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ARGO/JASON: A REMOTELY OPERATED SURVEY AND SAMPLING SYSTEM FOR FULL-OCEAN DEPTH

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The ARGO/JASON system is an integrated system that performs survey and sampling to depths of 6000 meters. This paper summarizes the capabilities of the system and includes descriptions of three vehicles: the deep-towed imaging sled ARGO, the ROV JASON, and the sidescan sonar DSL-120.

Introduction

The ARGO/JASON system is an integrated family of deep ocean scientific survey and sampling vehicles. operated for the scientific community by the Woods Hole Oceanographic Institution (WHOI). ARGO/JASON and the related technology base was first funded by the Office of Naval Research in 1982 .

During the course of this development program, the various vehicle systems have been used by the U.S. Navy and scientific and engineering communities to conduct important research cruises. With the completion of our 1990 operational season, all of the major vehicle systems and associated sensor suites had been developed and tested to full oceanic depths. These vehicles are now all approaching full operational availability. A complimentary program of basic engineering research and development is also continuing.

This paper describes three complementary vehicle systems. ARGO is a wide area search and survey system utilizing a coaxial cable that provides real-time video, electronic photography, and sonar imaging. JASON/MEDEA is a two vehicle system that utilizes a fiber optic cable to provide extremely high bandwidth telemetry to support a variety of sensors. JASON is highly manueverable and features a sophisticated manipulator system. The final vehicle, DSL-120, is a swath bathymetric sonar that operates from either a fiber optic or coaxial cable. Figure 1 illustrates imaging capabilities of the major vehicle systems developed under this long-range program.

The ARGO Vehicle

ARGO is a deep-towed search and survey vehicle. The ARGO system (figure 2) permits round-the-clock, wide area real-time optical and acoustic seafloor imaging at depths to 6000 meters and speeds of about 1 knot [1]. ARGO's strongest attributes are the variety and quality of imaging and its substantial endurance. While popularly known for the 1985 discovery of the TITANIC [2] and the BISMARCK in 1989, ARGO has also been used for science cruises on the East Pacific Rise [3],[4] and the Mediterranean [5]. The system is containerized and has been operated from five vessels of opportunity.

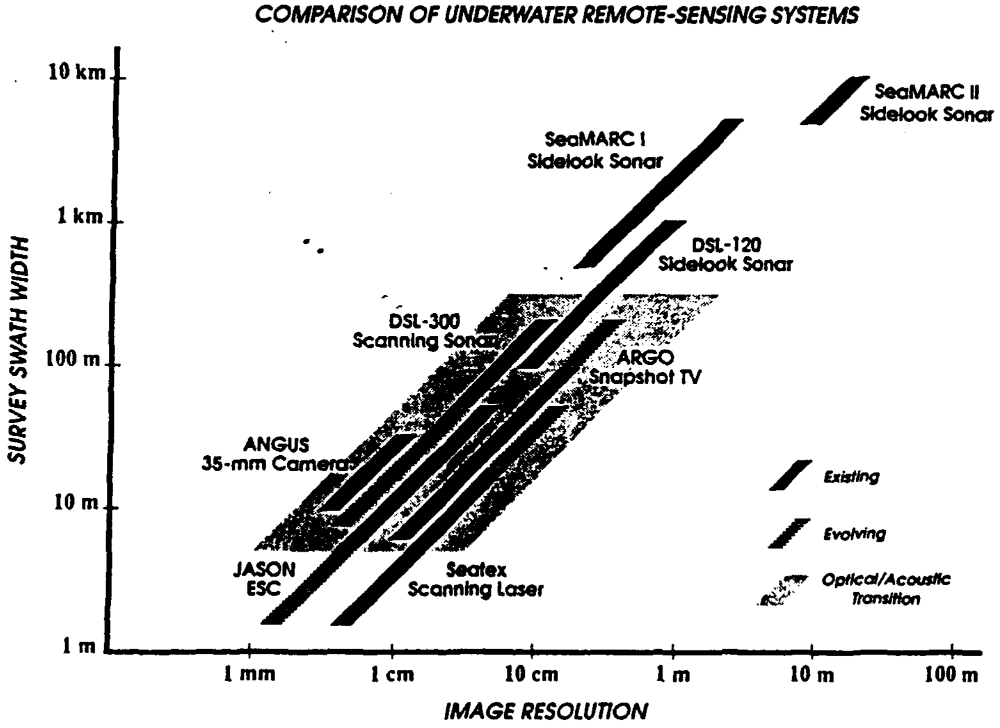


Figure 1. The imaging systems operated as components of the ARGO/JASON system cover a wide range of swath widths and resolutions.

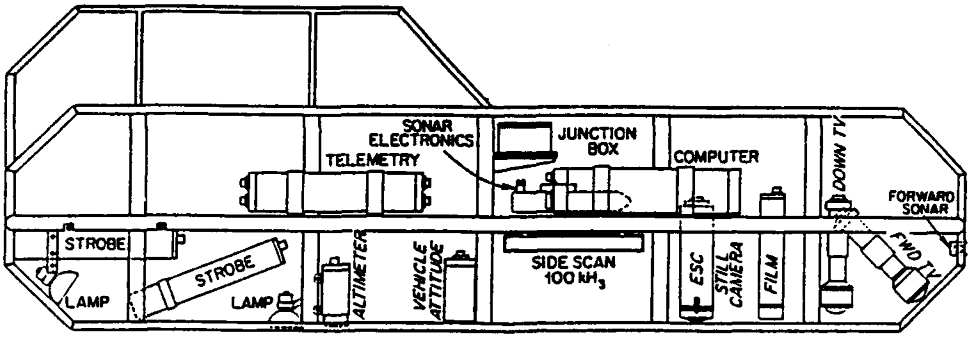


Figure 2. The ARGO system is a towed sled that performs simultaneous wide area optical and acoustic imaging.

ARGO provides real-time imaging of the seafloor from video cameras, an electronic still camera, and sidescan sonar. ARGO is towed on a UNOLS standard 17mm (0.68") coaxial cable. The cable provides 1 KVA downlink power and approximately 5 Mhz bandwidth.

The ARGO standard optical imaging package includes three real-time Silicon Intensified Target (SIT) video cameras, an Electronic Still Camera (ESC), and 35 mm film cameras. The SIT cameras provide forward-looking, down-looking, and down-looking zoom views. SIT image width is approximately 1.6 times the altitude, while the ESC provides an image width of about 0.6 times the altitude. Typical maximum imaging altitude for the SIT cameras ranges from 15 meters in poor quality water to 35 meters under more favorable conditions.

ARGO supports a suite of acoustic sensors consisting of a 100 Khz (Klein) side-looking sonar, 100 Khz narrow-beam forward-looking sonar, and a 100 Khz down-looking sonar for altimetry. The sidelooking sonar has a swath width of 20 times altitude and a cross-track resolution of 0.1-0.4 meters.

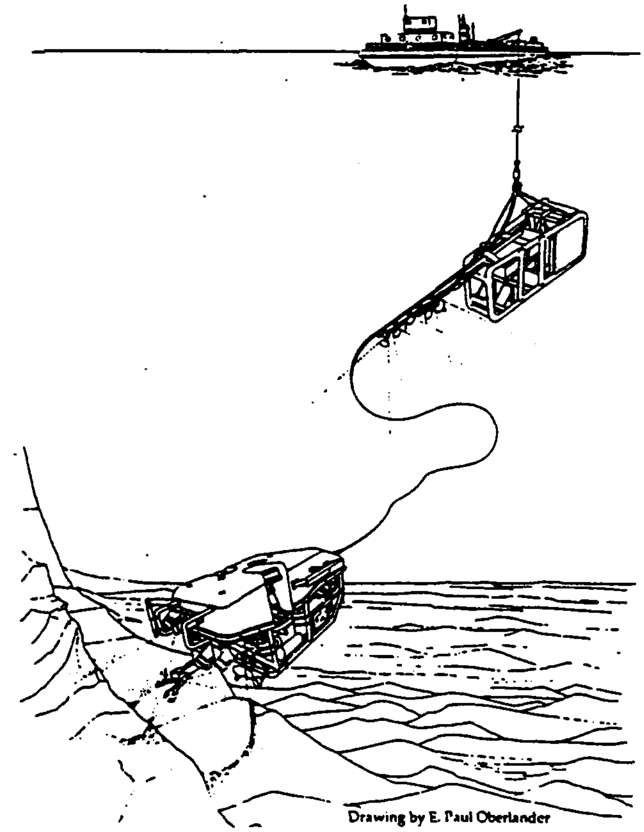
ARGO is a multifunctional sensor platform and additional telemetry channels are integrated to support a variety of scientific instruments. Vehicle parameters such as pitch, roll, heading, heave, and altitude are digitized on the vehicle and transmitted to the surface for display and logging. Audio quality analog channels are available for other sensors such as a CTD, transmissometer, or hydrophone.

ARGO and its navigation system are well suited to efficient, accurate wide area survey. A recent cruise [4] yielded detailed video, electronic photographs, and sonar maps over an 83 km length of the East Pacific Rise at a depth of about 2500 m. In 21 days on-station, 28 survey lines resulted in a complete survey of the 50-150m wide axial summit graben (ASG) along the entire 83 km length. The total survey track distance of 800 km, including over 400 hours of visual observation, resulted in a total visual coverage of over 9 million square meters. Sonar survey of the ridge crest covered an 800 meter swath, with extensive overlap and multiple look angles. Over 5000 frames of 35mm color film images and 1750 digital electronic still images were also recorded.

The ARGO navigation capability includes traditional long baseline acoustic navigation integrated with GPS in a novel way. On the recent EPR cruise [4], high quality navigation was required over a long narrow survey area. If conventional 3 transponder net survey techniques were used, approximately 18 linked surveys would have been required, each taking many hours. Instead, a linear array of 19 acoustic transponders were moored on the seafloor and surveyed quickly and accurately using GPS[6]. Based on the quality of the ARGO imagery and the accuracy of the navigation, DSV ALVIN was able to return to the site for detailed observation and sampling.

The MEDEA/JASON System

MEDEA/JASON is a remotely operated vehicle (ROV) system designed for scientific investigation of the deep ocean seafloor over a fiber optic cable (figure 3). The vehicles operate together, with MEDEA serving as a wide-area-survey vehicle and JASON as a precision multisensor imaging and sampling platform. Both MEDEA and JASON are designed to operate to a maximum depth of 6000 m (20000 ft.). The entire system is transportable, and has been operated from a variety of vessels.



Drawing by E. Paul Oberlander

Figure 3. The JASON vehicle is operated from MEDEA. MEDEA provides sufficient weight at the end of the long vertical cable, isolates JASON from ship motions, and also provides complimentary imaging and lighting.

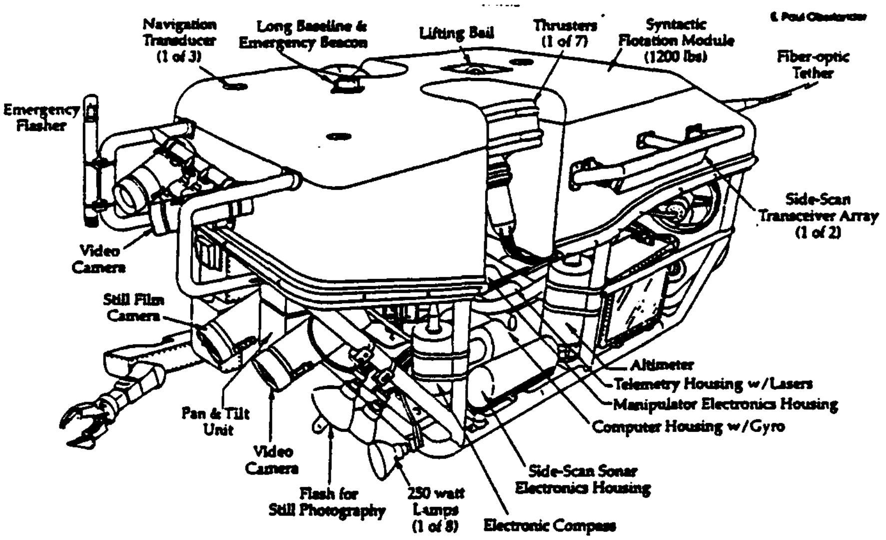


Figure 4. The JASON ROV can support a variety of sensors and sampling equipment.

JASON ROV (figure 4) was conceived as a precisely navigated and controlled platform that could survey and sample the seafloor using a variety of techniques [7]. JASON is an excellent platform for high resolution sonars, electronic photography, and video. These functions utilize a combination of good navigation, precise control, and high bandwidth telemetry. Several megabits/second of high resolution sonar data can be brought to the surface, processed, merged with navigation data, and displayed in real-time. Terrain modeling based on a stochastic backprojection methods [8], yields a quantitatively valid analysis that can blend the strongest attributes of multiple sensors.

MEDEA is maneuvered primarily by movements of a ship utilizing dynamic positioning. JASON, on the other hand, is designed for detailed survey and sampling tasks that require a high degree of maneuverability. It weighs about 1300 kg (2800 lbs.) in air, but is nearly neutrally buoyant at depth. The dynamics of JASON were designed to make it a very controllable platform. It is propelled by seven DC electric thrusters which provide about 300 N (70 lb.) in the vertical direction, 260 N (60 lb.) in the forward direction, and about 200 N (45 lb.) in the lateral direction. The vehicle has excellent passive stability in pitch and roll and has sufficient payload for a variety of sensing and sampling equipment without compromising its dynamics.

Fiber-Optic Cables

A major feature of the MEDEA/JASON system is the fiber-optic tow cable that connects MEDEA to the surface. The cable is 17 mm (0.68") in diameter and contains three copper conductors and three single-mode optical fibers. Two contrahelical torque-balanced outer layers of high-strength steel provide a breaking strength corresponding to a 18,000 kg load (40,000 lbs.). The cable can be operated using a variety of available traction winches, used with the existing UNOLS standard 17-mm coaxial cable, when outfitted with an appropriate slipring assembly. Minimum sheave size is 1.3 m (48 in.).

JASON is connected to MEDEA by a neutrally buoyant cable 15 mm (0.60") in diameter and approximately 100 m long. Like the tow cable, it also uses three copper conductors and three single-mode optical fibers, but uses Spectra fibers to provide strength and reduce size and weight. The cable has a working strength that will support a 1,300-kg load (3,000 lb.) and the breaking strength corresponds to a 5,400-kg load (12,000 lb.).

Power and Telemetry

The power system can deliver 12 KVA subsea, nominally 4 KVA to the MEDEA vehicle and 8 KVA to JASON. Power transmission to MEDEA and JASON is 400-Hz, 3-phase AC at approximately 1600 volts. Electronic voltage regulation at the surface is employed to keep the subsea voltage constant despite load variations. Power is available at both MEDEA and JASON for additional devices. MEDEA and JASON have 2000 total watts available in any of three forms: 120 VDC, 90 VAC 3-phase 400 Hz, or 120 VAC 3-phase 400 Hz.

Both MEDEA and JASON have been designed to take advantage of the large bandwidth available on the fiber-optic cables. This provides the user and the vehicle operators with high- quality video, responsive real-time control of the vehicles and manipulator, and provides an infrastructure for additional high-bandwidth sensors such as sonars and electronic cameras.

Four continuous video channels are provided, up to three of which can be on JASON or up to two may be on MEDEA. JASON can support eight different video sources that can be switched from the surface to the available channels. These channels are capable of transmitting near-broadcast quality video. Each vehicle also provides two audio channels with a bandwidth of 15 kHz. At least one of these is available for science users. For digital telemetry, each vehicle has a total of 10 full-duplex high-speed serial lines, each capable of running at a maximum synchronous rate of 10 Mbit/sec. On each vehicle, one of these full-duplex channels is split into 10 low-speed serial channels running at a maximum rate of 9.6 kbaud. Several of the high-speed serial lines will also be available to users. These provide convenient mechanisms for interfacing devices with serial links running up to 10 Mbit/sec. synchronous or 2 Mbit/sec. asynchronous.

Optical Imaging

Both MEDEA and JASON have been designed as real-time optical imaging platforms with high-quality cameras and lighting. The vehicles will be able to work together to provide lighting for each other in a fashion not commonly available in other submersible systems. MEDEA's standard optical-imaging suite includes low-light-level black and white video cameras and down-, or a forward-looking color video camera (Sony DXC102). A Benthos 372 35-mm still camera with 800-frame capacity can also be mounted. JASON's standard optical-imaging suite includes two single-chip CCD color cameras (Sony DXC-102, XC-177), a 3-chip broadcast-quality color camera (Sony DXC-325), a low-light-level black and white camera (Pulnix 840), and a 35-mm film camera (Benthos 378 with 400-frame capacity). Both the high-resolution color camera and the film camera can be mounted on a computer-controlled pan-and-tilt mechanism. Lighting includes 2000 watts of incandescent lights and a self-powered 100-watt-second strobe. JASON also routinely carries the Electronic Still Camera (ESC), which provides high resolution, high dynamic range imagery.

Acoustic Imaging

Depending on user requirements, either MEDEA or JASON can be equipped with several types of sonars. To date Mesotech and Ulvertech forward-scanning sonars have been used on JASON, and a SPOTRANGE laser/sonar system (a laser acts as a pointer for a narrow-beam 1- MHz sonar) has also been employed. The Mesotech system is designed to provide detailed terrain imagery and bathymetry at ranged up to 100 meters from the JASON vehicle. The available telemetry allows all sonar data to be transmitted to the surface in real-time. JASON also routinely carries a 200 khz split-beam bathymetric sonar, developed jointly by DSL and the Applied Physics Laboratory (APL) of the University of Washington.

Navigation and Control

Both MEDEA and JASON can be navigated using a low-frequency (10-kHz) long-baseline system similar to that used in ALVIN, ANGUS, and ARGO. A Benthos 455 acoustic signal processor has been modified to take advantage of the MEDEA/JASON telemetry system. By providing acoustic receiving capability at both vehicles, the ship position and the position of either vehicle can be obtained in a single acoustic cycle (6-10 seconds depending on water depth). The system can also navigate objects with no telemetry, such as elevators and off-load packages, using a relay transponder similar to the ones on ALVIN. Emergency relay transponders are also included for both MEDEA and JASON. High level navigation computations, display, and data logging are done using DSL software running on personal computers.

JASON has been designed with automatic control in mind [7]. The control system is based on the supervisory control paradigm. The automatic features are not designed to make the vehicle autonomous, rather they are designed to improve performance and to reduce operator workload. Automatic control of heading and depth are always available. When a precise seafloor-referenced navigation system such as SHARPS is used, the full JASON control system will be available. This system, which has been demonstrated and used operationally in shallow water [9], includes automatic station- keeping, track-following, and several interactive automatic modes.

Manipulation and Sampling

JASON is equipped with a new manipulator designed at DSL that features very precise control of position, velocity and force [10]. The operator input device for the manipulator is a rate joystick mounted on a portable remote console. JASON's multiple cameras provide good coverage of the work area. The manipulator is powered by high-performance DC servomotors and utilizes low-friction cable reductions, which permit the application of a variety of sophisticated control schemes. In normal operation, the pilot can control the compliance of the end effector, which allows the interaction forces to be regulated. Other force-control schemes, including automatic coordination with vehicle movements, are under development. The manipulator can be stowed and deployed automatically and can be fitted with several end effectors. The manipulator has a maximum lift capacity of 15 kg in the middle of its work space. When extended directly below the vehicle, the vertical lift will exceed the available vehicle thrust. JASON is capable of storing a small volume of samples in a basket mounted to the vehicle frame. Larger volumes can be off-loaded either into MEDEA or a free-ascent elevator.which allows real- time sample recovery without interrupting vehicle activities.

DSL 120

The Deep Submergence Laboratory (DSL) of the Woods Hole Oceanographic Institution (WHOI) operates a 120-kHz split-beam sonar designed for seafloor imaging and swath-bathymetric mapping. The sonar was designed and developed by DSL in conjunction with the Applied Physics Laboratory (APL) of the University of Washington and Acoustic Marine Systems, Inc. of Redmond, Washington. The DSL-120 is fully calibrated so that accurate backscatter measurements can be made, and the dual-receiver design provides phase information that can be used to generate high-resolution swath bathymetry. Sophisticated surface processing is based on complex-domain cross-correlation techniques developed by Darrell Jackson at APL.

Because the amplitude of a back scattered sonar signal is a function of sensor geometry, seafloor topography, and physical properties of the bottom (sonar characteristics and transmission losses through the medium can be modeled or measured directly), it is essential to obtain accurate measurements of all three parameters for complete characterization of the seafloor and of any emplaced artifacts. Sonar geometry can be determined through precise navigation and attitude measurements, an area in which DSL is at the cutting edge of underwater technology. However, commercially available sidescan sonars provide only a qualitative assessment of signal strength and no topographic data.

To meet the need for high-resolution, quantitative backscatter and bathymetric data, the DSL-120 design was based on the TARSUS system, a seafloor backscatter measurement tool developed by APL. The system is fully calibrated so that accurate backscatter measurements can be made, and the dual-receiver design provides phase information that can be used to generate high-resolution swath bathymetry. Significant features include digitization at the receiver, four channels of quadrature-detected data, and a high-bandwidth optical-fiber link to the surface. The deep-towed sled also carries a 4.5-kHz sub-bottom profiler and an instrument suite to measure pressure depth, pitch, roll, and heading.

Conclusion

The ARGO/JASON system is an integrated family of vehicles for scientific seafloor survey in the deep ocean. These vehicles are now in operational status and available to the scientific community. As a system, they can perform quantitative survey over a varitey of range/resolution scales. The system can also perform sampling, servicing of instruments, and recovery.

Acknowledgements

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