Deep Ocean Visualization Experimenter (DOVE): Low-cost 10km Camera and Instrument Platform

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***Abstract-* Recent developments in the manufacture of borosilicate glass housings offer scientific investigators and ocean engineers the opportunity to go "deep and cheap." The 17-inch OD spheres, manufactured By Schott Glasswerks in Jena, Germany, provide ample interior space and positive buoyancy. The clarity of the glass and manufacturing tolerance control make the housings useful for photographic imaging. Other sensors suites may be added or substituted. Multiple sphere configurations are achievable.**

Scripps Institution of Oceanography/UCSD researchers and its corporate partners recently completed sea trials of a 7km rated version of a baited camera inspired by the pioneering work of Scripps Professor John D. Isaacs. The project revisits great science of the past with today's technology in celebration of the 100th birthday of Scripps Institution in 2003. Key components of a 10km rated version have already been pressure tested.

I. INTRODUCTION

Photographic images of the deep sea serve to identify its inhabitants, to reveal their behavior, and to provide data in experiments. Continued advancements in deep-sea photography stand to impact broadly our understanding of the deep-sea ecosystem. We are designing and fabricating a deep-ocean digital camera system for still and motion picture photography to 11,000-meter ocean depths. We named the camera system DOVE (Deep Ocean Visualization Experimenter) after John Dove Isaacs who imaginatively pioneered the new applications of photography as a tool for experiments in the deep sea. Design features of the new DOVE camera include a macro photography capability, a light air weight for ease of deployment, a low cost relative to other deep-sea cameras, and a flexibility in both camera selection and illumination possibilities. The camera housing is a 17-inch OD glass sphere. Polishing a portion of the glass sphere results in an optical window allowing high quality images. Our discussion of the design of DOVE will cover housing design and manufacture, results of tests, selection of cameras, lighting system, control electronics, bait systems, battery options, ballast release options, electric cables and connectors, surface recovery beacons, launch and recovery procedures, and considerations of shipping logistics. We will discuss how the capability of DOVE could be extended with an expanded sensor suite, external pressure compensated batteries, variable ballast system, acoustic modem, and an expanded vehicle frame design. We envision applications of DOVEs to the study of liquid carbon dioxide sequestration in the deep sea, to the identification of the inhabitants of deep midwaters, to a suite of experimental biology possibilities, and to deep ocean observatories. Inspired by the John Dove Isaacs Monster Cameras of the 1960's, these new DOVEs have the ability to go deeper, stay longer, visualize a greater size range of objects, and take more photographs of higher quality.

II. GLASS HOUSING, INTERIOR MOUNTS AND EXTERIOR FRAME

A. Housing design and manufacture

Glass spheres are constrained by design to a 17-inch outside diameter. The design specifications were confirmed using DeepSea Power & Light's Computer Assisted Engineering (CAE) Program "UnderPressure". Post-manufacture pressure testing was done at the Schott Glasswerks. One hemisphere is polished for optical clarity centered on the apex and down 30°.

B. Feedthroughs

1. Electrical: A single three pin bulkhead connector, SubConn (LPBH3M) is used for the two burnwires and common cathode. Two spare ports are available for system expansion.
2. Purge: A single purge port is used to cycle air over a dessicant to dry it prior to deployment, preventing condensation at depth.

C. *Hardhat*

The hardhat is a vacuum formed 1/4" thick plastic protective shell that surrounds the glass sphere. The standard smooth hardhat is used. Cut-outs can easily be made. Holes are cut in the bottom for camera viewport, in the top for access to penetrators, two in the lower sides for the internal flash units, and eight around the upper half for the recovery strobe beacon light.

D. Ballasting and Release System

1. Description: With all electronics and batteries, the sphere is 42-lbs buoyant. To minimize anchor weight, 10-lbs of lead is added to the interior of the lower hardhat. This also provides additional stability of the DOVE in the upright position on the surface. A release collar encircles the bottom of lower hardhat, providing an unobstructed downward view for the camera. Individual chain links welded to the collar provide a convenient method of connecting two pieces of chain, 6-ft long, to the ballast weight. At the conclusion of the deployment, the collar, chain, and ballast weight are released to allow the camera to ascend to the surface.
2. Ballast weight: A piece of scrap I-beam weighing 75-lbs (air weight) is used. Additional weight may be added using surplus USN shackles. The weight of the two lengths of chain and the release collar described previously adds to the overall ballast weight.
3. Primary Release: The primary release is triggered by a modified 99-hour countdown timer (Fisher Scientific Model 06-662-41). The internal 1.5 v vibrate motor is removed. The voltage activates three parallel circuits, each optocoupled to prevent interaction. The circuits are the primary burnwire, a Radio Direction Finder (RDF) beacon, and a recovery strobe light.
4. Back-up Release: The back-up release uses the same countdown timer as the primary release. The internal 1.5 v used to drive the vibrate motor is used to directly activate a simple SCR circuit for the secondary burnwire. No optocouplers are used in this back-up system.
5. Burnwires are made at American Rigging (San Diego) to SIO design specification. Each cost under $10 and were individually load tested to 500-lbs.
6. Operation: The two burnwires are joined by a two links of chain. The chain passes through a carabiner which is connected to the release collar. Tension is applied to the burnwires using threaded eyebolts through the hardhat flanges. Breaking either burnwire allows the chain to pull through the carabiner and the release collar to be dropped.

E. Interior Pressure Indicator

A pocket altimeter (Edmund Scientific model CR30345-44) can be viewed through the glass, allowing controlled purging and confirmation the seals are holding. An internal pressure of approximately 10 psi is preferred.

F. Recovery Beacons

1. The Radio Direction Finder (RDF) beacon is a Novatech Design (Victoria, BC) RF-720 Transmitter board with integral antenna tuned to 159.480MHz. The beacon alerts researchers the moment the camera reaches the surface. No problems interfered with this working.
2. The Flashing light is a modified 3-cell waterproof strobe light providing light for dusk to dawn recovery. No problems interfered with this working.

G. Interior Mounts/Interior frame

Three mounts provided mechanical attachment to the glass. An aluminum plate with a threaded insert is potted inside a polyurethane disk. The disk is then bonded to the glass using 3M Fast Cure 5200 Polyurethane adhesive. The mechanical structure is then bolted to these mounts. A hinge plate allows easy access to both sides providing convenient mounting (See Fig . 1 & 2.) All components are mounted to one hemisphere. The matching hemisphere is the polished dome and is mounted once the detailed pre-cruise checkout is complete.

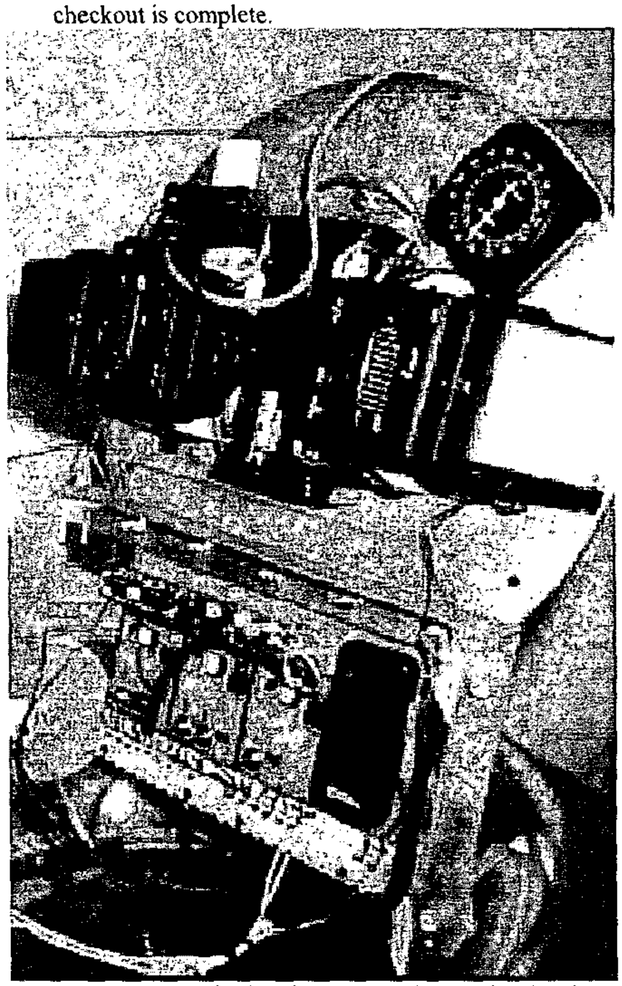

Fig. 1. DOVE is hinged open on the bench, showing the primary release timer and parallel control circuits for RDF, recovery strobe light, and burnwire 1. Also visible are two of the three polyurethane attachment mounts to the glass sphere. A protective rubber bumper is placed over the glass sealing surface for protection during handling. Also visible are camera flash units and the pocket altimeter.

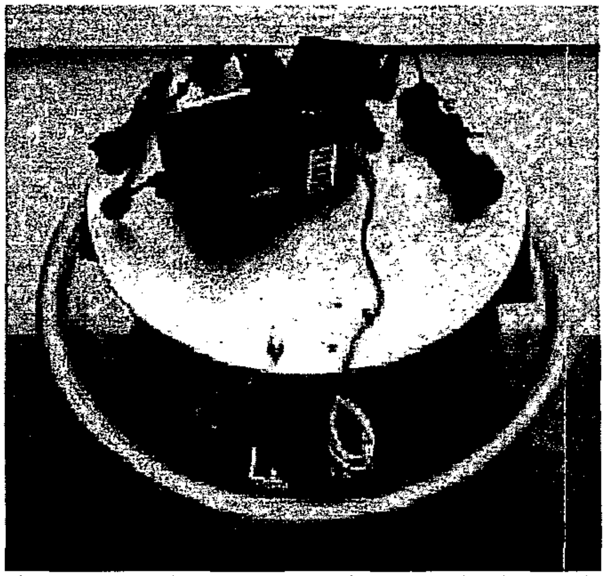

Fig. 2. DOVE is hinged closed on the bench, showing the Coolpix camera, and the back-up release timer. The DigiSnap controller is behind the camera.

III. IMAGING SYSTEM

A. Camera

A Nikon Coolpix 995 camera was selected because of its mechanical size, memory capacity, external battery power plug port, and simplicity of external control. The camera has a 3.4 Megapixal resolution. There are a few quirks to the camera which need to be understood, but are predictable and can be placed in a checklist.

B. Camera Controller

A DigiSnap 2000 was chosen as the simple controller. There was some concern the internal AAA battery might fail, so an external AA was added in parallel. The controller went to sleep when unplugged from the camera without loosing memory. When in operation, a green light flashed every 4 seconds. One "feature" that showed up unexpectedly is if the controller detects an error in the trigger signal, it will shut down until manually reset. Fortunately, that only occurred once in all the testing, but remains a possibility.

D. Camera Flash Units

Two Sunpak auto 383 flash units are used in parallel. Both are triggered by the sync pulse from the Nikon Coolpix. The cable connecting them in a simple Y-splice. The internal AA batteries were replaced by a pack of external D-cells. Both flash units run off the same battery pack. The flash units are mounted inside the sphere and point out to the side. Light is reflected off mirrored wings that are adjusted to direct the light to the focal point at the bait. The wings also provide increased separation of the light sources on the subject.

E. Batteries

All batteries used are alkaline primary cells. They are cheap, readily available, have plenty of power for the short deployment. Their chemistry presents no concern for outgassing.

IV. TESTING

The system was tested in the 10m Deep Tank on the campus at Scripps Institution. Initial photographs taken in the Deep tank allowed us to gain experience with the camera control and settings, and operation of the entire system. The final test was in the "as deployed" condition to test the full working assembly. The checklist of pre-launch procedures was developed during this testing phase.

Fig. 3. DOVE full-up test in Scripps Institution's 10m Deep Tank. Fins are the flash reflectors. Chains connect to the release collar at the base. Upper holes allow more light from the recovery strobe to get through. A trail of bubbles to the right is coming from the active burnwire release system.

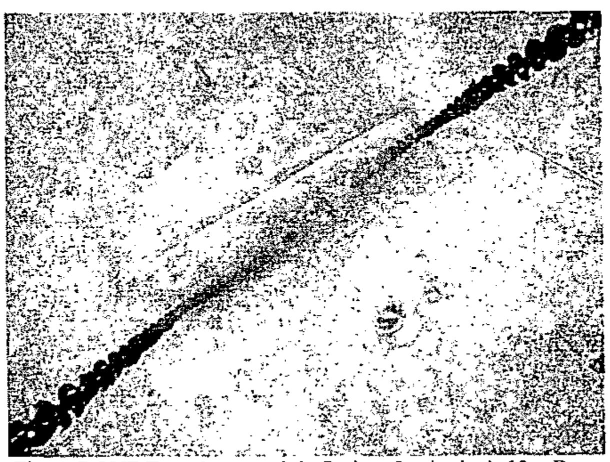

Fig. 4. DOVE Test photograph in Scripps Institution's 10m Deep Tank. Shadows of the chain indicate a need to rotate the anchor chains relative to the camera flash units. Brightness suggests the need to reduce flash power.

V. DEPLOYMENT AND RECOVERY

The DOVE is prepared in the ship's dry lab prior to deployment. A 9-page checklist is used to provide uniformity in preparation. The camera is turned on and continues to take photos every 5 minutes. In the course of an hour this only wastes 12 frames, a minor loss given the added confidence of seeing the camera operate on deck prior to deployment. With a 1Gb Compact Flash memory card, we stored 192 photos for a total of 249.8 Mb, less than 1/4 of the capacity.

A stainless steel bale, like a handle on a pail, is firmly attached to the top of the upper hardhat. It is used with a quick release hook on deployment and grabbed by a quick attach hook on recovery. A simple davitt and pulley would suffice for launch, though none was available on this ship. The DOVE camera sphere, chain, and anchor was lifted using a line through the A-frame to a quick release. The A-frame was moved aft to avoid striking the reflector plates against the side of the ship. Once the glass sphere was immersed, the quick release was pulled. The camera sank quickly. A GPS position was taken by the bridge at the moment of release.

It was anticipated from prior experience that the sphere would descend and ascend quickly, minimizing offset due to currents.

The primary release was scheduled to have the camera on the surface just prior to sunrise so the flashing light would be of advantage. The back-up release was scheduled to have the camera on the surface just after sunrise to allow the sunlight to glint off the reflective tape and orange hardhat. The radio beacon gave confirmation the sphere had surfaced prior to it being spotted, though the sphere appeared nearly exactly where expected within one minute of anticipated arrival.

Fig. 5. DOVE "Marycarol" is back on deck moments after recovery in the pre-dawn light. Completely self-contained, the DOVE camera system is capable of independent exploration to 10km depths.

VI. RESULTS

The system worked without failure at sea. Though the initial sea trial was an engineering performance test, the quality of the images showed numerous behaviors of many species. The photograph series is being reviewed in detail by Scripps Institution marine biologists.

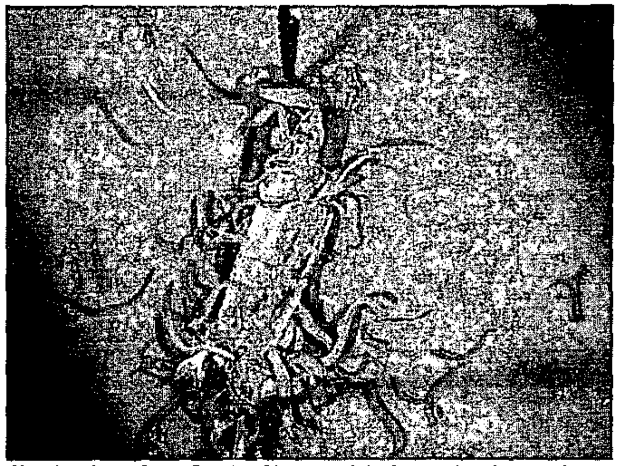

Fig. 6. Photo from first DOVE sea trial. Image is taken 14-hours into deployment at 256m on the 40-Mile Bank off San Diego. Over 190 photos were taken in the first test drop, each a digital file 1.1 Mb in size, producing a virtual 21" x 28" image.

VII. FUTURE ENHANCEMENTS

A. Camera

Cameras of higher resolution and greater memory could be installed.

B. Thicker Glass sphere

Spheres tested to 10km depths have already been manufactured, polished, produce images of similar quality.

C. Bait Systems

Experiments in bait systems, including enzymes, could be tested. Enzymes allow for much longer baited camera deployments.

D. *Batteries*

Batteries rechargeable inside the sphere would offer faster turnaround.

E. Deployment times

At present, timers are limited to 99-hours as that is as far as one can practically predict weather. A longer duration would require an acoustic link. Given that, deployments of up to a year in the trenches would provide a glimpse of the annual cycle in the deep sea.

F. Acoustic Link

Among other features, an acoustic link allows interrogation of the device as it descends or ascends, provides opportunity to survey the landing site coordinates, and command the release at a time when weather is good and the ship is on station.

G. Mobility

Presently the vehicle descends to the seafloor and rests there until the completion of its mission. Additional unique studies are enabled with the ability to translate to a new position somewhere else on the seafloor or in the water column. Guided by a jacketed wire rope mooring line, a vehicle might navigate up and down for a kilometer or more.

H. Frame

Presently the vehicle looks straight down. The ability to quickly reconfigure the camera angle to look to the side is possible with a slightly more complicated frame.

VIII. ACKNOWLEDGMENTS

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