EXTENDING SENSOR DEPLOYMENT THROUGH INTEGRATED ENERGY MANAGEMENT

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LONG-TERM GOALS

The long term goals are to extend sensor deployments in Autonomous Ocean Sampling Networks (AOSNs) by: Maximizing the available energy and energy efficiency in all necessary subsystems; Establishing strategies for utilizing energy to greatest effect, and; Developing fault-tolerant power management systems. By focusing on these areas, we will dramatically increase the amount of data produced in an AOSN deployment while using available battery chemistries.

OBJECTIVES

The objectives are to develop and demonstrate the key energy management methods for extended deployments of AOSNs. These methods are:

1) The efficient, inductive transfer of electrical energy from a mooring to a sensor platform.
2) A "smart battery" capable of using a wide range of call chemistries, with a seamless interface to the energy transfer system above.
3) The integration of these new technologies into an Autonomous Underwater Vehicle (AUV), and their demonstration through deployment as part of a scientific field program.

The challenges are: To maintain very high efficiency at every stage of the process from the mooring energy source all the way through to the battery on the AUV; To create ultra-low power electronics for the smart battery, thus preserving battery life; To define the interface to ensure both independence from cell chemistry and ease of integration; To develop methods of transferring electrical energy through sea water with DC isolation; To develop energy-efficient methods of interrogating the voltage of an electrochemical cell while maintaining DC isolation, and; To integrate all of the above into the limited volume and mass available on a small, survey class AUV.

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APPROACH

We began by identifying the key technical challenges (defined above). We recognized that, by careful definition of the standard for the power bus on the AUV, the problem decomposed itself into three efforts:

In-Situ Power Transfer (and its Interface to the Power Bus)
Autonomous Battery Management (and Interface to the Power Bus)
Maintenance of Power Bus Integrity and Load Switching on the AUV

The expertise of Dr. Feezor at in-situ inductive power and data transfer is unparalleled. Similarly, Dr. Bradley is widely acknowledged as one of the finest designers of micro-power instruments for oceanography. Drs. Bellingham and Bales have played critical roles in the design, development, and construction of the Odyssey-Class AUVs (and their power systems), and of the AOSN concept. Together, this team is uniquely qualified to advance the state of the art in energy management for autonomous sensor platforms. The key to success has been careful definition of the interfaces between the elements of the system, close communication among the collaborators, and extensive instrumentation of the apparatus.

WORK COMPLETED

In-situ power transfer was demonstrated during a May, 1997 cruise in Cape Cod Bay. The power level into the AUV was approximately 200 Watts. The overall transfer efficiency was measured to be 79%.

The prototype 3 kW-hr smart battery is complete and undergoing testing. The entire system has been exercised on the bench, with electrical energy being transfered from a power supply ,through the inductive power-transfer link, onto a prototype power bus, through the smart-battery interface, and into high-energy-density silver-zinc cells. The characterization of the transfer and charging process is continuing.

Integration of the prototype system into the Labrador Sea AOSN has begun.

RESULTS

The two biggest technical results over FY 97 were the demonstration of in-situ power transfer, and the creation of the prototype smart battery. Each will be discussed in turn below.

In Situ Power Transfer

We succeeded in transfer energy, in situ, from an AOSN dock into an AUV, and have collected the data necessary for quantifying the performance. Preliminary analysis shows that the performance in the field is similar to that seen in the lab (around 80% transfer efficiency at approximately 200 to 250 W). Below, we describe the apparatus (Figure 1) used during the cruise and the procedure followed to collect the data. Finally, the results from one of the ten runs are presented analyzed, and discussed.

Apparatus Figure 2a shows inductive-power-transfer cores mounted on the prototype AOSN dock developed at WHOI under the AOSN MURI (Yoerger and Singh). The electronics to drive the core are in the same pressure housing as the rest of the dock electronics The dock uses a motor-driven carriage to clamp the AUV in the dock (Figure 2b). Both the AUV and the mooring recorded the output of their respective power monitors continuously, updating at 5 Hz and 0.12 Hz respectively.

In laboratory test at WHOI on February 16, 1997, the power transfer system achieved 83% efficiency with 128 W received by the AUV. Calibration data for the system was retaken on 26 April 1997 and 16 May 1997, and the calibration was stable. The power transfer system provides concurrent Ethernet data transfer (10 megabits/sec, bi-directional), Hardware problems precluded testing the Ethernet in the May deployment, but in situ data transfer was quite successful during the first cruise of FY98.

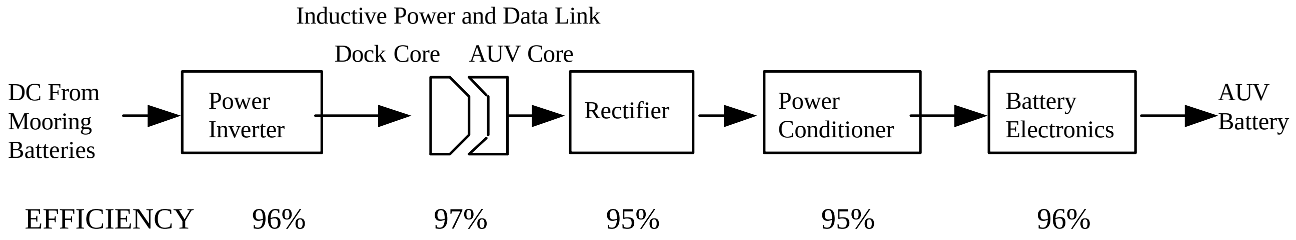

Figure 1: Schematic of the Power Transfer Link. The overall efficiency through the power conditioner is measured to be 83%. Multiplying the efficeinces above gives an estimnated overal efficiency of 80%.

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Figure 2: a) Photograph of the power-transfer cores mounted on the dock. The dock (funded through the AOSN MURI) is described in the literature [Singh, et al.]. The AUV caries a mating power-transfer core. When the AUV is on the dock, a motorized carriage forces the AUV against the white ring (labeled "2") and forced the core on the AUV to mate with a core on the dock. This inductive provide both power transfer (200 W, 79% efficiency) and data transfer (10 megabits/sec, bi-directional). b) Photograph of AUV in dock. For this photograph the dock was at the surface. In normal operation it is submerged.

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Figure 3: Results of in-situ power transfer (mission W0513.06 on 15 May 1997). The open blue circles are the power supplied the power transfer system. The green crosses are the power received resistive load on the AUV. The black line is the instantaneous efficiency. Note that the efficiency is typically 79% at a power level of approximately 200 W received by the AUV.

Procedure On each run the core was energized once the AUV was attached the dock, and magnetic switches showed the cores on the dock and the AUV were engaged. The dock recorded the voltage at the input to the power-transfer system and the integrated current consumed. These values were recorded once every 9 seconds (0.12 Hz sampling). The AUV recorded the voltage at the input to the resistive load and the integrated current delivered. These values were recorded once every 0.2 seconds (5 Hz sampling). The higher sampling rate used by the AUV introduces greater variations to the data than seen in the mooring data, but that variation can be handled by simple averaging.

Results Preliminary results of the power transfer is shown in Figure 3. The time axis has been arbitrarily set to zero just before power transfer began. We see that both the power received by the AUV tracks the delivered by the mooring, and they are relatively constant except for a period around 200 seconds and a longer period between 300 seconds and 450 seconds. These periods of high variability do not correspond to the times when the carriage motor was off (i.e. those periods when the carriage was not actively forcing the AUV into the saddle which might allow the cores to separate slightly). It appears that the cores had two states of contact, and when the AUV had some freedom to move, it could transition from one state to the other. A second generation dock built by WHOI addresses this issue. The new system is undergoing tests in sea water at WHOI. Taking the 500 second mark as characteristic of the power transfer when the AUV is actively clamped by the carriage, the power into the AUV is just over 200 W, while the power into the mooring system is approximately 250 W, for an estimated power transfer efficiency of 79%.

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Figure 3: The prototype smart-battery pack integrated into the aft sphere of an Odyssey II AUV. The 56 silver-zinc cells (45 A-hr each) are arranged in 4 series strings of 14 cells each. Each series string has associated electronics (e.g. mounted on the panel facing forward) that perform high efficiency (96%), bi-directional DC-DC conversion, monitoring of individual cell voltages (with DC isolation), true current integration, unattended recharge, and a simple serial interface to the AUV computer.

Prototype Smart Battery

The prototype of the smart battery has been assembled and is shown in Figure 4. Its specifications are summarized in Table 1. The system consists of 56 Yardney LR30 Silver-Zinc cells and four sets of custom, micropower, electronics developed by Dr. Bradley and his colleagues at WHOI. The top plate (held above the pack) includes the rectifier (center) and power-conditioning (right) electronics for the power transfer system developed by Dr. Feezor at EDC, as well as the watchdog load-management system (left) developed by Dr. Bales at MIT Sea Grant.

A design tradeoff was made between the modularity and robustness provided by segregating the cells into independent strings and the added complexity of the electronic design. By choosing this approach, we placed several stringent requirements on the electronics. A premium is placed on the efficiency of the step-up / step-down inverter, current travels through this system twice - once on charging and once on discharging. The details of the design of this circuit are dominated by this efficiency requirement, and, at 96% efficiency each way, the performance exceeds our requirements. Similarly, once assembled, the electronics are always powered by the battery - even when sitting on the shelf. Therefore a low quiescent draw was mandatory. Since each set of electronics consumes less than 30 mW (and the energy of each series string is 750 W-hours when fully charged) it will take over 34 months for the electronics to run the batteries dry when left sitting on the shelf - much longer than the one to two year shelf life of the cells!

Table 1: Specifications of Prototype Smart Battery

Mass:	30 kg
Energy:	3.5 kW-hr (est.)
Shelf Life:	2 Years
Charging:	Fully Autonomous and Unattended

Conversion Efficiency:	96%
Quiescent Draw:	< 120 mW
Environmental Parameters Sensed:	Pressure, Temperature
Electrical Parameters Sensed:	Cell Voltages, True Net Total Current

This system is now undergoing testing and integration into an Odyssey II-class AUV. It will be used in the upcoming Labrador Sea deployment (part of the AOSN MURI). Additional batteries are being constructed to enhance that effort, and the design of the next generation battery is under consideration by this research team.

IMPACT/APPLICATIONS

Most, if not all, autonomous platforms for ocean sensing are energy limited. This work directly address this fundamental limitation on ocean sciences by: Allowing unattended in-situ recharge of secondary cells; Creating power and data transfer methods that maintain isolation at DC; Providing for monitoring and management the energy use of platforms for in-situ sensing, and; Providing all of the above in a robust, flexible, and modular, architecture that can be readily adapted to a wide range of secondary or primary battery chemistries.

TRANSITIONS

The systems developed here are being integrated into the Labrador Sea AOSN (part of the AOSN MURI, working in conjunction with the Deep Oceanic Convection ARI). This technology will become the standard for AOSN deployments.

RELATED PROJECTS

1 - This work is tightly integrated with the field program of the AOSN MURI. It is a key element of that effort.

2 - The Labrador Sea deployment is in concert with the Deep Oceanic Convection ARI.

3 - The ONR project on Autonomous Underwater Vehicles Systems at N. C. State University.

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