ASSET - A PROGRAMME OF RESEARCH INTO ADVANCED SIDESCAN SONAR SURVEY TECHNIQUES

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1. INTRODUCTION

ASSET stands for Advanced Sonar Survey and Exploration Techniques, and is a research and testbed evaluation programme aimed at achieving a major advance in sidescan sonar survey technology to provide an increase in hydrographic and oceanographic survey efficiency. The research is centred on the evaluation of combined high performance sonar techniques including beam steering, all-range focussing and vernier interferometry. The project will facilitate the subsequent development of a new survey sonar product which will help to accelerate the exploitation of subsea resources by increasing the rate of acquisition of high quality seabed data.

Dowty Maritime Ocean Systems, Swath Sonar Techniques, Marine Acoustics, Gardline Survey and the Maritime Division of the Defence Research Agency are collaborating to carry out this grant-aided R & D project. The work is part funded under the Wealth from the Oceans (WEFTO) programme which is part of the DTI LINK initiative.

The main goals of the project are as follows:-

1) To improve seabed survey efficiency by the development of a multibeam sidescan sonar
2) To integrate seabed depth or topography data using a vernier interferometry technique
3) To use advanced DSP techniques to produce a software-configurable sonar processing architecture

To date Dowty, Swath Sonar Techniques and Marine Acoustics have completed the initial phase of this project; a detailed sonar study which has defined the signal and data processing methodologies which are to be evaluated, and established an outline specification for the testbed sonar. Work is currently underway to build prototype hardware and software modules, and a captive trial will be carried out in the near future.

2. BACKGROUND

Current seabed survey activity for commercial or scientific purposes generally employs either a sidescan imaging sonar, or a swathe sounding bathymetry sonar.

2.1 SIDESCAN

The sidescan sonars in current commercial use operate at acoustic frequencies of between 30-500 KHz and employ linear arrays of transducer elements connected in a broadside configuration to generate a narrow across-track beam on each side of a towfish.

The along track movement of the towfish causes the beam to scan successive strips of the seabed which can then be assembled, using suitable processing and a simple paper recorder, into a pseudo plan view image of the seabed. To provide the best texture and shadow information, the sidescan towfish is normally towed at a fixed height above the seabed, usually set at about 10% of sonar range.

This basic sidescan technique has been in use for 50 years, and although many improvements to the processing of the sonar data have been devised the underlying constraints imposed by the use of a single unsteered and unfocussed beam on each side are still evident.

It has however been recognised for some years that towfish speed restrictions imposed by the speed of acoustic propagation in water, and image distortions caused by fixed focus arrays and towfish motion, can be reduced by the use of multiple stabilised beams with individual steering and focussing. Unfortunately the cost and size of the necessary processing system has ruled this out for all but a few military applications, until the arrival of modern digital signal processing elements.

2.2 SWATHE SOUNDERS

Another fundamental problem suffered by simple sidescan sonars with single linear transducer arrays is that they offer no measurement of the vertical arrival angle of returning signals, and are therefore unable to provide any quantitative measure of seabed topology or shape. This problem can now also be overcome by the use of an arrangement of many separate vertical overlapping beams, or by the use of a phase measurement system such as a vernier interferometer.

Bathymetric survey products utilising multibeam or interferometric techniques, and in some cases a combination of the two, are in current use by commercial operators. These "Swathe sounders" are normally mounted on the hulls of survey ships, or towed alongside at shallow depths. These systems provide excellent bathymetry data, but because they are generally deployed at an altitude of 50% of range or greater, the seabed imagery which they produce is greatly inferior to that produced by conventional sidescan sonars.

2.3 USER REQUIREMENTS

Present survey companies and organisations are therefore faced with the difficult choice of which type of system to obtain and to use for each individual application. Sometimes both a sidescan sonar and a swathe sounder will be required to obtain the needed seabed data.

Discussions with survey operators have shown that their underlying requirements are not being adequately met by current systems. Ideally, operators would like a survey tool which can be rapidly adapted to suit the task in hand, tasks which can include the following divergent examples:

1) Very high resolution short range imaging of oil and gas pipelines
2) High speed wide area search for seabed objects
3) High quality hydrographic survey of coastal areas yielding both bathymetry and imagery
4) Deep water shelf edge surveys providing high quality imagery and seabed topology data
5) Pre and Post dredging surveys providing detailed channel profile data

All the above examples should ideally utilise a common hardware architecture and produce data in a common format.

It was against this background that the ASSET research programme was conceived.

The objectives of the ASSET programme were defined to bring together a versatile set of seabed survey techniques which can be employed in an optimum configuration to suit the application in hand.

Combined with the use of a software configurable digital signal processing "Open Systems" data and software format, it is hoped that the ASSET research may ultimately yield the basis of the universal survey tool which users have long been seeking.

3. THE ASSET PROGRAMME

The key elements of a versatile high performance sidescan sonar system can be individually identified as follows: (Fig 3.1)

a) 2D Sonar array with individual element accessibility
b) Remotely programmable front-end signal conditioning
c) Towfish with Attitude and Heading Reference System (AHRS)
d) High bandwidth telemetry link
e) Software reconfigurable DSP beam forming, beam steering, beam focussing, and gain adjustment
f) Flexible interactive data and image processing and archiving environment
g) Standard systems software architecture to allow new applications and third party software to be run.

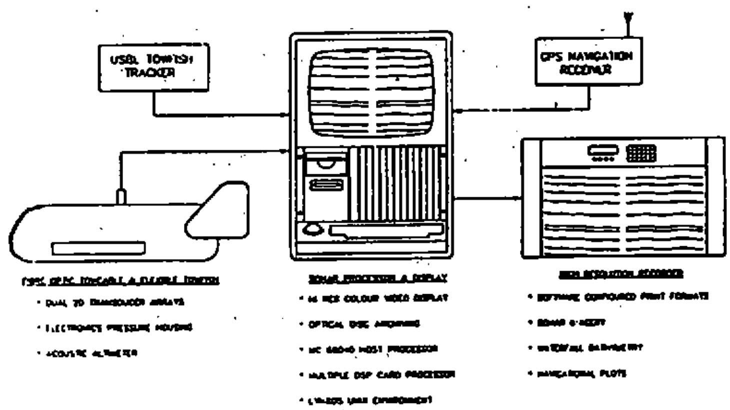


Figure 3.1 ASSET TESTBED CONFIGURATION

The ASSET programme aims to define a system which can provide these key elements, with the additional constraint of affordability, since the work will be of academic interest only if the chosen concepts cannot be implemented in a cost-effective way in a real product.

3.1 CONCEPT EVALUATION

The complex interactions of the various system elements can only be properly evaluated by constructing a testbed which employs them. Cost and time constraints, however, prevent the development of a prototype which will allow all elements to be comprehensively evaluated.

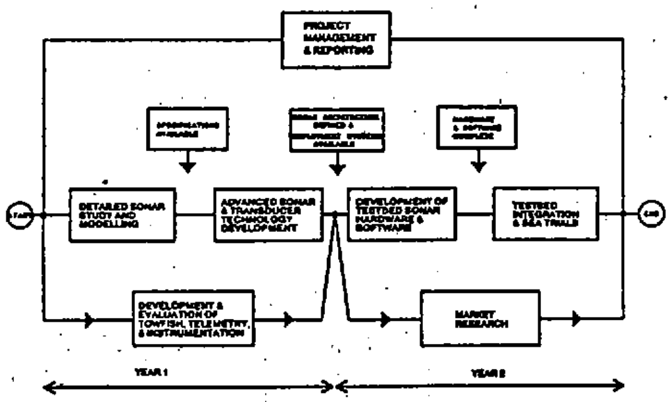
The ASSET testbed will therefore focus most attention on those elements of the concept which will yield the most significant results, whilst using "off-the-shelf" technology for others.

Our analysis during the initial study phase led to the conclusion that the elements to receive most attention should be:
a) Sonar array
b) Front end signal conditioning
e) Digital Signal Processing
f) Data management and image processing software

This approach also plays to the strengths of the ASSET team members, with Marine Acoustics concentrating on the arrays, Swath Sonar Techniques focussing on the front-end electronics and Dowty concentrating on the signal processing and display software.

3.2 PROGRESS TO DATE

Figure 3.2 shows the overall structure of the 2 year programme.



ASSET OVERALL STRUCTURE

Figure 3.2

The sonar study and modelling activity is now complete and the testbed sonar architecture has been defined.
Sub-sections of the acoustic array have been fabricated and tested, the final testbed array has been specified, and the first full array is being manufactured.
The sonar front-end architecture has been defined and breadboarded, and is currently being designed in PCB format.
The hardware and software architecture of the surface sonar processing workstation has been defined in detail and the foundation software is being developed.
A towfish configuration has been defined, but this aspect of the programme is currently behind schedule and the towfish will not be available until later in the year.
Off-the-shelf solutions have been specified for the fibre optic telemetry and the AHRS.
A captive data collection trial using DRA facilities will be carried out in the near future with the prototype array and front-end signal conditioning.

The ASSET programme has generated a feasible sonar architecture which will allow the evaluation of a range of high performance sonar techniques, both singly and in combination. (Ref7).

4 THE ASSET TESTBED SYSTEM

The ASSET testbed system will be used to evaluate a variety of advanced sonar concepts and the software configurable processing architecture defined during the study phase.

The Sonar Concepts include all range focussing, beamsteering, and vertical interferometry. These concepts and the major elements of the architecture are discussed individually below:-

ASSET RESEARCH PROGRAMME

4.1 ALL RANGE FOCUSSING AND BEAMSTEERING

All range focussing and beamsteering is achieved by using a multi-element transducer array. Electronically applying a phase shift to individual elements makes it possible both to steer and focus the beam to maximise the array's response at a particular point in space. By dynamically changing the focal point of the array it is possible to form a composite beam, perpendicular to the transducer array with a beamwidth that is inversely proportional to the array length. An example of a typical composite receive beam pattern is shown in Figure 4.1 for a 1.8 metre array that was initially considered during the study phase.

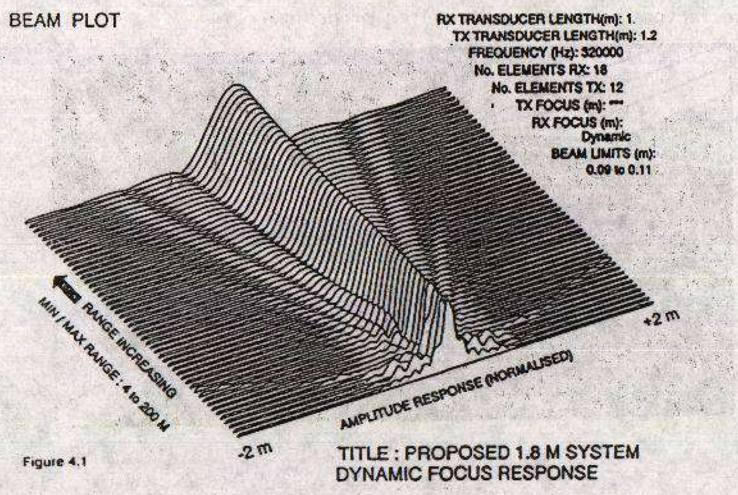
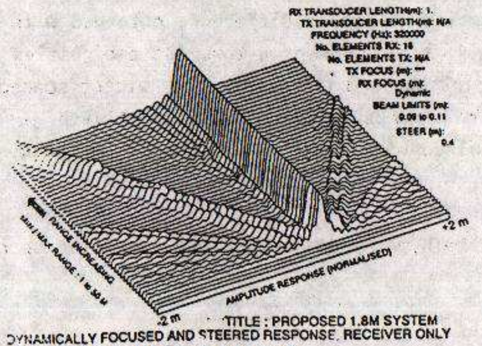


Figure 4.1

A detailed investigation of multibeam systems was undertaken during the study. (Refs 1,2,3,4). The purpose of this was twofold; firstly to verify the characteristics and performance of such systems, and secondly as a benchmark for proving the modelling software. Simulations have been carried out for a number of potential configurations including the originally proposed 1.8 metre 18 element array. One of the findings has been that the shape of the transmit beam can have a significant effect. This can be used to advantage in eliminating unwanted grating lobes in the receive beam pattern.

As an example Fig 4.2 shows the receiving response of this dynamically focussed array which has been steered away from broadside. Due to the large inter-element spacing the presence of significant grating lobes can clearly be seen. However, when the overall system response is examined, which consists of a convolution of the transmit and receive responses, as shown in Fig 4.3 the grating lobe response can be seen to have been effectively removed.



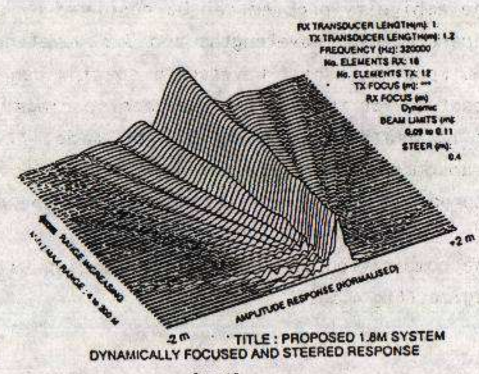


Figure 4.3

The simulations have also demonstrated that the phase response of the system will be compatible with the interferometric techniques required for bathymetry.

There are two main advantages gained over a conventional sidescan by focussing and beamsteering. Focussed beams allow detection of much smaller targets and give the ability to resolve objects which are closer together. Forming multiple beams (Fig. 4.4) allows a larger area to be covered with each ping and therefore faster seabed surveys are possible. The disadvantages are the additional complexity of a multi-element transducer and the dramatic increase in processing over a conventional sidescan. The minimisation of costs due to these factors is a key goal of the programme.

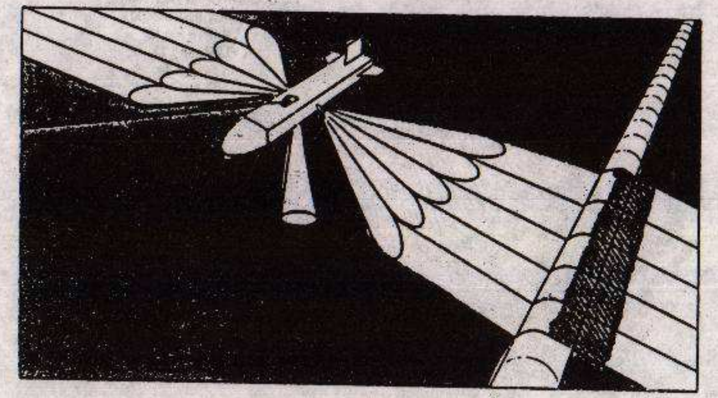


Figure 4.4

4.2 INTERFEROMETRIC SWATHE DEPTH SOUNDING

Interferometry uses two (or more) horizontally parallel transducer arrays to receive the sonar return. The backscatter signal from a point on the seabed will be received by each transducer at slightly different times. This time delay or phase shift can be used to calculate the elevation of the sonar return. If two transducers are separated by half a wavelength (of the transmit frequency) this elevation can be calculated unambiguously, since the phase difference can be no greater than 180 degrees.

In practice the presence of noise makes it difficult to accurately calculate elevation with a half wavelength spacing. Additionally such an array would be difficult to fabricate. The noise problem can be reduced by increasing the spacing of the transducers. However, with a spacing of greater than half a wavelength a phase difference can now equate to several possible elevations, only one of which is the true value. The greater the spacing the better the noise performance, but the larger the number of ambiguities.

The ambiguity problem can be resolved by using three parallel transducers. These could for example be separated by 3 wavelengths and 3.5 wavelengths. By subtracting the phase difference obtained with these two spacings a half wavelength spacing can be synthesised. This measurement allows the ambiguities to be resolved for the wider transducer spacings. By considering the phase difference in the widest spaced pair an accurate measurement can be made. (Refs 5,6). A similar result can be achieved with just two transducers and different frequencies to generate the required wavelength separation. Both of these approaches will be investigated during the ASSET research.

The combination of high quality imaging with interferometric bathymetry opens up a new potential operating regime (Fig 4.5).

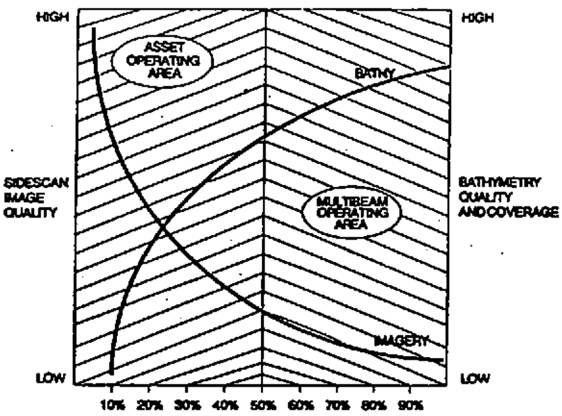


Figure 4.5

4.3 THE ARRAY

The transducer has been the subject of much discussion and a large number of factors were taken into account before a final specification was agreed. Areas that were considered include market survey data, the cost of the array, and the size and handling characteristics of the towfish. Another important factor was the towfish stability and whether this would support the theoretical performance.

The following range of operating conditions were suggested by the market survey data:-

10cm resolution over a 50m range @ 3 kts for pipeline survey,
60cm resolution over a 200m swath @ 8 kts for search operations
Maximum range 200m
Typical tow speed 3-8 kts

Initially consideration was given to using a 1.8m aperture array. Later, however, after considering all the above factors it was decided that the array should be no longer than 1 metre. From this the final parameters for the transducer were defined.

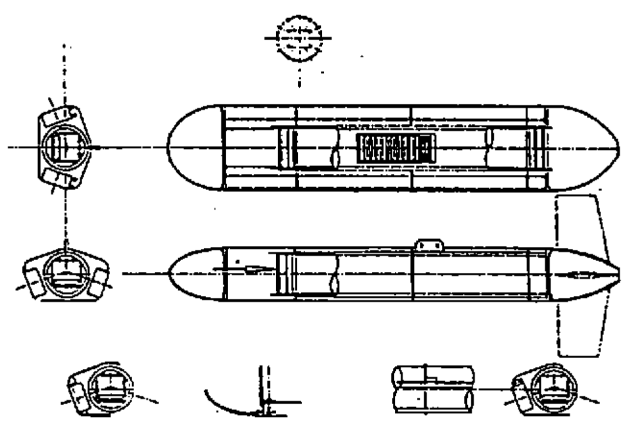
Rx array length	:	1 metre
Number of elements	:	10
TX array length	:	0.6 metres
Operating frequency	:	325KHz
Vertical beamwidth	:	32 degrees
Technology	:	Ceramic

Each of the elements in this array will be individually accessible to allow beams to be focussed and steered. It is also necessary to focus the transmit beam, and the towfish electronics design will include this capability.

4.4 TOWFISH

The study has concluded that the ASSET towfish should be primarily a passive design. The ASSET system will incorporate digital electronics for sonar beamforming and accurate attitude sensors. It is therefore possible that horizontal sonar beam stabilisation, with respect to the seabed, can be achieved electronically using data from the AHRS. This technique would compensate for yaw and roll making the towfish stability a less critical design consideration, and we hope to investigate this as part of the programme.

A streamlined body is the preferred option over an open frame design, the main considerations being predictability of hydrodynamic performance. A preliminary towfish design has been proposed. In this design the transducers are mounted either side of an electronics pod. Bulkheads are mounted forward, centrally and aft to maintain a rigid structure. The towing point is located at the central bulkhead. Simple fairings will be used to streamline the main body section and would be removable for easy access. The nose and tail sections will be formed from moulded GRP. Only the electronics and AHRS will be sealed, the rest of the towfish will be free-flooding. The free-flooding volume of the towfish will be minimised to reduce the recovery weight. Fig 4.6 shows a possible layout based on the above considerations.



PROPOSED MECHANICAL LAYOUT

Figure 4.6

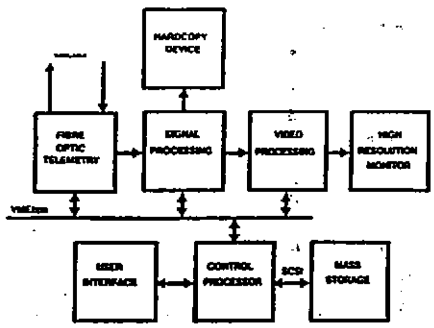
4.5 TELEMETRY SYSTEM

It is of great benefit to keep the towfish electronics as simple as possible, taking into account space restrictions, accessibility and reliability considerations. Because of this the towfish should contain little or no processing electronics and transmit all of the raw data to the surface. To achieve this a high bandwidth telemetry system is required and a solution using fibre optic technology has been proposed. A bidirectional link is required to the towfish. The uplink will carry both raw sonar data and data from other towfish sensors to the surface. The down link will allow the surface processing to communicate with the towfish electronics and may include control of transmit repetition rate, transmit pulse width, time variable gain laws, etc. The bandwidth requirement of the up link is much greater than that of the down link, much of the traffic consisting of the raw sonar data. A data rate approaching 100 Mbits/second is likely to be the minimum requirement.

Dowty has already developed an optical telemetry link for other purposes and this will be used for the ASSET testbed.

4.6 SURFACE PROCESSING

An analysis of the system data rates and processing requirements has been made. This has shown that the requirements for all-range focussing and beamsteering are much more demanding than for conventional sidescan. A search has been carried out on available techniques and processors which may offer a solution. The Texas Instruments TMS320C40 has been chosen for its very high DSP performance (275 MOPS) and its unique parallel processing capability supported by six high speed processor to processor links. With this device it is possible to design a scalable architecture which will not impose processing constraints on the ASSET research. The signal processing system will support a wide range of interfaces including analogue inputs and outputs, serial I/O, parallel I/O, IEEE488, SCSI and a fibre optic telemetry system (Fig 4.7).



SURFACE PROCESSING ARCHITECTURE

Figure 4.7

The control processor will be a Motorola MC68040 running LynxOS, a UNIX compatible real time operating system. This will be capable of supporting the high performance DSP architecture and handling all ancillary tasks such as the data archiving, user interface and navigation processing. The control processor will support the following interfaces: SCSI for data archive and program storage, Ethernet to provide a networking capability, and serial and parallel ports for the user interface and navigation instruments.

Data compression techniques have been investigated as a means of reducing storage requirements and data rates. Experiments have shown that conventional algorithms do not perform very satisfactorily with typical sonar data. For this reason the system will not include any dedicated compression hardware. It is felt that further investigation is warranted and that it may be possible to modify some of the techniques to achieve better results. The signal processing architecture could be extended to support this option in the future.

5. CONCLUSIONS

The ASSET research programme has identified a feasible architecture for a versatile seabed survey sonar of advanced performance. The construction of a testbed model is now planned to refine processing techniques and evaluate performance for a variety of potential applications.

6. REFERENCES

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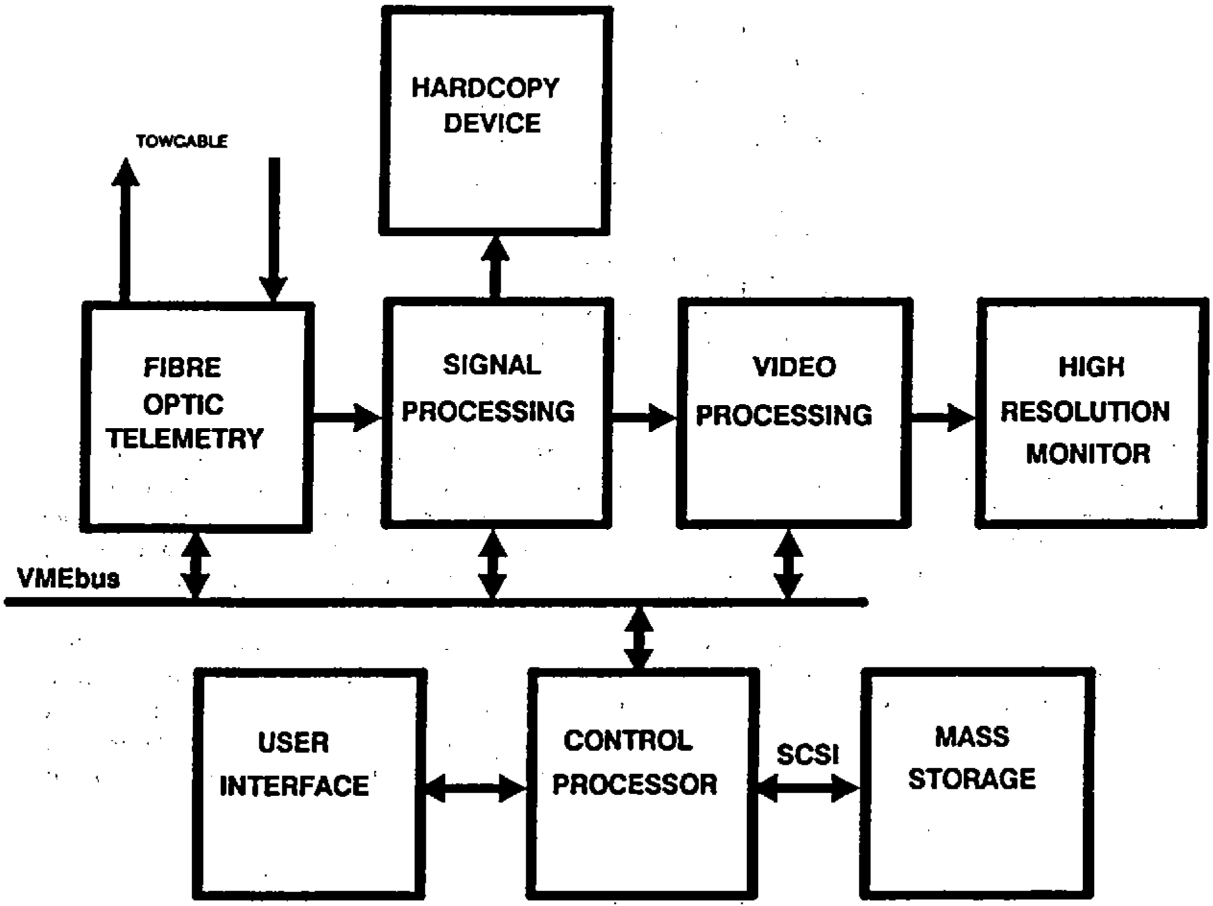

SURFACE PROCESSING ARCHITECTURE

Figure 4.7