Intergovernmental Oceanographic Commission
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International Workshop on Marine Acoustics

Beijing, China, 26-30 March 1990

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SUMMARY REPORT

INTRODUCTION

Sound waves are the only effective carriers for signal transmission over long distances in the ocean. Over the past 50 years, the technology of marine acoustics has progressed rapidly. During World War II, large-scale applications of marine acoustics for military purposes were initiated. In the 1960s, the use of marine acoustics for oceanographic research and ocean exploitation began to receive attention. Since then considerable research and development efforts in marine acoustics have been made, which have resulted in a fairly strong scientific and technological expertise in this field. In the early 1980s the Intergovernmental Oceanographic Commission (IOC) of Unesco held an Experts Consultation on Ocean Science for the year 2000 in Villefranche-sur-mer, France. In the consultation many experts emphasized the close relationship between oceanographic studies and the development and application of acoustics. Therefore, it was suggested that the IOC and other related organizations arrange an international workshop on marine acoustics within this decade. As a result of years of effort made by IOC, the Chinese Academy of Science, the State Oceanic Administration of China and the China Association for Science and Technology, this workshop finally became a reality in Beijing, China, 26-30 March 1990.

The purposes of the Workshop were to review the progress in research on topics related to marine acoustic applications to oceanography, to assess the state-of-the-art and to make suggestions for future research and international co-operation in this field.

Scientists and experts from 10 countries attended the Workshop. The list of participants is attached as Annex II.

The Workshop was held in plenary sessions, followed by two parallel group sessions: Session A focussing on the theory and experiments of marine acoustics and Session B on applications and technology. An Experts Consultation was held on 29 March 1990 to discuss international cooperation and recommendations. The Programme of the Workshop is attached as Annex I.

1. OPENING

The Workshop was opened by Professor Guan Dinhua, on behalf of the Workshop Chairman, Professor Wang Dezhao, who was unable to attend the Workshop for health reasons. Professor Guan warmly welcomed the participants to the Workshop.

Dr. L. Teller, the Unesco Representative in China, expressed to the Workshop his appreciation for China's active participation in the activities of Unesco, especially the activities of IOC this year. He wished the Workshop success.

Mr. Yihang Jiang, the Representative of IOC, on behalf of the Secretary of IOC, Dr. Gunnar Kullenberg, welcomed all the participants and thanked the State Oceanic Administration, the Chinese Academy of Science and the China Association for Sciences and Technology for hosting the Workshop and for the excellent arrangements. He briefly introduced the IOC Programmes in marine sciences and expressed the hope that more benefits can be obtained from use of the technique of marine acoustics inter alia as a result of this workshop.

The Vice-President of the Chinese Academy of Sciences, Ms. Hu Qiheng, extended her warm greetings to all participants and co-sponsors at the opening of the Workshop. She recalled the preparations for the Workshop and expressed her thanks to the former and present Secretaries of IOC, Drs. M. Ruivo and G. Kullenberg, and to the Workshop Chairman Professor Wang Dezhao.

Mr. Yang Wenhe, the Deputy Director-General of the State Oceanic Administration, welcomed the participants to the Workshop. He emphasized the importance of the ocean as a new source of food, mineral resources and energy. He referred to the tremendous progress achieved in both marine acoustics research and applications and indicated the need to further develop marine acoustics and to explore the possibility of international co-operation in this field.

The Secretary General of the China Association for Science and Technology, Mr. Gao Chao, extended, on behalf of the Association, a cordial welcome to the Workshop, and expressed the Association's desire to play a more active role in IOC Programmes and to further strengthen co-operation with the scientists from other countries.

2. PRESENT STATUS OF MARINE ACOUSTICS: RESEARCH AND APPLICATIONS

Acoustics is a respected branch of classical physics and marine acoustics continues to be an important, interesting and worthwhile subject for academic institutions to pursue.

Applications of marine acoustics are already numerous and will continue to increase in number and scope. Interest in the role of the oceans in climate change, as a provider of resources and as a sink for environmental pollution, is growing globally. Marine acoustics has a major contribution to make in the future for solving many of these problems.

Scientific and technological advances in other fields have enabled advances in marine acoustics:

(i) Theoretical and applied physics enable better representation of acoustic fields in complex media, better understanding of the interaction of sound with properties of the media including objects therein and better understanding of non-linear phenomena;

(ii) Electroacoustic transducer technology has matured and the acoustic systems' engineer can now purchase reliable transducers for most applications;

(iii) Electronics have developed enormously, reducing in volume, increasing in capability and reliability, enabling marine acousticians to incorporate complex, efficient circuitry in systems, often in situ, in easily-managed packages;

(iv) Computer and microprocessor developments have made possible very advanced signal and data processing in marine acoustic equipment; information theory is widely applied and now available in software;

(v) Efficient power sources, especially batteries, have steadily evolved with benefits to marine acoustic equipment;

(vi) Engineering materials for use in the sea including non-ferrous metals, plastics and composites have increased in availability and application; but

(vii) The background noise levels of ships on which acoustic equipment must work have, with a few exceptions, improved very little; this is a serious concern.

In the following sections, more details are presented for research and development, and application.

2.1 RESEARCH AND DEVELOPMENT IN MARINE ACOUSTICS

2.1.1 **Theoretical and Experimental Studies**

Sound Transmission

During recent years, experimental studies on sound transmission have been completed in nearly all seas and oceans. Various kinds of effects, such as the influence of the sound speed profile on transmission loss, the characteristics of the frequency dependence of shallow water transmission, the influence of the deep transmission channel on distant sound propagation and the convergence phenomena for sound transmission in regions with sloping bottoms, have been found and thoroughly investigated. The fluctuations of transmitted signals and their correlation with ocean currents, thermal microstructure and surface or internal wave motions of the water medium have been measured and analyzed statistically.

On the theoretical side, normal mode theory has been used for the analysis of sound transmission in a layered medium for more than forty years. This theory gives a clear physical interpretation of sound propagation phenomena and is still a powerful tool in marine acoustic studies. Various calculation methods have been developed in the past twenty years, which can solve, numerically, the transmission problem in the case of a non-stratified medium. Among these methods the wide-angle parabolic approximation and hybrid ray-mode theory have been widely used and can give quite satisfactory results even for complex oceanographic parameters. As for sound propagation in a turbulent medium, the perturbation method has been used for the unsaturated case, when the percentage amplitude fluctuation of transmitted signals is small. The method of Fiemann path integral using a transfer equation of intensity flow has been introduced for theoretical analysis in saturated cases. Useful criterions have been worked out for the estimation of fluctuation and space-time coherences of sound signals in cases of practical interest.

The direct problem of 'how environmental factors influence the transmission of sound in the ocean' has been well studied both experimentally and theoretically. If all necessary environmental factors are measured with sufficient accuracy for the ocean, one can give with corresponding accuracy the spatial temporal distribution of sound fields in the ocean for any given sound source.

Today, efforts are concentrated on the 'inverse problem', i.e. to meet the requirements for estimating oceanographic parameters by means of measurements of acoustic fields, e.g. bottom topography, sound speed profiles and ocean current measurements. It should be noted that, in general, there is no single solution for inverse problems. This difficulty can only be solved by the combined efforts of oceanographers and acousticians who must first work out some theoretical models or acceptable assumptions about the subject to be considered. For instance, sound speed profiles may be deduced from the measurement of the vertical intensity distribution of the sound field generated by a monopole sound source using the assumption of a layered medium. If the sea bottom is considered to be a layered fluid medium, the vertical distribution of sound impedance of the bottom can be calculated from the value of the field intensity measured along the surface of the bottom by using the Gelvin-Livetan integral equation or other suitable methods. More examples of the solution of typical inverse problems will be given in the section on application.

Scattering and Reverberation

Sound scattering by various inhomogeneities in the sea was discovered long ago. The origin of the deep-sea sound scattering layer is a concentrated layer of plankton and different kinds of fish; different values of the scattering co-efficient of this layer correspond to different concentrations of fish schools.

Sound waves will also be scattered when they encounter an irregular sea surface or sea bottom. Corresponding scattering co-efficients are related to the roughness of the boundary.

Scattering co-efficients have been measured in different regions of the ocean at all depths of interest. Their frequency dependence and daily or monthly variations have been studied experimentally. Theoretical models for reverberation have been developed, and the law of time-decay for long-range reverberation has been deduced by means of transmission theory.

Great progress in the statistical theory of sound scattering and reverberation has been achieved in recent years. It fulfills the requirements of sound signal processing for marine acoustic technology and helps to solve many inverse problems, i.e. using acoustical measurements to determine oceanographic structures.

Some theoretical work, concerning the relationship between the frequency dependence of the scattering co-efficient and the physical nature of the scatterers, has also been done. It may be a fruitful area for future research.

Ambient Noise

The ambient noise and its spectral distribution change from place to place and from time to time. The main contribution to ambient noise at different frequency ranges comes from sources of varying physical natures. The spectrum of ambient noise at different places has been measured, the contribution from different sources has been identified and the average level of ambient noise has been determined.

At frequency ranges below several hertz, ambient noise comes from sources of hydrodynamic nature, micro-seisms and earthquakes. Different theories have been developed to explain the mechanism of noise radiation. Each theory provides a partial understanding of the mechanism, but no one solution can give an estimated noise level in agreement with the experimental values.

In the frequency range 10-300 Hz, ambient noise mainly comes from distant traffic and is quite different in each ocean region, depending on the distance from shipping lanes. In the frequency range from several hundred hertz to 50 kHz, the ambient noise level is strongly related to sea state. Noise with biological origins and noise caused by heavy rain also may at times become the principal part of the ambient noise in this frequency domain, which forms the basis of passive listening in fishery investigations and distant storm forecasting.

Above 50 kHz ambient noise is caused mainly by thermal agitation in sea water and increases with frequency at a rate of 6 db/octave.

Since ambient noise is the accumulated results of individual sources, experimental results show that its probability distribution function agrees well with the Gaussian distribution. But the actual measured noise level, as well as its directional distribution, depends not only on the nature of the sources, but also on environmental conditions, such as the sound velocity profile and the character of the sea bottom. The spatial distribution of the ambient noise field under different environmental conditions has been analyzed both theoretically and experimentally. This is helpful in understanding the noise source characteristics and may also give a better estimation of the acoustic properties of the seabed.

Target strength

Recent advances in fisheries science require not only detection of the fish school as a whole, but also an estimation of the concentration and approximate identification of the fish. Therefore, the target strength of individual fish must be thoroughly investigated. In offshore engineering, the detection of underwater objects requires knowledge about sound reflection from those objects.

Although diffraction of sound is a classical problem in acoustics and many basic investigations can be found as early as in the work of Rayleigh, there are great difficulties in the mathematical treatment for objects with complicated geometrical configurations and physical properties. Various methods for numerical calculations have been developed, but in general the computational procedures are tedious, and analytical results can be obtained only for simple cases by approximate methods.

For elastic objects with simple geometrical forms, the target strength can be obtained from the superposition of geometrically reflected waves and circumferential waves of different modes. The frequency dependence of the target strength can be interpreted by the phase difference between superimposed waves. Experiments show that for all species of fish, there is also a strong frequency dependence of target strength, and usually the gas bladders in the fish play an important role in sound scattering; but no existent theory can give a satisfactory explanation about the frequency dependence law for the target strength of fishes.

Recentlv. active research has been undertaken, both experimentally and theoretically, in the area of object identification by analysis of impulse reflection from the object under consideration. There are combined efforts from acousticians, working in the fields of sound scattering and signal processing.

Some basic physical considerations and criteria have been worked out, which may be used to distinguish objects of different natures, e.g. 'soft objects' and 'solid objects', but there is still a long way to go before reaching any conclusive result, which can be used for practical purposes.

2.1.2 **Development of Technology**

A. **Underwater Acoustic Transducers and Arrays**

In relation to research and development, transducers and arrays may be considered as a rather mature field. The following is a review of the development of transducer materials and transducers and arrays.

Transducer Materials

A variety of transducer materials have been developed. They are: (i) piezoelectric materials like quartz, Rochelle salt, ADP crystals and ceramics. The piezoelectric ceramics widely used today are based on lead zirconate titanate, modified lead titanate and bismuth titanate, the bard um titanate still finds some transducer applications; (ii) magnetostrictive materials and rare earth-iron alloys, nickel-cobalt alloys and rave-earthiron mixtures including the recently developed giant magnetostrictive material: Terfenol-D; (iii) electromagnetic transducers; (iv) hydraulic-based transducers; (v) polymer materials, like PVDF; (vi) piezoelectric composites, which combine some of the advantages of piezoelectric ceramics and polymers; (vii) optical fiber-based transducers, which are used for hydrophores; (viii) metallic glasses and ferrofluid, which are potential candidates for the basis of future transducers; and (ix) impulsive sources, like explosives, sparkers, air guns and boomers, which are most widely used as signal sources in underwater acoustics.

Transducers and Arrays

The most essential factors influencing the requirements are based on: (i) Far field conditions and (ii) acoustical parameters. Far field conditions include source level, wave shape and band width, wave form, the repetition rate and the beam shape. Among the acoustical parameters emphasized should be the radiation impedance, the radiated acoustic power, the source level, the directivity pattern and the electroacoustic efficiency together with the Q-value.

There are many types of transducer and array constructions : (i) ceramic rings; (ii) single-ended piston radiators; and (iii) flexural vibrators, flexural disc transducers, bender bar transducers and flextensional transducers. Piston and ring type (scroll) magnetostrictive transducers are well developed.

Transducers and arrays are widely used in acoustical apparatus for oceanography .

B. **Signal Processing for Marine Aco us tics**

During the past decades, underwater acoustic signal processing has advanced significantly in both the software and hardware domains. The basis for the development lies in computer-based modelling and simulation as well as VLSI microprocessor-based implementation.

Theoretical and Software Development

Adaptive filtering and array processing theories and algorithms have been studied intensively. Some of the studies deal with practical applications, and in particular the theories and algorithms for Adaptive Line Enhancer (ALE), Adaptive Sidelobe Canceller (ASC) and Adaptive Equalizer (AK) are ready for application.

High resolution spectrum and parameter estimation show great potential for underwater sound applications, particularly for target location, classification and high accuracy measurement. However, robustness and engineering feasibility of these new methods need further study.

Mathematical modelling of the underwater sound field has developed rapidly in accordance with the progress made in computer science and technology. Based on the modelling, large-scale software packages have been developed for research and system analysis. Computer simulations and numerical methods have become routine methods for underwater sound scientists and engineers.

The time-space distribution of the underwater sound field and the channel response attracts much interest. Correspondingly, matched field processing has become a fresh field in underwater acoustic signal processing.

Instrument and Hardware Development

Pushed by the evolution of electronic devices, particularly the VLSI signal processing chips, sonars and underwater sound instruments became computerized. Digital data acquisition, signal processing, keyboard control and TV monitor (black and white or colour) displays dominate underwater sound electronic products.

Large-scale, high throughput, real-time signal processing systems for underwater sound research became feasible. Newly developed advanced signal processing algorithms can be realised by these systems. Further development is needed for practical applications.

The evolution of devices and related development skills are extremely important for system designers, particularly for the hardware engineers working in the field of underwater acoustic signal processing. Correspondingly, training and knowledge-refreshing are critical for them.

System integration has become easier and shows great potential. Compatibility and modularity are increasingly important, and many problems concerned with system control and efficiency are yet to be studied.

2.2 APPLICATIONS OF MARINE ACOUSTICS

Over the past years, acoustics techniques have been applied to a variety of objectives for the use and exploitation of the sea. The major applications include the following aspects.

2.2.1 **Probing the Ocean Environment**

The oceans cover more than 71% of the global surface. This giant water mass is not only a source of food, minerals, energy, and a channel for transportation, but also a decisive factor affecting the world climate. Sometimes ocean processes and conditions can give rise to severe calamities. Acoustic methods are most effective for probing the ocean environment. Sound waves, in comparison with radio and light waves, travel with the least absorption through the sea, and the acoustic method is a non invasive method, causing no interference with the environmental field. Consequently, remote sensing of parameters of the ocean environment can be realized by using underwater acoustic techniques. Knowledge of the 'direct problem' of acoustic research, such as wave-front spreading, absorption, refraction and fluctuation of sound during its transmission through the medium, as well as the reflection and scattering from inhomogeneities, and taking into account the conditions of the area to be probed, permits determination of the environmental parameters, i.e. the inhomogeneities of ocean environment, by measuring the variations of sound waves carrying information about the ocean phenomena.

Human activities, particularly the use of fossil fuels, may contribute to an enhanced green-house effect, which may result in sea-level rise and possibly pose a threat to people living in coastal areas. Acoustic techniques hold great potential for determining parameters in connection with sampling, coring and chemical analysis. Discharge of sewage (both industrial and domestic) and oil spills may cause deterioration of the water quality and deplete the organic resources. Dumping of dredged materials and other solid-state waste into the sea may result in hazards to mankind. Sound signals have been used to trace the dumped sewage and waste and assess the time-space accumulating field, from the reflection and backscattering of the signal, and also to analyze the dilution process and influence on biomass. Sedimentation in harbours and estuaries causes problems for navigation. The sedimentation process can be monitored by Acoustic Doppler Current Profilers (ADCP), optical devices and other samplers. The measurements offer valuable information for the management of navigational channels.

Dynamic parameters, such as currents, current profiles, eddys diffusion coefficient, surface waves and internal waves are of great interest to oceanographers and offshore engineers. ADCPs, both bottom- and shipboard-mounted, are now well established as instruments for determining current and current profiles. Turbulence, small scale processes, bubbles near the surface, internal waves, suspended particles produced by natural sedimentation and polluting processes, and suspended sediment concentrations can also be estimated and monitored by ADCPs. Calibration of the measurements in the laboratory and in situ remains a very important problem. Powerful ADCPs with narrow beams along the horizontal can be used to detect internal waves and estimate coherent length and other properties of microstructure.

Current meters based on the sing-around principles time-difference, which became available only recently, are capable of measuring the residual current with very low threshold and very high accuracy. For some aspects of oceanography, data from the flow through a strait or channel between two ocean basins are needed. By increasing the baseline of an acoustic current meter, it may be possible to obtain an integrated flow whose temporal variation can be monitored.

Inverted echo-sounders with a single, vertical narrow beam measuring the scattering from the air-sea interface and the near-surface bubbles and other inhomogeneities can be used as a sea-level and wave recorder, as well as a monitoring device for the near-surface dynamic layer.

Acoustic tomography on a basin scale initiated by Munk and Wunsch in 1978 is expensive but offers data about sound velocity, temperature, and density profiles in the ocean. This method uses many long-range crossing receiver/transmitter pairs, and for each pair a number of different ray paths allow the ocean to be sampled at different depths. It may be used to detect mesoscale variability in the ocean, but it is recognized that the technique lacks a unique solution. Recently it was suggested that a loud sound initiated in the Southern Ocean may be heard via great-circle paths across all the ocean basins. The travel time will be sensitive to the integrated temperature along the paths, leading to the concept that they could be indicators of global climate change.

2.2.2 **Probing the Seabed Sediment**

Information about the seabed sediment is indispensable for the following objectives:

(i) To produce authorized hydrographic charts;

(ii) To predict or analyze long-range acoustic propagation;

(iii) To evaluate and exploit mineral resources;

(iv) To provide fundamental data for use in coastal and offshore engineering projects;

(v) To provide precise data for the dredging and construction of waterways used for safe ship navigation in shallow water areas harbours with shifting topography;

(vi) To provide information on the nature of ground for fishing operations as well as for fisheries aquaculture;

(vii) To find soil useful for biotechnology;

(viii) To evaluate marine pollution; and

(ix) To provide geological and mineralogical information for fundamental science.

Compared with sampling and optical methods, acoustical methods exhibit evident advantages in time-consumption, cost and capability of eliminating site disturbances such as dehydration and decompression.

In order to develop acoustic methods for sediment probing, the correlation between physical and chemical properties of sediment and their acoustic properties should be clarified. The factors involved in the correlation are as follows:

(i) Physical (chemical) properties of sediment (grain size, porosity, density of particles, weight of particles, volume concentration of particles and others);

(ii) Geotechnical properties of sediment (bearing capacity, shear strength, etc.); and

(iii) Acoustic properties (of longitudinal as well as transverse waves) of sediment (reflection loss, scattering strength, sound speed, attenuation constant, acoustic impedance, resonance resistance and others).

Studies to obtain the correlation between these factors started almost 25-30 years ago. Since there are a lot of variables in connection with this correlation, scientists were careful when selecting statistical algorithms to obtain the final results. They selected characteristic parameters which were easy to measure, store and classify with a computer in situ or in real-time. It appears that these practical studies are now approaching their goal.

Manganese nodules are potentially economically valuable and provide a good source for supplementing the land resources such as cobalt and nickel which are rapidly being exhausted. The data obtained using grabs, trawls, corers, underwater cameras and TV are unreliable and the efficiency of the surveys is very low. The acoustic remote sensing technique provides a fast and effective means for locating nodules. This technique is based on the frequency dependent characteristic of the backscattering of acoustical waves by particles of various sizes. The strength of backscattering which depends upon the Rayleigh law as ka « 1 (ka: Wave n umber x radius, dimensionless) is very weak, and it increases suddenly near ka=1 reaching a large value independent of frequency. The critical frequency and strength of the two kinds of backscattering can be used to estimate the presence, size and abundance of the manganese nodules on the ocean bottom. Research for using this acoustic technique for nodule detection has been carried out in several countries; a multi-frequency system has been developed and used for surveying deep ocean nodules.

Deep-towed, side-scan sonar has also been used for exploration of manganese nodules and hot liquid minerals in the deep ocean and sea mountains.

Both techniques, capable of providing reasonable information over large areas with moderate efficiency, offer helpful means for surveying mineral resources.

Sand and gravel on the continental shelf are also a very important source of minerals and building materials. The exploration and assessment of these resources can be accomplished by an acoustic sediment profiler with the capability of penetrating tens of meters of the sand layer.

2.2.3 **Ocean Acoustic Topography and Acoustic Imaging**

Ocean Acoustic Topography

Detailed systematic sounding of the sea floor becomes increasingly important with the rapid development of ocean research and ocean engineering.

In general, a single beam echo sounder can only measure the depth of water along the track of a ship, thus, the depth between courses remains unkno wn . This depth corresponds to the first echo received. Most sounders use non-stabilized cones of wide aperture (±15°to±30°) therefore, the accuracy of the measured depth is low. Side-scan sonar was developed to detect targets on the sea bottom or in the water on the two sides of a course, e.g. wrecks, rocks, pipelines, cables on sea bottom, etc. and obtain the sonographs, i.e. sea bottom image. Since the middle of the 1970s, any sea-bottom mapping without side-scan sonar coverage is considered unreliable.

There are three ranges of side-scan sonar. The first is the longrange side-scan sonar, GLORIA. Its maxim um operating range per side is 25 km . It can survey 2000 km 2 per day, and it is a fast recconaisance tool for a large area. Many countries, e.g. the United States, the United Kingdom, Brazil and Australia used it for surveys of their Exclusive Economic Zones (EEZ). The second scale of side scan sonar has an operating range of about 2X(500-1000)m. The third is the short- range side-scan sonar, and its operating range is about 2X(50-100)m.

Side-scan sonar is a very useful tool to survey the sea bottom, but the precise depth of the sea bottom cannot be obtained by it. In the middle of the 1970s, the first multi-beam sounding sonar with 16 beams width of 2 2/3° X 2 2/3° was developed. Its maxim um operating range is 11,000 m. It has been used by many countries, e.g. the United States, the United Kingdom, Australia, France and Japan to su rv ey their EEZs.

In the future, acoustic signal processing, digital imaging processing and VLSI will be used to improve performance.

Ocean Acoustic Imaging

Surveying the sea bottom and small undersea objects in detail is more and more important due to the fast development of ocean research and ocean engineering. Light diminishes quickly in water, therefore the maximum operating range of underwater TV is only 5 to 10 meters. Consequently imaging sonar is more useful, and it can be equipped on a ship or ROV. It can be used to survey the terrain of the sea bottom and to detect the target on the sea bottom and in water, e.g. wreck, rock, pipeline, or cable.

There are three kinds of imaging sonar: mechanical scanning, mechanical and electrical scanning and electronic scanning.

High resolution mechanical scanning sonars were developed in the 1980s. In the mid-1980s, some mechanical and electrical fast scanning sonars could scan 10 times faster than the early mechanical scanning sonar.

Recently, a type of digital acoustic imaging system was developed. This new sonar provides rapid access to a high-resolution, three-dimensional image field, viewing simultaneously in both azimuth and elevation, to produce a 'starring' image as well as the traditional range/bearing presentation. This capability is relevant to a number of important requirements, particularly forward-looking sonar for target detection and identification, obstacle avoidance and under-ice navigation.

2.2.4 Sub-Bottom Profiling

Sub-bottom profiling is used by marine geologists and geophysicists to obtain information on the nature and distribution of subsurface sediment. It is also needed by the coastal and offshore engineering community. However, sound behaviour in sediment is more complicated than sound behaviour in the water column. The requirement for deep penetration demands the use of a powerful source with a low frequency, while at the same time, the high resolution requirement needs a sound pulse with a very short duration and high frequency. Thus, the spectrum of the source must extend to several kHz.

Since the 1970s, several new techniques have been applied to improve the sub-bottom profilers. Other than the magnetostrictive transducer, powerful piezoceramics, boomers, sparkers and air guns have been used as sources with wide frequency spectrums and sufficient transmitting power to penetrate from tens to thousands of meters. In order to minimize the interference of ship noise from horizontal an array, an optimized in directivity without increasing size, is towed by the ship.

To achieve a compromise between penetration and resolution, a parametric acoustic array which transmits and receives high frequency sound waves with a pumping frequency has been developed. The heterodyne frequency of the two frequencies in comparison with the original ones is very small and capable of deeper penetration as well as better directivity and resolution.

A towed vehicle is used to carry the array to reduce ship-borne noise and make the array stable. A fairing is placed on the towing cable to suppress its vibration. When the profiler is used to survey the deep ocean, a deep-towed seismic (DTS) system is capable of laying the array deep and probing the sediment at a rather small distance.

Signal processing methods are implemented for various functions. Time-varying filtering is a good approach for maximizing signal-to-noise

(S/N) ratio and reducing multiples. Signal stacking statistics in real-time will increase the S/N ratio greatly. Sea-bottom tracking AGC contributes to reliable bottom reflectivity measurement, digital data display and ease of operation. Expert system stored characteristic properties will be helpful to identify the sediment with high acoustic reflectivity, such as sand and gravel, from soft sediment, such as clays and silts.

2.2.5 Underwater Data Transmission in Oceanography

Present Technology

Most of the underwater acoustic data transmission systems commercially available offer bit rates of 10-500 bits/see over a distance of a few kilometres. These systems are designed to provide excellent performance with a minimum of misinterpretation and false alarms. This is possible by using simple techniques like frequency diversity coding and is implemented by simple hardware.

Applications

The existing systems are used for the control and status determination of submerged equipment. In oceanography, acoustic telemetry is used to transmit data from submerged equipment for measurements of ocean currents and temperature.

One system, especially designed for ocean acoustic tomography, telemetered information between buoys over 3000 km apart. Systems which include tags for fish telemetry are also available.

Research Trends

Current research has been carried out in two directions:

(i) high bit-rate systems designed to operate in a multi-path environment; and

(ii) transmission over very long distances (hundreds of kilometres).

The long distance system requires a model which includes transmission through the bottom layer. For the long distance channel, the frequency spread acts as noise while the time spread gives rise to slow fading.

For the high bit-rate system adequate range is expected to be $\leq$ 1 km, and a high frequency approximation is used for the channel model. The goal of the model is to predict the expected time and frequency dispersion.

System Development

For the long distance systems, pseudo-noise sequences are used for the simultaneous suppression of noise and multi-path interference.

For the high bit-rate system, the major effort is finding methods to overcome multi-path interference. Four different schemes are currently under investigation.

The frequency hopping/spread spectrum techniques offer both moderate multi-path protection and low implementation complexity.

The adaptive equalization (AK) based systems provide efficient multi-path protection without any sacrifice of band width. The same applies to maximum likelihood sequence estimation (MLSE). But, both schemes are sensitive to movement of the transmitter or receiver platforms.

Complexity is also a key issue for these schemes.

The fourth scheme is based upon adaptive beam forming (AB). This method is less sensitive to movement than the AE and the MLSE schemes, but is only able to suppress multi-path arrivals sufficiently separated in space from the direct path. There is considerable implementation complexity associated with this scheme.

The conclusion of the present status is that:

(i) The technology for transmission of simple sensor information over a few kilometres is ready for use;

(ii) Research for high bit-rate systems is going on. These systems can be used for transmission of images over 100-1000 meters;

(iii) Systems for transmission over very long distances (>50 km) are of interest for ocean acoustic tomography for communication between and control of sensor buoys;

(iv) Efficient concepts have been developed by incorporating channel knowledge (adaptability) into the systems;

(v) Attention has been paid to technical issues rather than cost issues and operational demands; and

(vi) The time has come to establish acoustic data transmission as a mature technology by development of realiable easy-to operate system.

2.2.6 Acoustic Positioning

Acoustic positioning of oceanographic equipment on the sea surface, in the water column and on the sea floor has a long history. Two decades ago, low frequency (10 kHz) long baseline systems (LBS) using multiple sea-floor transponders were available commercially. At the same time, the offshore oil industry was purchasing short baseline systems (SBS) to dynamically position oil rigs. Meanwhile, the engineering community was busy extending the resolution, accuracy and range of these systems; oceanographers and ocean engineers were equally busy devising more diverse applications. Ultra-short baseline systems (USBS) only reached the same level of application in recent years with the advent of modern digital processing technology.

At the present time, all three related acoustic positioning technologies have reached a similar state of development. Commercial equipment is available for nearly all applications. The capabilities, limitations and methods of use for each of the complementary technologies are well understood. It is thus safe to say that most user needs can be met with commercial systems. However, if the capability of existing systems were extended, user satisfaction would increase and new experiments could be carried out.

The performance of present USBS equipment, while impressive, does leave room for improvement. The newest receiver on the market supposedly achieves a bearing accuracy of about 0.1 degree, although it is difficult to confirm this claim. Another worthwhile goal would be to substantially extend the USBS operating range to several thousand meters.

The **positioning of manned** submersibles, ROVs and towed systems has always been a task ideally suited to acoustic positioning methodology. There is now a growing interest in autonomous, unmanned, untethered underwater vehicles. A first generation family has been built and tested (ARCS, EPAULARD). These make use of existing positioning technology. The next generation systems are under development (e.g. EAVE East). These will employ positioning systems which merge traditional acoustic positioning systems with obstacle avoidance sonar, inertial navigation and other information through the application of Artificial Intelligence and Knowledge Based System concepts. These vehicle systems will operate for long periods in inaccessible areas such as under the Arctic ice cap or on trans-oceanic crossings. Alternately, they may be operating in close proximity to structures where reflections and noise levels become a serious problem.

2.2.7 **Applications in Fisheries**

One of the earliest applications of marine acoustics was in fisheries. During the last decades, fisheries acoustic methods have evolved into an indispensable tool for fishermen, fisheries biologists and fisheries managers. Theoretical and experimental research in fisheries acoustics has been carried out for a long time. Methods have been studied not only to locate fish schools, but also to measure fish size and estimate abundance. Reliable echo sounders, fishing sonars and other sonar systems have been developed and are now commercially available to locate fish, measure fish distribution and density, and survey fish resources. These standard techniques are complemented by acoustic tags, passive listening, etc.

Recent developments have brought fisheries acoustics to a new threshold. Methods for 'acoustic species recognition' are now being developed. Results from species recognition experiments show in excess of 90% species recognition on groups of three or four species. These have potential to revolutionize fisheries work.

Research efforts have been devoted to using fish emitted sounds for measuring the geographic distribution of fishery resources and to the differences in behaviour versus the time of day and season. Analysis of the fish produced sound in the frequency and time domains has been done, and this knowledge can be used to distinguish the sound from different species, sexes and ages. At present, methods for controlling fishing gear by acoustics are under study, such as the methods for indicating fishing-net position, and trawl opening depth, location, sinking speed, etc.

3. **TRENDS IN MARINE ACOUSTICS**

With the preceding background, trends of interest to the marine acoustics community are now addressed in broad terms.

3.1 SOUND AND THE OCEAN ENVIRONMENT

Sound received in the ocean varies enormously in the space, frequency and time domains. This is both a problem and an opportunity. It is a problem because it complicates performance in many applications; it is an opportunity because acoustic propagation may be used to sense the properties of the ocean remotely.

Understanding the interaction between sound propagation and ocean properties may be regarded as the ´forward´ problem, using acoustics as a probe as the ´inverse´ problem. Clearly advances in theoretical understanding of propagation in the sea are necessary and fundamental; it must proceed as a major academic topic and be encouraged. (Reference 1989 Survey of Models USA). While greater computer powers enable better theoretical models to be developed and ocean propagation to be simulated, difficulties arise because of the inadequate knowledge of dynamic ocean properties as initial and boundary conditions, and because of the limited acoustic data from experiments available to test the models. For long-range studies using low-frequency bands there are additional difficulties requiring more synoptic measurements over reat ocean spaces, which is expensive in ship time, and requires physically larger and more expensive transmitting transducers. The ocean may often be regarded as a linear filter between source and receiver, but the channel is not reciprocal because of the asymmetry caused by current shear and because there are fluctuations in the ocean on time scales comparable with, and shorter than, the travel time. Despite this apparent lack of determinism, many good propagation models exist, and in many applications. Future trends in this forward topic include more propagation experiments in shallow and deep water, short- and long-ranges, and low- and high-frequencies. New agencies wishing to enter in the topic will find short-range high-frequency work cheaper, but there is scope for all. The geographical variation of ocean sound speed structure, seabed parameters, vol um e scattering and noise background means that every worker has virgin territory within reach.

Turning now to the applications of acoustic propagation, the inverse problems, the most ambitious example is ocean acoustic tomography. So far only the United States - and presently also France - have either made or initiated experiments to demonstrate this technique, because of the resources required. The method delivers sound speed fluctuation in 3 dimensions with time, and possibly ocean currents as well, using reciprocal paths. From the first experiment at 300 km horizontal scale, the American teams are moving to 1000 km scale. The opinion of the Workshop participants was that, although no tomography expert was able to attend, useful contributions can be made by others working at shorter ranges; these results will interest oceanographers studying small scale phenomena such as internal waves and fronts, and eventually, the interaction of ocean flow fields with topography. The latter may present extra experimental complications. More tomography experiments are needed to develop the inverse methods, which are not trivial and are a real challenge to statisticians and for analysis.

In addition to the full tomographic (3D plus time) work there are many other simpler applications where inverse methods may be applied, for example, inverted echo-sounders to infer baroclinic property changes at a point and reciprocal 2D transmissions to determine current and shear along a section. An assessment should be made of what properties other than sound speed and current may be possible. One such study reported at the Workshop was the potential of frequency dependent sound absorption co-efficient as an indicator of pH, now highly relevant because of its relationship to CO2 in the ocean and climate. From sound speed and with some salinity assumptions, temperature and density may be estimated. An extreme example proposed recently would observe the interannual changes in very long (inter-ocean) travel times to infer climate changes to average ocean temperature.

The challenge for acoustic technologists will be to simplify and reduce the cost of tomographic methods, perhaps using drifting buoys positioned with precision by satellite navigation and telemetering data via satellite communication.

Successful tomography using seabed geophones has been able to image the 3D structure below the seabed. The static nature of the media is an advantage in this case. Seismic profiling using multi-element hydrophore streamers is an example of 2D tomography and is very highly developed.

In all these propagation applications signal energy must be received, detected and recognized. In the models signal amplitude and phase are calculated but in most applications the essential parameters are travel time and the paradigm sound speed. Thanks to modern clocks, precision of timing is very high and improvements will relate to reduced size and power consumption by possibly placing atomic clocks in situ.

3.2 OTHER PARAMETER ESTIMATIONS USING ACOUSTICS

Signal amplitude is already widely used, for example, in the detection and identification of sources of sound. Further work on mechanisms, directionality, spectra, statistics, and geographical occurrence of noise sources is necessary. Natural sources include surface waves, bubbles, bubble clouds, marine mammals, fish, zooplankton, geoseismics, gas vents, sediments in motion, ice cracking and colliding and many more. Characterization may enable future monitoring of such events in an inexpensive way. Man-made noise includes ships, offshore platforms, aircraft, interference from other acoustic equipment, naval activities, SCUBA venting, port and harbour works.

Signal Backscatter is difficult to measure in absolute, calibrated levels. However, it is required for more complete tests of propagation models and is fundamental to acoustic fish stock estimation. Further progress in methodology and application is expected. Technique standardization is close to realization, but there is some concern about consistency of interpretation which needs attention in the immediate future.

Backscatter will find further application in seabed surveying, already a mature technology using side-scan sonar, for shallow and deep, short-and long-ranges. Absolute scattering has been less important than the patterns of relative scattering revealed by the technique; however, interpretation may be enhanced by further work on Backscatter from rough and sloping surfaces. Recent work on scattering from manganese nodules has shown the way forward.

Backscatter from suspended sediments is potentially useful, especially in view of the role sediments have in pollution sources, sinks and transport. Seabed dynamic morphology will benefit from improved representation of the erosion, transportation and settlement processes which may result from such work in the benthic boundary layer.

Backscatter from near-surface bubbles warrants further study as a means of monitoring the turbulent upper ocean boundary layer and with relevance to air/sea gas exchange and pollution. Backscatter from bubbles also affects long-range propagation as it modifies the acoustic boundary properties. Bubbles also cause errors in short-range inverted echo sounders designed to measure sea level and waves.

Other approaches to measure the directional wave spectrum using acoustics have been proposed but they need further study. Conventional surface wave measuring buoys are difficult and expensive to use especially in extreme conditions, so there may be a future for acoustic methods. Calibration of the satellite altimetry measures is one application, but high resolution of the angular wave spectrum is particularly attractive.

Backscatter from zooplankton, an important component in the marine ecological balance, is less advanced than fish stock estimation but would clearly benefit from similar approaches.

Backscatter from within the water column from any passive obj ect is necessary for acoustic Doppler current profilers. These have become highly developed in recent years and are being deployed in considerable number, on ships looking down and on the seabed looking up. Further improvements may not be so dramatic.

3.3 TRENDS IN MARINE ACOUSTIC TECHNOLOGIES WITH WIDE APPLICATION

3.3.1 Acoustic Navigation

Acoustic navigation has been available for many years but cannot yet be regarded as mature. Expertise in operation is required, so the need remains for robust algorithms to overcome multi-paths, noise problems and surveying in overhead. Application areas include oceanographic equipment moorings, locating ROVs and AWs, divers and manned submersibles; the location of towed vehicles relative to the ship is important, especially since 24 hour surface navigation is expected to improve dramatically when GPS is fully operational. We should look toward acoustic navigation of a submerged object at 5000 m depth to be located relative to the ship within 10 m (0.2%); present systems barely achieve 1%.

3.3.2 Acoustic Telemetry and Control

Acoustic telemetry and control is another long-established technique similarly subject to multi-paths and noise. Data rates are low and need to be improved for many applications, particularly new AUVs and the telemetry of data from seabed instrumentation for onward transmission via satellite communication. New advances in processing signal may offer prospects here. A near future goal is to establish a link with capacity 20 Kbit/s between moving terminals seperated by l km. This link is to have better than 95% availability

3.3.3 Multi-Beam Swath Sounding

These are now becoming available from a number of suppliers, which is good news for customers seeking competitive prices. Advances in signal processing, detection and display are all likely to improve operational performance and convenience.

3.3.4 Imaging

Acoustic imaging has quite a long history but relatively few implementations. Modern signal and image processing and the needs of ROVs and AUVs may bring this forward. Expert systems may aid identification in offshore platform applications where underwater TV inspection systems are obscured by suspended matter. Acoustic non-destructive testing (NDT) by ultrasonics is a specialized application of acoustics, also applied underwater.

Marine Transport Applications

Little development in navigational sounders is expected, although fishing sounders may continue to improve as more is understood about fish, fish schools and zooplankton acoustics.

Acoustics speed logs interacting with the water if the seabed are available, and some large vessels employ acoustic ranging to aid berthing.

Acoustic beacons to mark narrow or difficult channels may find favour in specific sites where buoyage is problematic, e.g. icebound areas.

This brief review of trends in marine acoustics and its application, though by no means exhaustive, does illustrate the wide-ranging nature and potential of the technology. It has an important and fascinating future. There are plenty of opportunities for imaginative science and creative engineering to attract quality specialists, financial support and profitable applications.

4. INTERNATIONAL COLLABORATION

An Expert Consultation was organized on the afternoon of 29 March 1990. Professor Yang Shi'e chaired the Consultation. Further international co-operation and recommendations were discussed. The main results are indicated below.

(i) From the section on future trends, a number of international collaborative opportunity become apparent, and there appears to be great potential benefit from international collaboration. It is clear that science and technology of marine acoustics can contribute greatly to the advancement of marine science.

(ii) It is also clear that marine acoustics should have a broad remit as a branch of acoustic physics, best co-ordinated internationally by ICSU related bodies, and including the ICA, IUGG, IAPSO, SCOR.

(iii) The international co-ordination of the applications of marine acoustics, however, seems more appropriate to the intergovernmental agencies having responsibilities in specific areas:

IOC - for marine science and oceanography where marine acoustics pervades nearly all branches and Programmes;

FAO-ICES-IOC - for fish stock estimation, fisheries science and zooplankton estimation;

IMO - for navigation and transport applications;

IHO - for survey and bathymetry applications; and

Unesco-IOC - for education, training and mutual assistance Programmes in marine acoustics.

(iv) Within the existing and planned Programmes and projects of the above agencies there are components with marine acoustic contributions and potential for more. For example:

IOC-FAO - Ocean science in relation to living resources (OSLR);

IOC - Ocean Dynamics and Circulation (TOGA, WOCE); as appropriate in cooperation with WMO;

IOC-UN - Ocean Science in relation to non-living Resources (OSNLR); and

IOC - Ocean Dynamics and Circulation on the Continental Shelf.

Where marine acoustics can contribute to these efforts, it should. The Workshop recommends that the international committees or groups of experts for these projects seek guidance from acousticians.

(v) Where there are several agencies involved in a Programme, it is recommended that a lead agency take responsibility for seeking and accepting acoustic advice, e.g. FAO for fish stock assessment and IOC for ocean science, oceanography and training relevant to marine acoustics.

(vi) It is recommended that a Group of Experts on Marine Acoustics be set up under IOC. It is also recommended that IOC give the following tasks interalia to the Group of Experts:

a) To form a focus for international collaborations;

b) To plan a second Workshop on Marine Acoustics at the next International Conference on Acoustics in China, 1992;

c) To advise IOC on the applications of marine acoustics to the IOC Programmes; and,

d) To advise IOC on Sections (vii), (viii) and (ix).

If this recommendation is accepted, it is suggested that the group be strengthened by wider international membership. Acceptance implies the provision of resources for meeting and secretariat assistance.

(vii) It is recommended that IOC consider the following activities:

a) Training courses in marine acoustics for scientists and technologists from developing countries. (The Peoples' Republic of China is keen to contribute.);

b) Sponsor an Advanced Study Institute (2 weeks) on Marine Acoustics and Civilian Applications thereof (similar to NATO ASI); and

c) Sponsor international exchanges (1 or 2 years) of scholars and advanced students.

(viii) It is recommended that IOC encourage collaboration among national agencies undertaking marine acoustics:

a) To avoid complete duplication;

b) To ensure information exchange and intercomparisons between possibly overlapping research areas and applications;

c) To identify and fill gaps in knowledge; and

d) To encourage joint and multi-lateral projects especially where single nation resources are inadequate, for example, the long-range ocean propagation experiments. Many national agencies have the theoretical talents to bring these projects into being.

The way in which IOC may implement these collaborations is open for discussion. The following are some suggestions:

a) IOC uses its good relationships with other international agencies to communicate the benefits of collaboration in this field;

b) IOC designates projects in marine acoustics as being recognized. This will often unlock further resources from national agencies; and

c) The national delegates to the IOC Assembly be informed and exhorted to communicate these opportunities to their own countries and agencies if these are not already involved.

(ix) There is a need for wide-ranging marine acoustic data bases, for example, on noise levels and on standardized oceanographic input data for acoustic propagation models. It makes sense for these to be associated with the international and national oceanographic data bases (as in the case for example the Peoples' Republic of China) and included in the IODE Programme.

The Committee on IODE and the IOC Group of Experts on Marine Acoustics should work together to determine parameters to be banked and the standardized formats for the input and output of such data.

(x) Resource surveys by acoustic means, particularly of the EEZs of developing nations, are expensive. It is recommended that IOC facilitates the carrying out of such resource surveys, as appropriate, inter alla by:

a) Informing through its own contacts the availability of such procedures;

b) Using its inter-agency contacts to obtain financial support for such surveys;

c) Acting as introductory broker between surveyor and customer to ensure efficient use of international funds; and

d) Encouraging exchange of major facilities between developed nations.

(xi) There are aspects of marine acoustics which come close to legal problems in international waters. Few workers in marine acoustics would wish to introduce frequency band allocations as in the electromagnetic spectrum, but there is a case for an IOC sponsored voluntary code. Alreadymuch fish stock assessment is carried out at 38 kHz (with 110 kHz and 200 kHz as further options). Several airlines follow CAA guidelines on underwater location beacon frequencies. Changing acoustic frequencies of existing equipment is not easy because of the inherent narrow band nature of transducers. Any recommendation must be couched in terms of a future voluntary code. There are benefits to the user as compliance may reduce inter-equipment interference. Some experiments must inherently be wide band. Problems are more likely at low frequencies because of the longer ranges and lower absorption.

5. **CLOSURE OF THE WORKSHOP**

Professor Guan expressed his gratitude to the participants for their contribution to the Workshop. He closed the Workshop at 16:30 on 30 March 1990.

ANNEX I

PROGRAMME OF THE WORKSHOP

MONDAY MORNING, MARCH 26

Plenary Session PI 9:30 - 11:10 a.m.
Chairmen : L. Bjorno, Li Yunwu
Pl-l 9:30
SOME EXPERIMENTS ON THE LOW FREQUENCY LONG DISTANCE PROPAGATION IN ATLANTIC (L.M. Brekhovskikh)

P1-2 9:55
HIGH FREQUENCY INTERNAL WAVES AND ACOUSTIC FLUCTUATION IN THE SHALLOW WATER THERMOCLINE (Wang Dezhao)

P1-3 10:30
RESEARCHES ON SOUND SCATTERING AT HSEI (Yang Shi'e)

Plenary Session P2 1:30 - 4:45 p.m.
Chairman: Yang Shi'e

P2-1 1:55
SOME RECENT ADVANCES IN SHALLOW WATER ACOUSTICS IN CHINA (Guan Dinghua)

P2-2 2:20
UNDERWATER ACOUSTIC TRANSDUCERS AND ARRAYS (L. Bjorno)

P2-3 2:45
ON PERSPECTIVE OF USING ACOUSTICS TO PROBE OCEAN ENVIRONMENT (Li Yunwu)

(Tea Break 3:10 - 3:30 p.m.)

P2-4 3:30
UNDERWATER ACOUSTIC STUDY AND ITS APPLICATION ON OCEAN RESEARCH IN JAPAN (Minoru Nishimura)

P2-5 3:55
INVERSE SCATTERING PROCEDURES FOR LAYERED SEA BOTTOM (tin Junxuan)

P2-6 4:20
SOME PROBLEMS ON BEAMFORMING (Gong Xianyi)

TUESDAY MORNING, MARCH 27

Plenary Session P3 8:20 - 12:00 a.m.
L.M. Brekhovskikh, Guna Dinghua

P3-l 8:20
ADVANCED SIGNAL PROCESSING IN MARINE ACOUSTICS (Hou Chaohuan)

P3-2 8:45
MARINE ACOUSTIC NAVIGATION AND POSITIONING: A STATUS REPORT (D.L. McKeown)

P3-3 9:10
ARRAY DESIGN AND PROCESSING METHODS FOR UNDERWATER SOUND MEASUREMENT (Ma Yuanliang)

P3-4 9:35
OCEAN MEASUREMENTS USING ACOUSTICS (B.S. McCartney)

(Tea Break 10:00 - 10:20 a.m.)

P3-5 10:20
SOME ADVANCES IN RESEARCH ON OCEAN ACOUSTIC FIELD (Zhang Renhe)

P3-6 10:45
A PORTABLE HIGH PRECISION THREE-DIMENSION TRACE MEASURE SYSTEM FOR UNDERWATER HIGH SPEED MOVING TARGET (Ding Yuzhong)

P3-7 11:10
PROGRESS IN THE THEORY OF SOUND PROPAGATION IN LAYERED AND QUASI-LAYERED MEDIA (O.A. Godin)

P3-8 11:35
THE APPLICATION OF DIGITAL TIME CORRELATIVE ACCUMULATION TO ECHO SOUNDER AND FISH FINDER (Xu Tianzeng)

TUESDAY AFTERNOON, MARCH 27

Plenary Session P4 1:30 - 4:45 p.m.
Chairman : Ma Yuanliang

P4-1 1:30
COMMUNICATIONS PROBLEMS IN UNDERWATER ACOUSTICS : THE SHIP TRAFFIC NOISE (G. Tacconi)

P4-2 1:55
SELF-ADAPTIVE PERIODIC SIGNAL ENHANCER/INTERFERENCE SUPPRESSOR (Xiang Dawei)

P4-3 2:20
HIGH SPEED UNDERWATER ACOUSTIC DATA TRANSMISSION, A BRIEF REVIEW (G.H. Sandsmark)

P4-4 2:45
REMOTE SENSING OF OCEANIC MANGANESE NODULES BY ACOUSTIC WAVE (Liao Yunhe)

(Tea Break 3:10 - 3:30 p.m.)

P4-5 3:30
M.851 IMAGING SONAR AND M861 MINI MULTI-BEAM ECHO-COUNDING SONAR (Zhu Weiqing)

P4-6 3:55
SOUND SCATTERING FROM THE BOTTOM COVERED BY MANGANESE NODULES (Y. Zhitkovsky)

P4-7 4:20
IN SITU MEASUREMENT OF ACOUSTIC PROPERTIES IN MARINE SEDIMENT (Chen Huagong)

WEDNESDAY MORNING, MARCH 28

Session A1 8:20 -12:00 a.m.
Chairmen : M. Nishimura, Lin Junxuan

Al-1 8:20
INVERSION FOR THE SCATTERING FROM A CYLINDER (Feng Shaosong)

A1-2 8:40
ACOUSTIC AND SEDIMENTOLOGICAL EVIDENCES OF GAS CHARGED SEDIMENTS IN ADRIATIC SEA (MEDITERRANEAN) (P.V. Curzi)

A1-3 9:20
THEORY OF COHERENCE OF SHALLOW WATER SOUND FIELD (Zhu Ruichao)

(Tea Break 10:00 - 10:20 a.m.)

A1-6 10:20
CHARACTERISTICS OF RANDON TIME-VARIANT SOUND CHANNEL IN SHALLOW SEA (Pu Yubin)

A1-7 10:40
INVESTIGATION OF THE LOW-NOISE CHANNEL IN THE SEA (Wu Guanjun)

A1-8 11:00
ACOUSTIC ESTIMTATES OF STOCK ABUNDANCE OF YELLOW SEA SARDINE (sardinops melanostictus, Temminck and Schrdinops) (Chen Yuzhen)

A1-9 11:20
CRITERION OF MAINLOBE SHARPNESS FOR BEANFORMING OF TOWED LINE ARRAY (Shan Bingyi)

Session B1 8:20 - 12:00 a.m.
Chairman : B. McCartney, Hou Chaohuan

B1-1 8:20
DEVELOPMENT AND APPLICATION OF DDC1 - 1 GEO-SONAR (Zhang Shuying)

B1-2 8:40
SUBMARINE PROSPECTING AND PARABOLOIDAL ACOUSTIC SOURCES AND COMPARISON WITH CONVENTIONAL DEVICES (G.B. Cannelli)

B1-3 9:00
IN SITU TARGET STRENGTH MEASUREMENTS ON ANCHOVY (Engraulis japonicus) AND SARDINE (Sardinops melanostictus) (Chen Yuzhen)

B1-4 9:20
TWO DIMENSIONAL WIGNER-VILLE SPECTRUM OF THE RANDOM TIME-VARIANT ACOUSTIC CHANNEL IN OCEAN (Zhu Ye)

(Tea Break 10:00 - 10:20 a.m.)

B1-5 10:20
FFT-BASED FREQUENCY DOMAIN ALE (Wang Yanlin)

B1-6 10:40
APPLICATIONS OF ACOUSTICS IN UNDERWATER GEOLOGICAL SURVEY (Hue Lesun)

B1-7 11:00
TIME DELAY ESTIMATION BY ADAPTIVE NOISE CANCELLER (Wang Jinlin)

B1-8 11:20
THE PERFORMANCE OF EIGEN-ASSISTED ARRAY PROCESSORS IN PRESENCE OF CORRELATED SENSOR SIGNAL FLUCTUATION (Ren Dejian)

Bl-9 11:40
A PASSIVE SONAR SYSTEM WITH MULTIPLE TWO-ELEMENT ARRAY (Xiang Chuqi)

WEDNESDAY AFTERNOON, MARCH 28

Session A2 1:30 - 5:10 p.m. Room 211
Chairmen: G. Tacconi, Zhang Renhe

A2-1 2:10
SOUND PROPAGATION THROUGH THE THERMAL FRONT IN THE COASTAL SEAS OF KOREA (Jung Yul Na)

A2-2 2:30
NUMERICAL PREDICTION FOR VIBRATION AND SOUND RADIATION FROM SUBMERGED REVOLUTIONAL SHELL EXCITED BY SOUND SOURCE (Zhang Jingdong)

A2-3 2:50
THE INVESTIGATION ON A NEW WIDE-BAND TRANSDUCER WITH PIEZOELECTRIC LAYERED RING (Yuan Yiquan)

(Tea Break 3:10 - 3:30 p.m.)

A2-4 3:30
TRANSMISSION LOSS OF SOUND SIGNALS IN THE NORTHERN YELLOW SEA REGION (Xiao Jinquan)

A2-5 3:50
ACCELERATION RESPONSE CANCELLATION AND MEASUREMENT OF TOWED LINE ARRAY HYDROPHONE (Zhu Houqing)

A2-6 4:30
LOW-FREQUENCY ELECTROACOUSTIC SENSITIVITY OF A COMPOSITE CYLINDER TUBE TRANSDUCER (Song Mingkai)

A2-7 4:50
APPLICATION OF THE TRANSDUCER WITH FIBER-OPTIC LEVER IN HYDROACOUSTIC MEASUREMENT (Chen Shou Liu)

Session B2 1:30 - 5:10 p.m.
Chairmen: D.L. McKeown, Gong Xianyi

B2-1 1:30
RESPONSE OF ADAPTIVE MATCHED FILTER TO SIGNAL VIA MULTIPATH (Qian Qiushan)

B2-2 1:50
BREAKING DOWN OF A MULTIPLE ECHO MADE OF OVERLAPPING SINGLE ECHOES OF IDENTICAL TARGETS (G. Gimenez)

B2-3 2:10
THE DESIGN OF PROGRAMMABLE DICANNE SYSTEM (Cai Huizhi)

B2-4 2:30
HIGH RESOLUTION BEARING ESTIMATION FOR WEAK SIGNALS IN NONWHITE NOISE FIELD 5Shen Wenmiao)

B2-5 2:50
A NEXW ACOUSTIC CODED COMMAND SYSTEM (tin Shaoxian)

(Tea Break 3:10 - 3:30 p.m.)

B2-6 3:30
A TRIAL OF USING THE CLUSTER ANALYSIS FOR CLASSIFYING THE SHIPS WITH THEIR NOISE (Chen Geng)

B2-7 4:10
DEPTH MEASUREMENTS OF SCATTERING LAYER IN SHALLOW WATER (Zhang Yunpeng)

B2-8 4:30
THE FEASIBILITY OF MEASURING OCEAN PH BY LONG-RANGE ACOUSTICS (din Guoliang)

B2-9 4:50
A DEEP-SEA ACOUSTIC ELEVATION TELEMETER (Huang Ximing)

THURSDAY AFTERNOON, MARCH 29

EXPERT CONSULTATION 1:30 - 5:00 p.m.
Chairman Yang Shite

FRIDAY MARCH 30
8:30 - 12:00 a.m. 1:30 - 5:00 p.m.
DISCUSSION AND ADOPTION OF SUMMARY

ANNEX II

LIST OF PARTICIPANTS

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ANNEX III

LIST OF ACRONYMS

ADCP	Acoustic Doppler Current Profiler
ADP	Ammonium Dihydrogen Phosphate
AE	Adaptive Equalizer
AGC	Automatic Gain Control
ALE	Adaptive Line Enhancer
ASK	Adaptive sidelobe Canceller
ASI	Advanced Study Institute
AUV	Autonomous Underwater Vehicle
CAA	Civil Aviation Authority
DTS	Deep-towed Seismic
EEZ	Exclusive Economic Zones
FAO	Food and Agriculture Organization
GPS	Global Positioning System
IAPSO	International Association for the Physical Sciences of the Ocean
ICA	International Congress of Acoustics
ICES	International Council for the Exploration of the Sea
ICSU	International Council of Scientific Unions
IHO	International Hydrographic Organization
IMO	International Maritime Organization
IOC	Intergovernmental Oceanographic Commission
IODE	International Oceanographic Data Exchange
IUGG	International Union of Geodesy and Geophysics

LBS	Long Baseline System
NATO	North Atlantic Treaty Organization
PVdF	Polyvinylidenefluoride
ROV	Remotely Operated Vehicle
SBS	Short Baseline System
SCOR	Scientific Committee on Ocean Research
USBS	Ultra-Short Baseline System
VLSI	Very Large Scale Integration

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