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Supplementary Lighting in Underwater Photography

Sound will provide the principal way by which men and instruments will do precise navigation in the sea.

ABSTRACT: *Photography in the sea, particularly the deep sea, requires a light source near the camera because daylight from the surface does not penetrate. Continuous sources of light require an energy source which may be large and involved, and are, therefore, only used for visual observation, for motion-picture photography, and for television. Flash lighting is almost universally employed for single-picture still photography as ample energy is contained in a small battery to expose thousands of photographs. Calculations are shown to aid in the design of an illumination system that allows for the absorption and scattering effects of sea water.*

SUPPLEMENTARY LIGHTING IN THE SEA

HUMAN OBSERVATIONS AND photography at depth in the sea must be accomplished with auxiliary lighting as sunlight is rapidly absorbed with depth. Even at 30 meters below the surface, sunlight is very feeble. A source of light should be taken into the sea when working at almost any depth.

If close to the surface and below a ship, an electrical cable can be used for power to operate an over-volted tungsten lamp. Cousteau has used this system most effectively in his remarkable award winning motion pictures *The Silent World* and *World Without Sun*. He uses tungsten lamps that are over-volted momentarily during the operation of the motion picture camera. The diver-photographer signals the engine room of the R/V *Calypso* by means of a buzzer when the full power of the lamp is required for photography. Cousteau uses a daylight type of color film with tungsten illumination. The color balance of the camera-light is corrected at one distance because the water absorbs the red light more than the blue. A yellow picture results for closer distances than this, and a blue-green one for further. The casual audience attending an underwater movie is not conscious of these subtle color changes as they are so occupied by watching the action on the screen.

Strobe and flash lamp lighting equipment are of the greatest importance in the sea for still photography, because the illumination from the sun ceases to be useful at shallow depths due to the absorption and scattering in the water. It is always *night* or *bad weather* or *foggy* when one goes below the surface of the sea. Supplementary lighting equipment is an essential item whenever still cameras are used in the sea, not only to furnish light, but also to overcome the color unbalance, and uneven lighting from light transmitted from the surface.

The expendable flash lamp is of great use for underwater photography, because of the large quantity of light that is available from the chemical burning of the oxygen and metal foil. A slow shutter speed (1/25 sec.) is desired so that as much light as possible can be used. As with the motion pictures, Cousteau and others use the expendable flash lamp at a distance of 3 meters plus from the subject and

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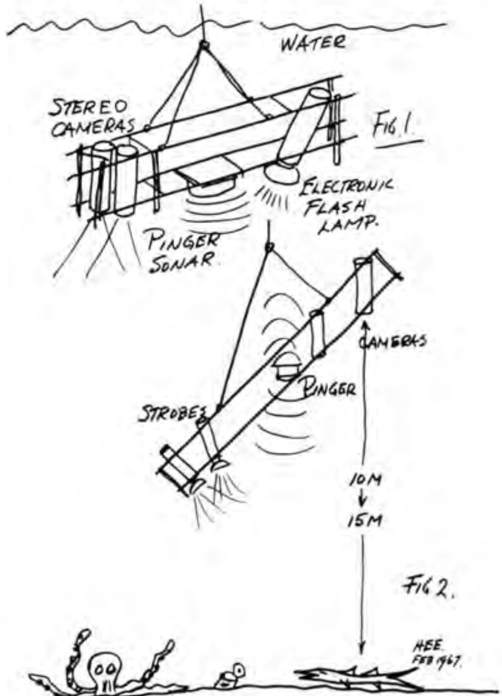
depend on the selective absorption of the water to reduce the red light so that the balance is *correct* for daylight color film. A *daylight* blue flash lamp can be used at closer distances in water, for example, less than about 2 meters.

Electronic flash is an advantage underwater if many photographs are taken because the diver does not need to replace the lamp as he does with the expendable flash lamp. Another important property of an electronic flash source for underwater photography is its ability to produce thousands of flashes efficiently from a small electrical battery. Thus, the inability to control exactly where and when a photograph is to be made underwater by suspended cameras can be compensated partly by taking many thousands of photos.

The photographer of underwater subjects, especially deep-sea, seldom has the artistic freedom of his above-water brother. Most of the time the underwater camera operator is shooting *blind* with a camera by some sort of remote control. It is possible to go with the camera in a bathyscaphe or diving saucer as a view finder, but this is a luxury arrangement which is not available for most routine deep-sea photography assignments. In some cases a television camera can be used as a remote view finder to aid the photographer to select the *right* moment to release the shutter.

Unfortunately, one cannot see or photograph greater than approximately 30 meters from the camera, even in the clearest of ocean water. A more practical limit for photography seems to be 10 or 15 meters in mid-ocean at the bottom where conditions are good. Beyond 15 meters a haze absorbs light and destroys the photographic image. Many attempts have been made to overcome the optical limitations by selecting the most favorable wave length, but to my knowledge no spectacular results have been attained. One may conclude that the camera should have a wide-angle lens which should be kept as close as possible to the subject, so that optical effects from the water are minimized. Likewise, the lights should be separated from the camera and closer to the subject than the camera in order to prevent back scattering, absorption, and to give shadows and modeling.

Photography of the bottom of the ocean is of great importance. To cover a square mile with 10-by-10-meter photographs will require some 29,000 photographs if no photo-overlap is obtained. This is a lot of photos to process, study, and position. Accurate bottom mapping by photography is a big task. There are



many square miles in the ocean! And then there is also the space between the bottom and the surface to be explored.

A few practical systems of underwater photographic equipment will now be described and some examples will be shown. Figure 1 shows a typical arrangement of two cameras (stereo pair), an electronic flash unit, and a pinger on a metal rack (Unistrut system). Dr. J. B. Hersey, formerly with Woods Hole Oceanographic Institute, and now at the Office of Naval Research, says "A single camera is only one half of a stereo camera system!" His experience with stereo has impressed him with the added information that the stereo presentation produces, and he insists on a two-camera stereo pair. He also wants color in at least one of the stereo cameras, because it gives added information.

Another underwater camera arrangement used on W.H.O.I. ships is shown in Figure 2. Note that the strobe is closer to the bottom and off the axis of the camera as this positioning tends to reduce the back scatter from the strobe. A similar arrangement with as many as three cameras and two 200-watt-second strobes have been used to obtain photographs with the cameras at 15 meters above the bottom in clear ocean water. The Unistrut system enables a camera user to modify or change his camera-lamp arrangement quickly to suit his whims.

An improved camera system, with 400 foot reels of film instead of 100, has been developed in response to a request from W.H.O.I. and others who wish to take many photos in the sea.

The recent discovery of very large sharks at great depths (1100 fathoms) off San Clemente Island, California was made with a camera system conceived by Prof. John D. Isaacs (Scripps Institution of Oceanography). The camera-flash lamp system is thrown overboard and allowed to stay on the bottom until a time delay release mechanism permits the camera to float to the surface for retrieval. Rare bottom fish have been photographed as well as a large shark at a bait box on the bottom.

Light Requirements

Below a few hundred feet of depth in water daylight is inappreciable and auxiliary lighting is required. A lamp on or near a camera is needed to produce the following beam-candela-seconds (BCPS) to expose a photograph.

$$(\text{BCPS}) = D^2 A^2 \frac{c}{s} \epsilon^{\alpha 2D}$$

where

- D = lamp-subject distance and camera-subject distance
- A = camera lens aperture
- s = ASA film speed
- c = a constant 15 to 25, when D is in feet a constant 162 to 270, when D is in meters
- α = absorption co-efficient of the water in natural log units ($\epsilon = 2.73$)

If $\alpha D = 1$ the light (BCPS) must be increased by 2.73^2, or 7.5, compared to air use. At two attenuation lengths the factor is 55. Beyond this distance the light losses are so great that photography is almost impossible, especially due to the image loss in the low-contrast photograph. No convenient easy-to-use meter is available to measure the factor, $\epsilon^{\alpha 2D}$, which could be called the *water factor*.

The absorption coefficient depends upon the wave length (color) of the light with the largest value in the red. Duntley[1] gives information for distilled water (Table 1). It is observed that the red light will be absorbed much more than the green or blue with distance, thus disturbing the color balance.

Suspended particles in the water of the ocean absorb and scatter the light so that the attenuation length is much shorter than the above information for distilled water.

Camera Control

A very practical problem of photography in the sea is measurement and control of the height of the camera over the bottom while photographs are being made. A camera for example, must be held accurately at some selected height, such as 10 meters from the bottom. There are at least four ways to do this.

1. The *trigger*[2] method where a shutter operating device, usually a switch, hangs below the camera. This bottom-activated electrical switch causes operation of the camera when it is at the desired height. After the exposure is made the camera is raised in preparation for the next operation.

2. The use of a *pinger*[3] sound source on the camera which enables the operator on the ship to know at all times where his camera is located above the bottom. A pinger sends out a short powerful pulse of underwater sound at regular one second intervals. One sound wave goes directly to the surface from the pinger, and another goes down to the bottom of the sea, is reflected, and then arrives at a later time at the surface. The operator on the ship measures this time delay between the two signals, and thereby knows where his camera is positioned as the velocity of sound in water is known to be about 5,000 feet per second.

3. The *sled* system of Capt. Jacques Cousteau. His device, a special sled which carries the camera and strobe, has the ability to right itself regardless of how it is dragged across the bottom by a strong cable from the ship.

The sled, or *troika* as Cousteau calls it, is an ideal platform for a deep sea camera. The lamps and cameras are carefully placed behind the heavy metal parts of the sled to reduce the probability of damage as the sled goes through rough areas on the bottom of the

Table 1

Color	*Blue*			*Green*		*Red*		
Wave length, $m\mu$	400	440	480	520	560	600	650	700
$1/\alpha$ (ln) meters	13	22	28	25	19	5.1	3.3	1.7

sea. Cousteau is always careful to make a detailed sonar study of the area he plans to drag his sled over, also observing winds and tides. Then lowering the device to the bottom, he begins traversing over the area of interest.

What if the sled becomes wedged into a tough spot and becomes an anchor? Cousteau partially solves this problem with a double cable attachment method. The main cable is firmly attached to the stern of the sled. A weaker cable ties the main cable to the bow. If the sled is stuck, a powerful vertical pull will break the weak connection and the sled will upend, hopefully releasing itself from the bottom attachment.

Cousteau once dragged his sleds over the mid-Atlantic rift mountains and obtained some remarkable photographs. One of these appears as an illustration in his book *The Living Sea*[4]. I urge you to take a look at that moon-like scene and wonder how in the world his sled could go in such a rough place without trouble. Incidentally, one of his sleds is still on the bottom, about halfway to Europe. If you want this sled with its movie camera and strobe for a souvenir I am sure that Cousteau will give it to you if you find it. Please note the location, the sled is halfway between Monaco and New York, possibly north of the direct line by some 500 or a thousand miles!

4. The *captive vehicle*[5] method. One system uses a TV camera on a tethered submersible with a cable to the master ship. A monitor screen permits the operator on the ship to control the submersible into the desired pattern. Then when the subject is in view, the photographic equipment is turned on to obtain high quality photographs for measurement or record purposes.

An ambitious project was undertaken in 1961 on the continental shelf off Newfoundland to photograph submarine cables. As stated by G. R. Leopold in his Bell Telephone Laboratory report (File No. 34912-16), "The purpose of the investigation was to examine the cables and the ocean bottom at firsthand and to seek out possible physical explanations for our apparent vulnerability to trawler breaks in the area."

This *vehicle*, with a controlled buoyancy frame using electrical propulsion, was made by the Vare Industries. An electric cable joined it to the mother ship, the *Polar Star*. On board the vehicle was a television screen to record the action below, and the necessary controls to guide the vehicle to follow the cable once it was found.

A deep-sea 35-mm. camera and a 100-watt-second xenon flash lamp were mounted near the TV camera tube as a remote view finder. An operator watching the TV screen could take photographs whenever he desired by pressing a push button.

Another very difficult but successful deep-sea effort was the photography of the *Thresher* site, some 200 miles east of Boston, in 8,500 feet of water. The ill-fated *Thresher* was a nuclear powered submarine that sunk during her deep diving tests in April, 1963. Many groups worked on the photography effort. Worzel of the Lamont Geological Observatory, Columbia University, while aboard the *Robert D. Conrad* made many photographs with a Thorndike Camera of the *bottom* contact type. Hersey used the *pinger* system on several Edgerton, Germerhausen & Grier cameras, together with four widely spaced hydrophones while aboard the *Atlantis II*, for camera location information. Buchanan and Patterson, Office of Naval Research, used cameras with remote surface control. The cameras were started from the surface when a magnetometer near the camera showed the presence of iron. Some 40,000 photos were made within 1,000 feet of the wreck. From these a photomosaic was made. Part of the *Thresher* wreck was photographed with the number of the submarine clearly visible.

The bathyscaphe *Trieste* (remodeled and called *Trieste II*) made eight dives at the *Thresher* site. Photographs were made and also a clearly marked piece of pipe was retrieved from the bottom.

Excellent photographs of the *H*-bomb that was lost and recovered off Spain were made from the *Alvin* and other underwater vehicles during the past year.

There are many cameras at the bottom of the sea. I personally know of one stereo pair that is full of exposed pictures, probably the best that I have ever made. This loss was experienced at a spot on the north wall of the Puerto Rico Trench at 20°07′ North, 66°30′ West. We were pulling the gear up with the winch after the photo run. Suddenly the cable parted and down it went. There are thousands of feet of cable on top of the camera.

I thought it would be worth a retrieval effort, so the next year I was at the same spot with an improvised hook and had the use of the ship for an all night dragging search. No luck. Perhaps we snagged the cable but it slipped free. We were probably at the wrong spot due to navigation errors. Better fishing next time! If anyone finds the camera system please remember that the film should be developed. One camera has Plus X film, the other has super Ektachrome color film.

Positioning and Navigation

Bottom photography usually is uneventful, showing many miles of desert-like sediment. Therefore, it is not too important to know *exact* positions. If one expects to photograph the *identical* area for a second time, it will be very difficult for two reasons: (1) the exact ship's position is not known; and (2) tides and currents displace the camera in an unknown manner even if the ship is held directly above the target. Some method of *bottom* navigation is required if the camera is to be brought back to an identical bottom area.

One way to locate a spot on the bottom is to anchor a buoy. The position of the buoy, with respect to the anchor position, will depend on the water currents and their effects on the float. Tight cables from large buoys to a large anchor tend to minimize the positional error.

A second and more involved method is a sonar transponder on the bottom which sends a ping when commanded. Let us call this a *sound-house*, as contrasted to a *lighthouse* used in surface navigation. Whenever one sends a sound signal from the surface, or from a pinger on a camera, he will receive an echo response at a delay corresponding to the distances involved. Thus, he can measure two distances, one to the bottom, and a second to the sound-house.

A transponder sound-house receives sound pulses from the sonar on the ship and returns a re-enforced echo which is also recorded on the sonar receiver. A series of signals will appear on the chart from the sound-house. The ship and sound-house are at their closest position when the signal is received at the earliest time on the recorder chart. A second pass can then be made from another direction to obtain further information.

If two sound-houses are used, two positions can be located on a chart where the ship might be located. With three sound-houses, there is no ambiguity in the ship's position. The positioning and navigation problem is exactly the same as the surface navigational *fix* where information from three known lighthouses is used. A lighthouse gives an *angle*; in contrast, a sound-house gives an *echo delay time* which is proportional to distance as the velocity of sound in water is almost a constant. The bottom navigation problem is more difficult than the surface navigation problem because of the added complication of water depth. The submerged water craft and an aircraft have exactly the same problem of navigation in a three-dimensional medium. Several problems may be experienced in the initial installation of the sound-houses; but once they are in place, an accurate survey can be made and the ship should be able to go repeatedly to the same pinpoint spot in the sea.

Now the camera, or other devices, can also be accurately located by the use of a pinger on the object lowered. The pulses from the pinger will give the operator on the ship the usual camera-to-bottom distance. At the sametime, the pulses from the camera will stimulate the transponder sound-houses and they in turn will send additional signals to the ship. These signals enable the operator to know where his camera is located with respect to the target, if the position of the target is known with respect to the sound-houses. Then the remaining job is the manipulation of the ship so that the camera photographs the desired subject. This requires skill. The same sonar procedure can be used with the bathyscaphe, with the additional feature that a human observer can take over the controls when the subject comes into view. Also, the use of a side-looking[6] sonar can be very helpful if the target sticks out of the bottom, once the bathyscaphe has been put into the desired area.

The sound-house transponder can be used as a marker. For example, a submarine could take one along on her dives with the provision for dropping it at the main center of interest. In this way the sub can go back to the identical spot for another effort to photograph or search.

In conclusion, it seems evident that sound will be the principal way in which men and instruments can do precise navigation in the sea. Both light and radio are not effective for large distances underwater because of absorption. Sound will be effective to several miles, whereas photography is only effective to 30 meters under ideal conditions. However, the two methods are used together for obtaining information about the bottom of the sea; and sound, of short pulse length[6], can furthermore give important information to the geology and archaeology of the sediments below the bottom.

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color control in printing far more accurate than any combination of filters with transparency film can provide in the rapidly changing undersea conditions.

Left until last in this report is the most versatile of color-control tools when used skillfully—artificial light. Flash bulbs (both clear and blue), photoflood lamps, quartz iodide lamps, and electronic flash are excellent agents of color restoration. Blue flash bulbs and electronic flash approximate the color temperatures of daylight. For short light-to-subject distances they bring out color well. Longer distances reduce their effectiveness. An ideal light-to-subject distance of 5 to 6 feet gives a subtle, pleasing effect of partial restoration but does not overpower the blue underwater feeling. Flash weak enough to be a fill-in and not a main light source is especially effective at this distance.

Clear flash bulbs, or incandescent lamps burning with a warm light, are effective color controllers at greater distances than colder daylight-balanced light sources. The blue of the water acts as a normalizing filter when the lights are used with a daylight film instead of the tungsten film for which they were designed. When too close to the subject, however, the underwater effect can be lost.

Underwater photography is growing out of its adolescence and equipment is becoming more sophisticated. Some day underwater scenics will show subtle color nuances under the grey-blue mantle, and underwater close-ups will modify the fiery reds and mustard yellows of coral in back of startlingly unreal-looking fish to give a more genuine feeling for the fish's watery environment.

I should like to see the twilight world of underwater penetrated but not overpowered.