOGUE BETWEEN
INSTRUMENT AND USER VIA TERMINAL