OCEAN TECHNOLOGY: BENEFICIARY OF AND BENEFACTOR TO ENERGY AND DATA STORAGE, COMMUNICATIONS, AND MATERIAL DEVELOPMENTS IN SISTER FIELDS

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Abstract – Ocean technology is a subset of technology in general with a few peculiar constraints and a few areas of technological elaboration. Certain commercial developments have been extremely beneficial to ocean technology, such as electronics developments driven by portable calculators and laptop computers. In a few cases such as underwater acoustic telemetry and robotics, ocean applications drive technology that benefit the general field.

1. LOW POWER, THE THEME OF UNDERWATER ELECTRONICS

In 1969, when I came to ocean engineering from physics, I was introduced to Complimentary Metal Oxide Semiconductor (CMOS) logic circuits for digital electronics. Our group at Woods Hole Oceanographic Institution was desperate to get a CMOS microprocessor, and Frank Snodgrass at Scripps took one from the new HP35 pocket calculator. Digital electronics was new to me and my tutors made CMOS seem natural; however, I soon came to realize that the rest of the world didn't care much for CMOS, thought the 1802 CMOS microprocessor was arcane and engineers from other industries thought our power constrained world was a backwater in electronics.

A. Commercial Benefactor – Pocket Calculators

In time, as pocket calculators became more popular, we were vindicated. Our low power backwater became big business, stimulated by a consumer product, leading to microprocessors, data storage, and battery developments from which we have benefitted greatly. Other industries must experience similar benefits from outside market developments.

We got lucky when the constraints of battery energy for pocket calculators matched our own constraints for volume and weight to power autonomous instrumentation. Each is energy constrained, unlike space instruments which are power constrained by solar or thermoelectric generators.

Now we, as consumers, have become so fond of cutting the electric power cord that we have stimulated development of portable (read small, low power, rugged) disk drives, camcorders, and cellular phones. There has even been a revolution in small electric motors such as used in battery powered screwdrivers and drills. We ocean engineers have benefitted from all of these.

B. Battery Developments

Our need for compact energy sources for underwater instruments led us from Leclanche cells to NiCad cells to alkaline carbon-zinc cells to lead acid gel cells and to lithium cells of various types with offshoots to magnesium cells, air-zinc cells, silver-cadmium and silver-zinc cells, and various fuel cells. None of the offshoots have had a significant impact on us yet. But we depend greatly on alkaline and lithium cells to provide energy over long periods in underwater instruments. When short duration, heavy loads must be supported, we use gel cells, trickle charged from the higher impedance but longer shelf life sources.

New energy sources are eagerly sought and one, the aluminum seawater cell, is being used in a few applications. This last is a development peculiarly ocean related and thus driven

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by our needs, but limited by the unavailability of a consumer market.

Possibly the biggest benefit we as ocean engineers have received in the battery business is the internal volume expansion of the alkaline D cell driven by advertising competition between Duracell and Eveready.

Lithium cells have proved critical to many volume and weight limited applications, and the lithium-thionyl chloride chemistry has reduced our fear of lithium explosions. Difficulty in shipping these cells and their high cost are now the greatest barriers to their increased use. Our need to put cells in sealed housings was a factor in the development of hermetically sealed (in glass to metal seals) lithium cells. Our early experience with corrosive gas diffusion from plastic sealed lithium cells almost killed their acceptance as underwater energy sources. Accidents with Li-SO_2 chemistry and with damaged batteries of lithium cells slowed their acceptance. Great efforts have been made to educate us by the lithium cell manufacturers as well as to improve the cells.

C. Power Saving Techniques

Shortage of lithium cells during the 1991 Gulf War encouraged me to do what many of us have been doing in our technical developments: I learned to do the same job with lower power by using more efficient switching regulators, going to sleep mode between measurements, and strobing the power to components and A/D converters when analog signals were present. In fact, power saving techniques offer orders of magnitude increases in mission length compared to factors of two for cell improvement. Low power devices, microprocessors and A/D converters with sleep mode, and efficient switching regulators, are now available, thanks in part to demands of portable computers.

2. DATA STORAGE, AUTONOMOUS INSTRUMENTATION'S DEMAND

The extension of mission length leads to demand for increased data storage capacity. Tape, the choice twenty years ago, has been challenged by hard disk, courtesy of laptop computers. Video cassette recording has increased capacity of tape to make digital cassette recording an option for some applications. Optical disk recording has its fans too. However, low temperatures encountered in deep-sea applications have not generally been considered in commercial digital cassette tape designs and tilt has presented problems for optical disk recorders designed for desk top use. Intel's newly announced 20 M byte EEPROM flash memory card may become popular with ocean engineers for the same reason it is hoped to be popular with laptop designers: low power, small size, and robustness.

The impact of laptop computers indirectly on ocean engineering brings me to the next observation on technological benefits to our craft. The power of PCs and workstations has permitted post processing of data that was formerly a major task on a large computer. This opens up the possibility of fitting observations to models that might not have been attempted previously. Thus shoreside compute power increases ocean instrument capability. Coupled with in situ processing of low level data and immense in situ data storage, the shoreside analysis packages make very complex measurement systems possible.

3. COMMUNICATION, A WAY AROUND DATA STORAGE

Real time data return, data return from expendable instruments, and untethered vehicle control require underwater communications.

A. Acoustic Telemetry

Telephone modems and deep space telemetry techniques have not helped us much with moderate and long pathlength acoustic telemetry in the sea. More general signal processing theory has been applied to the multipath, fading acoustic channel in the ocean to create multi-frequency shift keying (mfsk) and coherent mfsk modems for high bandwidth data telemetry. At the opposite end of the frequency spectrum, basin scale and longer acoustic signals have been sent to probe the heat content of the ocean surface tomographically. Also, mid-water floats have been tracked for the last decade and a half by long range acoustic chirp. In this area, ocean engineering has led the field of communication, rather than borrowing from it. Our need was peculiar, a layered, moving sound channel with stable phase but unstable amplitude. If similar conditions occur in radio transmission, radio engineers can learn as much from us as we do from them.

B. Fiberoptic Cables

Where a cable can be tolerated, ocean engineers have developed and used fiberoptic tethers and power cables to communicate video images and will soon use them to communicate muon particle coincidence in the Deep Underwater Muon and Neutrine Detector (DUMAND) experiment and real time environmental conditions at a bottom observatory off New Jersey. Their role in Remote Operated Vehicle (ROV) tethers is assured. The development of high strength fiberoptic cables is an ocean engineering achievement, distinct from the important development of fiberoptic land lines and undersea telecommunication cables. Much is taken from termination technology developed elsewhere, and the glass technology and fiber construction itself has been driven by the commercial users (although oceanographers were the first to clamor for 10 km lengths of single fibers). The cable construction, torque balanced and nonkinking, is an ocean engineering success.

C. Satellite Telemetry

Satellite telemetry of data transmitted from surface buoys has provided the communications link for meteorological instrument packages and completed the link for subsurface instruments communicating to the surface by acoustic modem or inductive or conductive cable. Expendable instruments and drogued surface (or subsurface) drifters depend on satellites to determine their positions and return their data. We have not provided these satellites, but rather used excess capacity on satellites put up for other purposes. Argos has been the most accessible position and data linking satellite, though its data throughput is low. Some of us are pushing the satellite community for more bandwidth and they are responding.

D. Radio Telemetry

In the coastal zone, developments in packetizing modems for radio transmission of data make buoy to shore links easier. Cellular phone service can provide a communications network of use to certain richly instrumented regions. Ocean engineering can benefit from the packaging effort that has gone into the commercial demand for communication products. Radios are small and interface easily to microprocessors.

E. Networks

Communications ashore have improved greatly through high speed networks. Internet permits scientists and engineers at different institutions to exchange data sets and programs rapidly and easily. There is great pressure to increase the size of data sets that can be exchanged and the capacity appears to exist to do it via fiberoptic telecommunications.

4. MATERIAL DEVELOPMENTS

Microelectronics material developments have impacted ocean engineering as they have other fields.

A. Successes, Semiconductors

Laser semiconductor diodes (LSDs), developed to drive fiberoptic cables and to read compact disks, provide an important light source for underwater sensors. We need LSDs that emit in the blue or green (670 nm was the shortest wavelength available a few years ago) and these are not being developed.

Polyvinylidene fluoride (PVDF), a piezoelectric copolymer, has been a benefit to hydrophone designers who can even integrate the hydrophone sensor into the preamp circuit for miniaturization and robustness. Similar progress has occurred on hydrophone development through microelectronic fabrications, etched and deposited structures producing tiny transducer elements.

B. *Misses*

Our craft has not derived much benefit yet from high temperature superconductivity. Cryogenic magnets for magnetohydrodynamic propulsion research is the sole exception I know. Molecular engineering is not a part of any sensor I am aware of, but could conceivably provide material to coat glass fibers for specific chemical sensing.

C. *Structural Materials*

Structural material developments have been more helpful to us. Graphite fiber composites are very light and stiff, which is valuable for underwater frameworks to maintain precise alignment. Pressure housing materials have not changed greatly, but titanium is used more frequently for small pressure cases that result from electronic miniaturization and decreased battery demand. Titanium can be left bare, saving the cost of surface treatment and maintenance and extending deployment life beyond five years. It is economical to bore cases from solid rod, saving the closure at one end. In larger size cases, aluminum remains the material of choice. Both glass and injected plastic are finding their way into special instrument cases where they perform very well, not corroding and being transparent.

Cable material developments have permitted non-corroding lightweight mooring lines of Kevlar and Spectra to be made. We have learned to use the former material, over several years, in appropriate ways. Our applications are peculiar, not the tire tread application that drove the development. But they benefit us greatly.

5. PLATFORMS

Sensor platforms are peculiar to every specialty and we use Swallow floats, Autonomous Underwater Vehicles (AUVs), Remote Operated Vehicles, and free and tethered profilers to supplement our more traditional deep sea winch lowered instruments and moored buoys. We have borrowed little from sister fields in these areas, but in a few have made contributions to them.

A. *Undersea Robotics*

The seafloor is sufficiently remote that control of vehicles there is not trivial. Navigation and positioning requires robotic intelligence and the seafloor environment provides a laboratory for the development of these techniques. There are few legitimate demands for robotics other than the deep sea, particularly with the relatively low bandwidth connection to the operator imposed by coaxial or multiwire cables. As a result, developments in supervisory control and pattern recognition in undersea robotics may benefit the entire field in a major way.

B. *Swallow Floats*

Hovering, neutrally buoyant floats are the underwater satellites of oceanography. Taking no power to maintain depth, they can mark or monitor a parcel of water for an extended time. The elaboration of types of Swallow floats from Sound Fixing and Ranging (SOFAR) Floats in the 1970s to Rafos (inverted SOFAR), Autonomous Lagrangian Circulation Explorer (ALACE), and Slocum (named for the first solo circumnavigator) in the 1990s, shows the technology to be an important one. SOFAR passively drifted, transmitting sound into the SOFAR channel for remote tracking. Rafos listens to fixed acoustic beacons as it drifts, storing the navigational raw data for transmission to satellite at the end of its mission, when it surfaces. Alace comes to the surface repeatedly, pumped up by electric power, to give its position and report environmental conditions. Slocum will eventually glide from the surface to a depth within or below the thermocline, powered by the thermal difference over its vertical excursion.

C. Autonomous Underwater Vehicles

Slocum is an AUV, but a special member of the class. Other powered AUVs are under development, some gliding like Slocum, other propelled more conventionally by thrusters. Little can be borrowed in these developments from sister fields. Possibly the ultra low powered aircraft (Gossomer Albatross, for example) offer some lessons. AUVs depend a great deal on what has gone before in ocean engineering in platforms, robotics, electronics, and material choices.

6. SUMMARY

Ocean engineering has in the past benefitted greatly from technology developed for commercial products such as computers, toys, and land communications. It has developed technologies of its own driven by power limitations, bandwidth limitations, long ranges and long durations in deployments, and to a degree, its corrosive and otherwise hostile environment. Some of these have fed back to sister fields. There is increasingly a core of technology that is peculiar to oceanography and internally interdependent. But for a long time to come, we in ocean engineering will continue to benefit by technology developments in sister fields.

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