The purpose of the Sound Propagation Data Analyser (SPADA) is to perform pre-analysis and analysis operations on digital and analogue data recorded at sea for underwater sound studies. Its tasks can be described as follows:

- Data acquisition
- Various types of data display
- Data editing
- Preserving data on magnetic tapes
- Data analysis.

SPADA is not just a simple instrument, it consists of a mini-computer system to which certain devices are attached, and is controlled by a sophisticated software package.

The functions to be performed by the SPADA are selected by the operator through an interactive terminal consisting of a keyboard and screen. Parameters needed during processing and certain operator's decisions may also be requested through this terminal. Should a device within the SPADA malfunction, the operator has the possibility of interrupting any process.

The aim of this paper is to give a summarized description of the structure and features of the SPADA.
1. **SPADA HARDWARE SPECIFICATIONS**

The SPADA is based on the use of a mini-computer in order to minimize the cost of the hardware and to facilitate the transport of the computer between shore and ship.

After a careful study of a large number of mini-computers, we felt that the Hewlett Packard 2116B computer would suit our requirements even though other computers that are faster and more powerful in hardware or software aspects do exist. Our decision was mainly based on the fact that the HP computer is particularly suited in computational power and input/output flexibility for measurement application, i.e., voltmeters and scanners, which are standard HP peripherals. It was not necessary to choose a military version of the computer as its specifications for environmental temperature and humidity were adequate for use on board our research ship. Furthermore, apart from a few restrictions, the software supplied by HP fulfilled our requirements.

The availability of HP's Fourier Processor was most attractive to us, particularly the hardware-wired version recently announced.

Figure 1 demonstrates the HP configuration chosen for the realisation of the SPADA; this block diagram does not, however, show the peripherals used for the oceanographic data acquisition i.e., data logger etc.
Table 1 describes the specifications of all the units shown in Fig. 1.

<table>
<thead>
<tr>
<th>Unit</th>
<th>HP Number</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer HP 2116B</td>
<td></td>
<td>Memory : 24 K (extendable up to 32 K)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wordsize : 16 bits</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cycle Time : 1.6 μs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Options :</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Two Direct Memory Access</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Channels with a total transfer rate of 625 Kwords/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extended Arithmetic Unit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Power Failure Restart Option</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Memory Protect Option</td>
</tr>
<tr>
<td>Paper Tape I/O Units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Punch</td>
<td>HP 8100A</td>
<td>Speed : 75 characters/s</td>
</tr>
<tr>
<td>Reader</td>
<td>HP 2758</td>
<td>Speed : 500 characters/s</td>
</tr>
<tr>
<td>Fixed-Head Disc</td>
<td>HP 2771A</td>
<td>Maximum Size : 737 Kwords</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transfer Rate : 176 Kwords/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average Access Time : 17.4 ms</td>
</tr>
<tr>
<td>Magnetic Tape Unit</td>
<td>HP 7940</td>
<td>Format : NRZI</td>
</tr>
<tr>
<td></td>
<td>HP 3030</td>
<td>Density : 800 bpi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Speed : 37.5 ips</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rack mountable</td>
</tr>
<tr>
<td>Calcomp Plotter Model 565</td>
<td></td>
<td>Format : NRZI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Density : 200, 556, &amp; 800 bpi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Speed : 75 ips</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Speed : 300 steps/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Resolution : 0.01 in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plotting Width : 11 in</td>
</tr>
</tbody>
</table>

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The following few comments are dedicated to the graphic terminal which is one of the two units not supplied by HP; the other unit being the High Density Digital Recording System (DRS) developed by SACLANTCEN.

As the graphic terminal with its interactive units is the operator's central means of controlling the SPADA operations, a rapid and efficient information exchange is required between man and computer. As this had to be achieved without overloading the computer's power we chose the Tektronix Computer Terminal T4002, since its display unit consists of a direct-view storage tube.
The advantage of a storage tube is the elimination of a separate refreshing memory and of the computer instructions to keep the computer busy in refreshing the screen. On the storage tube the data is written only once at a rate of up to 2000 characters per second. The entire communication interaction is achieved through the data entry keyboard and the Tektronix T4901 Interactive Graphic Unit.

Table 1 does not give the specifications of the HP Fourier Processor and the Sound Propagation Digital Recording system as these units are fully described in the presentations by R. Seynaeve and A. Barbagelata respectively.

The interface of the Digital Recording system to the HP computer has been designed by A. Barbagelata using two standard HP Microcircuit Interface cards (HP 12566A). One of these cards is used for the transfer of data words and counter-track words to the computer, which is based on the use of Direct Memory Access channels. The data words contain a four-bit identification tag, in order to facilitate the necessary unscrambling procedure that has to follow everytime data acquisition is made. The second interface card is used for the remote control of the digital recording system.

2. CONCEPT OF THE SPADA SOFTWARE

The software of the SPADA consists of computer programs that control all implemented peripherals and which activate and monitor the data acquisition, the data display, the editing procedure and analysis functions.

In order to achieve a high flexibility of the SPADA and to meet the user's exact requirements the program set had to be organized as a modular system; each module being activated by the operator, by the preceding modules, or by the real-time clock. Furthermore, some acquisition of oceanographic data had to run in real-time concurrently with the SPADA functions. As only a sophisticated operating system could combine all our requirements we decided to implement the HP supplied Real-Time Executive system as the general operating system.
2.1 HP Real-Time Executive System

The main features of this system are listed in Table 2.

<table>
<thead>
<tr>
<th>TABLE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-programming Capability : Interleaved Execution of Programs</td>
</tr>
<tr>
<td>Simultaneous I/O Operations : I/O Operations performed concurrently with executing programs</td>
</tr>
<tr>
<td>Foreground and Background Processing</td>
</tr>
<tr>
<td>Complex Real-time Software, including I/O drivers for all units shown in Fig. 1 except for the FFT-Processor and the Digital Recording System : HP Assembler, Compilers for Fortran II, IV and ALGOL, Editor, Loader, Library with Plotter routines</td>
</tr>
<tr>
<td>Flexible Program Priority Structure : Up to 95 priority levels.</td>
</tr>
<tr>
<td>Modular System Organisation : System configuration on user's requirements</td>
</tr>
</tbody>
</table>

Figure 2 shows the control functions and the information flow in the Real Time System. Furthermore it demonstrates that the system can be tailored according to the user's requirements with respect to his hardware configuration and his software modules.

In order to complete its description the following summary is given on the defects of the Real Time Executive:

(1) The response time of the RTE to any type of interrupt is too long — more than 1 ms. Hewlett Packard recommends the following methods to avoid problems in this respect:

   a. The use of the DMA even in cases where the transfer rate is around 1 kHz.

   b. The privileged interrupt option decreases the response time to 100 μs, but excludes the use of the DMA.
FIG. 2 REAL TIME EXECUTIVE BLOCK DIAGRAM CONFIGURED FOR SPADA

- CONTROL FUNCTIONS
- INFORMATION FLOW

POWER FAILURE
MEMORY PROTECT
TIME BASE GENERATOR
DRIVER READER
DRIVER PUNCH
DRIVER DISC
DRIVER MAG.TAPE
DRIVER PLOTTER
DRIVER TERMINAL (= TTY)
DRIVER DIGITAL RECORDING SYSTEM
DRIVER FFT ANALYSER

REAL TIME EXECUTIVE

INTERRUPT CONTROL
SCHEDULER

I/O CONTROL

SYSTEM REQUESTS
OPERATOR REQUESTS

OPERATOR

SPADA PROGRAM #1
SPADA PROGRAM #2
SPADA PROGRAM #N
FILE MANAGEMENT
SPADA PROGRAM #M
FORTRAN IV COMPILER
ASSEMBLER

HIGHER PRIORITY LOWER
c. The suspension of the interrupt system during the whole transfer for transfer rates that need DMA and response times of less than 100 μs. That is, no interrupt may be processed during the transfer, not even the time-clock interrupts and therefore the duration of the transfer has to be measured. The clock has to be updated by triggering in a faster rate than its usual rate of 10 ms. This method has to be used for data transfer from the Digital Recording System.

(2) A file management for files on discs and magnetic tapes is missing. We have extended the RTE by a file program but because of its low speed and schedule problems it only permits the filing of background programs.

2.2 Connection of SPADA Peripherals to the Real Time Executive

Since the SPADA uses HP standard peripherals it was only required to connect SACLANTCEN's Digital Recording System to the Real Time Executive and to foresee the needs for the conversational software of the FFT Analyser, in order to operate it under the RTE. The Computer Section has now provided a connection between the Time Series Analysis system and the SPADA system.

The driver for the Digital Recording System (DRS) has the following purposes:

High-speed data transfer from the DRS to the disc.

Input of counter-track numbers.

Remote control of the tape recorder, i.e.

- rewind
- fast forward
- stop
- reproduce
- record

The counter-track input uses one DMA channel, the tape movements are interrupt controlled.

Two important factors of the data transfer are that the transfer rate should be 286 Kwords/s and the required storage medium should have the capacity for 600 Kwords. Let us consider the available computer storage possibilities where data can be transferred during an experiment. We can have core memory,
disc, and computer magnetic tape. Now considering our above mentioned requirements it can be seen from Table 3, referring to 16-bit words, that only the last system will completely satisfy our needs.

<table>
<thead>
<tr>
<th></th>
<th>Word Rate w/s</th>
<th>Word Capacity K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>600 000</td>
<td>32</td>
</tr>
<tr>
<td>Disc</td>
<td>150 000</td>
<td>700</td>
</tr>
<tr>
<td>Mag Tape</td>
<td>30 000</td>
<td>12 000</td>
</tr>
<tr>
<td>Five-channel Recording System</td>
<td>286 000</td>
<td>1 000 000</td>
</tr>
</tbody>
</table>

A fixed-disc had to be implemented to enable the processing of the data by computer. However, the disc has the disadvantage in that the input transfer rate has to be reduced by a factor of two as the disc is too slow. This means that using a disc memory we can perform on-line data acquisition on only two of the five channels. However, all five channels are recorded on our tape recorder, and if we want to have the complete set of signals on the disc we must play back the tape at half speed so dividing the word rate by two.

It is foreseen that in the near future the discs will be replaced by new types of memories that will compete in price with discs and will have the advantage of a faster access time which will, therefore, exclude recording onto magnetic tape.

In order to use the full transfer rate of the disc, the writing onto the disc had to be synchronized with the data input from the DRS. The number of words to be loaded into every disc track had to be equal to the number of words inputted during the disc rotation. It, therefore, follows that about 15% of the space on disc is wasted, but the full disc speed is used.
The start of the data transfer is either determined by its position on the tape (counter track) or it has to be found by means of a level detector. In this case the data transfer continuously cycles on the disc up to the moment the voltage level is reached.

The testing of the driver is rather tedious, because any change in the driver requires a new configuration of the RTE (time required around 30 minutes). You may remember that we had some difficulties during our demonstration when at times the whole system blocked; this trouble was due to a software error.

2.3 General Layout of the SPADA Program System

The heart of all SPADA programs is the program "SPADA" which displays a "menu" of all the available functions in the system. This menu has an open end and therefore may be easily extended according to new requirements.

Upon the operator's decision a certain operation is initiated and since such operations are composed of relatively small modules these have to schedule each other automatically according to the logic of the operation. Every activity terminates by scheduling the "SPADA" program again. The function STOP terminates the whole SPADA system. Figure 3 shows the logic of this concept.

3. Example for the Usage of the SPADA

Our aim is the acquisition of the data onto a disc, inputted from the Digital Recording System. The data, produced by a pistol shot, was recorded on the DRS tape and simultaneously transferred via the computer onto the disc. The results are shown on the screen of the terminal. The operator may manipulate these data in order to select an interesting part of the signal for further analysis.

Up to the time of this conference, we have not been able to apply the FFT-Processor to the selected signal. In the meantime, a two-directional link between the SPADA and the FFT Processor has been realised.
FIG. 3  GENERAL TEXTURE OF THE SPADA SOFTWARE
The following represents a sequence of screen hard copies, which we used to activate the described operations. Generally, in the upper left-hand corner of the screen, the computer displays the operator's previous decisions.

I

ON SPADA

COMMENTS: This command initiates the SPADA system. The available function menu is displayed.

II

SPADA

SOUND PROPAGATION DATA ACQUISITION AND ANALYSIS SYSTEM

SELECT BY TYPING TWO CHARACTERS

AN = ANALYSIS
DA = DATA ACQUISITION
DS = DISPLAY FILES
LA = LABEL MAGNETIC TAPE
MT = TRANSFER TO COMPUTER MAGNETIC TAPE
PL = PLOT FILES
RE = RELEASE DISC FILES
ST = STOP SPADA

DA

COMMENTS: The menu can be extended to implement new functions. The operator has selected "Data Acquisition" by typing "DA".
DATA ACQUISITION

OPERATION MODE
SELECT BY TYPING TWO CHARACTERS

NS = NEW OPERATION SEQUENCE
RS = REPETITION OF PREVIOUS OPERATION

NS

COMMENTS: If the operator activates the data acquisition modules the first time, he has to specify the data acquisition mode. Afterwards he can repeat it under the same conditions.

DATA ACQUISITION

DATA SOURCE
SELECT BY TYPING TWO CHARACTERS

DF = DIGITAL RECORDING SYSTEM OFF LINE
ON = DIGITAL RECORDING SYSTEM ON LINE WITHOUT M.T.
OT = DIGITAL RECORDING SYSTEM ON LINE WITH M.T.
AD = A/D CONVERTER

OT

COMMENTS: ON and OT are the modes that operate at the full speed of the DRS. Less than 5 channels may be transferred to the computer. DF operates it at half the speed. The A/D data acquisition module is not available yet.
DATA ACQUISITION
DRS ON LINE

TAPE CONFIGURATION
SELECT BY TYPING TWO CHARACTERS

NT = NEW TAPE CONFIGURATION
FT = REPEITION OF PREVIOUS CONFIGURATION

NT

COMMENTS: The system has to know once, the environmental conditions during the experiments.

VI

DATA ACQUISITION
DRS ON LINE

CONFIGURE TAPE

RANGE OF SAMPLING  48 KHZ  24 KHZ  12 KHZ
HYDROPHONE NAMES NOT PERMITTED  AA  XX

CHANNEL = 1
  HYDROPHONE = 1
  SAMP. FREQ. = 48

CHANNEL = 2
  HYDROPHONE = 2
  SAMP. FREQ. = 12
  HYDROPHONE = 3
  SAMP. FREQ. = 12
  HYDROPHONE = 4
  SAMP. FREQ. = 21

CHANNEL = 3
  HYDROPHONE = 5
  SAMP. FREQ. = 12
  HYDROPHONE = 6
  SAMP. FREQ. = 12
  HYDROPHONE = 7
  SAMP. FREQ. = 12
  HYDROPHONE = 8
  SAMP. FREQ. = 12

CHANNEL = 4
  HYDROPHONE = 9
  SAMP. FREQ. = 24
  HYDROPHONE = 10
  SAMP. FREQ. = 24

CHANNEL = 5
  HYDROPHONE = 11
  SAMP. FREQ. = 48

COMMENTS: The computer asks the operator which hydrophones are recording on the different channels. The possible sampling frequencies are 48 kHz, 24 kHz or 12 kHz per hydrophone. The computer controls the configuration very well: the maximum sampling frequency per channel is 48 kHz, the names of the hydrophones must be unique.
COMMENTS: The available hydrophones on each channel are displayed in order to facilitate the choice of the hydrophones to be transferred. If the data acquisition operates the DRS in ON-Line mode, the computer accepts only the transfer of up to two channels.

If the operator has already specified one of the operation modes from IV to VII, he is able to repeat the data acquisition for an undetermined time without re-typing IV to VII.
DATA ACQUISITION
DRS ON LINE

TRANSFER START
SELECT BY TYPING TWO CHARACTERS

CT = COUNTER TRACK NUMBER
EX = EXTERNAL PULSE
LD = LEVEL DETECTOR

LD

COMMENTS: The mode of controlling the transfer start might differ from event to event. It has to be given every time. Since we want to record the data, the level detector determines the start.

DATA ACQUISITION
DRS ON LINE

LEVEL DETECTOR

SELECTED HYDROPHONES ON CHANNEL 1 1

ENTER TRIGGER LEVEL IN MILLIVOLTS 5000
ENTER TRANSFER LENGTH IN MILLISECONDS 340
ENTER EVENT CODE SP2071

COMMENTS: The trigger level is requested and the length of the transfer.
Every event has to have an identifier of up to 6 characters.
IX (Comments Cont’d)

This identifier permits the access to the data by all modules of the SPADA. If the transfer is controlled by the counter track, then the counter-track number should be requested instead of the trigger level.

After having specified the acquisition, the data transfer to the computer and the recording onto the tape of the DRS are initiated. The transfer runs in cyclic mode on the disc up to the arrival of the trigger level. One disc track before the level is preserved and the last cycle is completed.

If the transfer is controlled by the counter track, the tape is positioned in front of the given counter track and only one disc transfer is executed.

If the transfer and the necessary unscrambling procedure are completed, the digital tape is stopped and program SPADA is rescheduled.
SPADA
SOUND PROPAGATION DATA ACQUISITION AND ANALYSIS SYSTEM
SELECT BY TYPING TWO CHARACTERS

AN = ANALYSIS
DA = DATA ACQUISITION
DS = DISPLAY FILES
LA = LABEL MAGNETIC TAPE
MT = TRANSFER TO COMPUTER MAGNETIC TAPE
PL = PLOT FILES
RE = RELEASE DISC FILES
ST = STOP SPADA

COMMENTS: The operator may choose any function to continue; in our case he wants to see the result of the transfer.

DISPLAY

EVENT = SP 2071

AVAILABLE HYDROPHONES ON CHANNEL 1 1
SELECT BY TYPING TWO CHARACTERS HYDROPHONE NAME
HYDROPHONE 1
HYDROPHONE XX

COMMENTS: The operator selects the event code, the system displays the names of the available hydrophones. Up to 5 hydrophones can be seen on the screen.
EVENT = SP2071    HYDROPHONE = 1    CT1 = 7000000.    CT2 = 7000100.

LEVEL (MV) = 615

A = ABORT    B = BIAS    H = COPY    I = INVERSE    L = LEVEL    M = MAGN    R = REFER    T = TIME
The selected curve is displayed in the upper part of the screen together with the time base in milliseconds. The software buttons in the lower part of the screen are selected by means of the joystick:

- **A** = **ABORT**
  - ABORT the display operation

- **B** = **BIAS**
  - Change the 0-line

- **H** = **HARD COPY**
  - Copy the momental screen content on the hard copy unit

- **I** = **INVERSE**
  - Invert the polarity

- **L** = **LEVEL**
  - Measurement of the voltage level at a point selected by the joystick

- **M** = **MAGN**
  - Magnify the y-direction up to certain level given by the joystick

- **R** = **REFER**
  - Display of the reference curve

- **T** = **TIME**
  - Measurement of the length of a time interval

The operator has magnified the time interval \(<51 \text{ ms}, 56 \text{ ms}>\) in the time direction. The y-amplitude remains unchanged. From now on he may also magnify the curve below in the y-direction as much as he wants. Furthermore, he has measured the level \(\text{LEVEL (MV) = 615}\) of the point on the reference curve indicated by the cross.

For any further manipulation on the curve, an erase of the screen is necessary because no selective erase is possible on a storage tube. In order to avoid unnecessary display times the reference curve is only drawn upon operator's request; it contains indicators that correspond to the position of the magnified curve interval.

The operator after a certain number of manipulations will terminate the display modules by means of the software key A. SPADA is re-scheduled.

Selected parts of the signal could be preserved by typing "MT". Parts of the signal can be Fourier transformed by typing AN.

Finally the demonstration is terminated and we type ST in order to stop the SPADA.

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