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Acoustic Daylight Imaging: Vision in the Ocean

Michael J. Buckingham, Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA 92093, and Institute of Sound and Vibration Research, Southampton University, Southampton SO9 5NH, UK

John R. Potter, Marine Physical Laboratory, Scripps Institution of Oceanography, La Jolla, CA 92093

ABSTRACT

Sound provides a natural means for exploring the ocean, but current sonar systems, as used, for example, in swath-mapping applications, do not provide directly pictorial images of the ocean depths. Such systems are more akin to radar, which relies on travel-time information to map the environment. A new acoustic technique for providing real-time, visual images of the interior of the ocean is being developed, and results from initial experiments at sea provide evidence in support of the concept. The imaging process relies on ambient noise, or "acoustic daylight," as the source of illumination, the underlying idea being analogous to photography in the atmosphere with daylight illuminating the subject. An object in the noise field scatters the incident sound, and the scattered field is focused with an acoustic lens to form an image on an array of transducers. After signal processing, the acoustic image is displayed as a pictorial image on a television monitor. Acoustic "color," characterizing the spectral reflectivity of the object, could be represented as artificially generated optical color in the display, and a rapid refresh rate could yield moving images much like those from a conventional video camera. Acoustic daylight imaging holds promise for several underwater applications, including mapping the topology and geology of the seafloor.

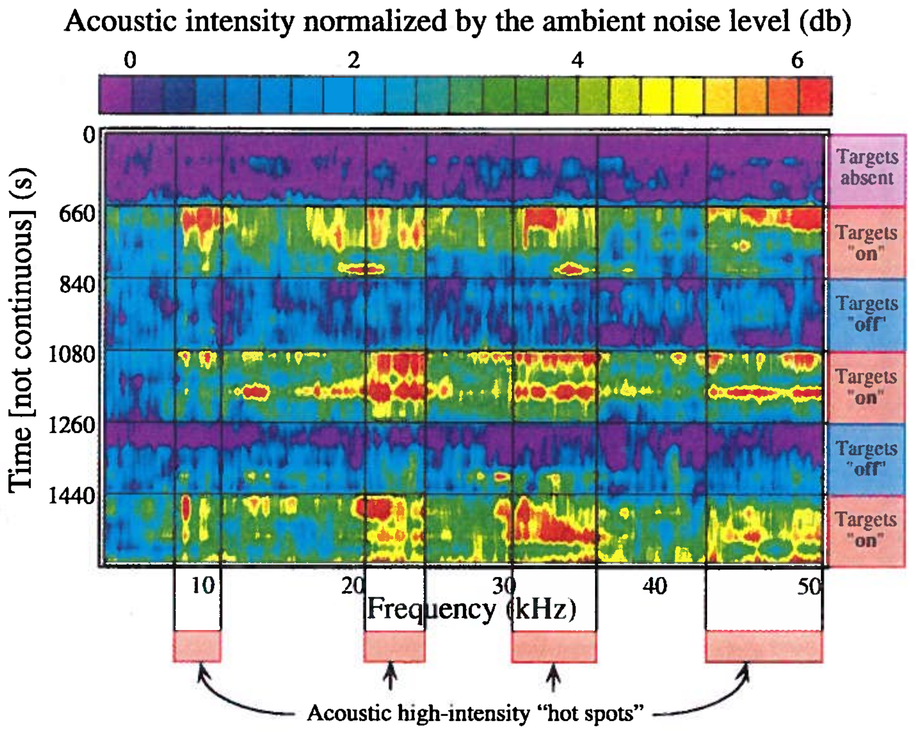

Figure 2. Ambient noise spectra obtained with neoprene-faced targets "on," "off," and absent.

INTRODUCTION

Daylight is strongly absorbed by sea water: below a depth of a few tens of metres the ocean is enveloped in darkness. Lack of visibility seriously impedes exploration of the ocean depths and is one of the main reasons why activities such as seafloor mapping are so slow and costly. Artificial light sources can be used at depth but, like daylight, are heavily attenuated by the medium, which limits the effectiveness of all forms of optical illumination to very short ranges. Turbidity, which may be severe in shallow environments, exacerbates the problem by reducing the range achievable with optics effectively to zero.

Acoustic techniques for probing the ocean are more promising than light, because sea water is essentially transparent to sound. As demonstrated recently in the Heard Island experiment (Baggeroer and Munk, 1992), sound, under the right circumstances, can be transmitted and detected over oceanic path lengths of tens of thousands of kilometres. Traditionally, acoustics is used in two ways in the ocean: "passive" methods involve simply listening for the sound produced by an object, such as a submarine, whereas "active" systems transmit pulses of sound and listen for returning echoes. Swath-mapping sonar is an example of an active system that is used in an exploratory application, in this case leading to the production of contour or topographic maps of the bathymetry (Macdonald et al., 1993).

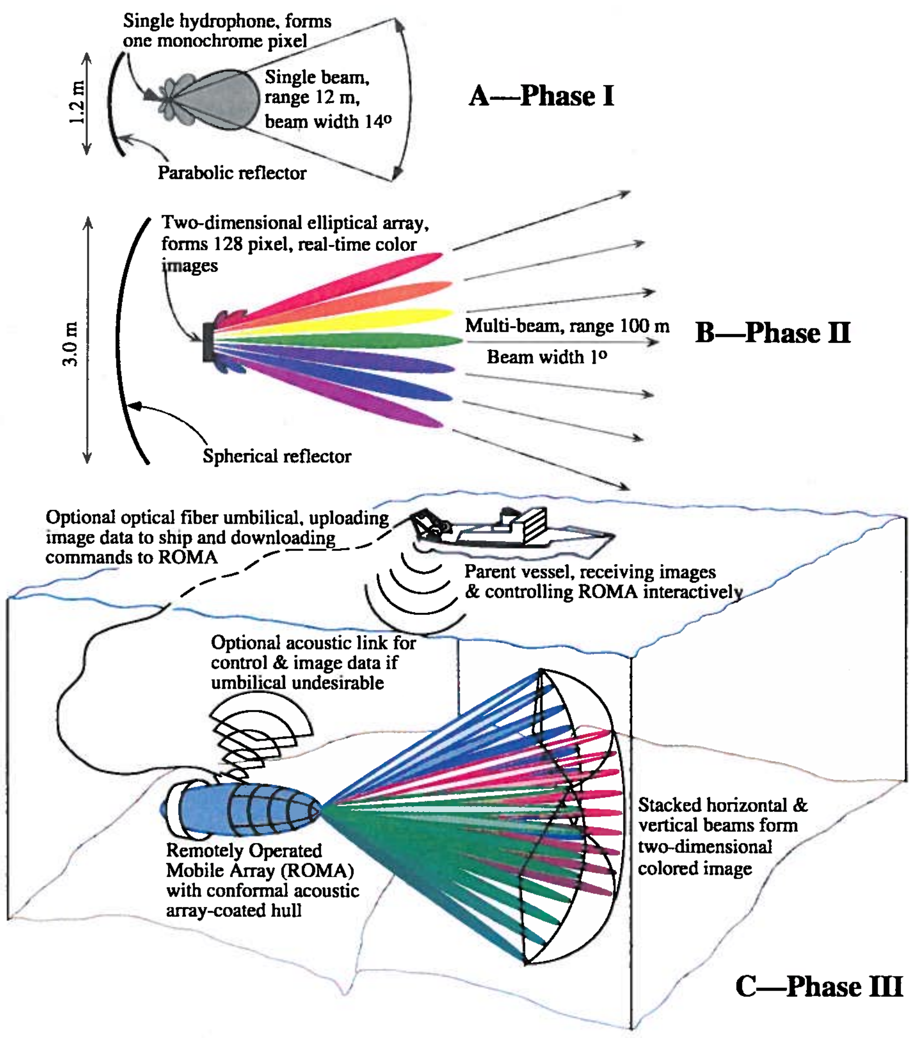

Figure 1. A: Phase I acoustic lens (parabolic reflector with single hydrophone at the focus). B: Phase II acoustic lens (spherical reflector with array of 128 hydrophones in the focal surface). C: Phase III acoustic lens (conformal phased array of 1000 hydrophones on the hull of a remotely operated vehicle).

Most acoustic systems used for probing the ocean are based on some form of active technology. This is equivalent, in the case of a swath-mapping sonar, for example, to exploring the surface of Earth in pitch darkness using a flashlight; or more accurately, using radar transmissions, which provide travel-time information but no direct visual image. In the circumstances, it is not surprising that ocean exploration is such an arduous activity. Because sonar systems do not yield pictorial images directly, considerable computational effort or a high level of skill and experience is required to interpret their output. Such systems are far from being the underwater equivalent of a conventional photographic or video camera in the atmosphere.

In fact, optical imaging, which is so familiar in the atmosphere, has at present no acoustic analogue in the ocean. Conventional images, as formed by the human eye or a photographic camera, are possible because the presence of an object modifies the ambient illumination by scattering the incident radiation. When the scattered light is focused by an optical lens onto a focal surface (retina or film), an image is created. An essential ingredient in this process is the illuminating field which, under natural conditions in the atmosphere, is daylight. Although it embodies elements and advantages of both, photographic imaging with daylight is neither an active nor a passive technique: the objects being imaged are not intrinsic radiators, nor is the object space illuminated by an artificial light source.

Photography, both still and video, is an extremely effective method of communicating information, as exemplified by the news media, advertising, and television. An analogous acoustic system for creating pictorial images of objects in the ocean could show similar potential. For reasons that may be associated with the evolution of sonar, such a system has never been developed; it is, however, feasible.

ACOUSTIC DAYLIGHT

Ambient noise in the ocean is the analogue of daylight in the atmosphere. Both are incoherent, random fields of radiation propagating in all directions, although the source mechanisms in the two cases are obviously different. The oceanic noise field is produced by numerous natural sources, including breaking waves, bubbles, spray, and precipitation (Kerman, 1988, 1993), in addition to shipping, offshore

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engineering activities, and marine mammals (Urick, 1983). An object in the noise field scatters some of the incident radiation, suggesting, by analogy with photography, that the ambient noise could be the basis of an "acoustic daylight" imaging system.

Producing an acoustic daylight image requires an acoustic lens to focus the scattered sound onto a focal surface. The lens could be a reflector, refractor, or phased array. Differences in acoustic intensity across the focal surface constitute the image, making acoustic daylight imaging an incoherent technique that, unlike holography, for example, does not rely on phase information to produce the image. (With a phased array as the acoustic lens, the phasing is important only for steering the beams). Once the acoustic image has been formed, the intensity distribution across the focal surface would be displayed as a familiar pictorial image on a television monitor.

The ambient noise frequencies useful for imaging lie between 5 and 100 kHz, where the upper limit is dictated by the onset of thermal noise arising from thermal agitation of the water molecules (Mellen, 1952). Thermal noise, a localized, microscopic phenomenon, is not a radiating acoustic field and hence cannot be used for imaging. At a frequency of 25 kHz, near the (geometric) center of the operating band, the acoustic wavelength is 6 cm, which is approximately five orders of magnitude greater than the wavelength of visible light. Inevitably, this means that the resolution of acoustic daylight images will be inferior to that of their optical counterparts. In fact, the lower limit of 5 kHz for acoustic daylight imaging is set, rather arbitrarily, at a frequency below which the angular resolution of the lens is deemed to be unacceptably low.

The (dilated) pupil of the human eye is about 10 000 optical wavelengths in diameter, which accounts for the remarkable acuity of human vision. To achieve similar angular resolution with an acoustic daylight system would require an acoustic aperture of the order of 600 m, which is not practical for a variety of reasons. An aperture of 10 m—i.e., approximately 200 acoustic wavelengths, is about the largest that could be achieved in the immediate future. Although not of optical quality, an image from such a system would be by no means unacceptable. Moreover, image enhancement techniques offer the prospect of improving the perceived sharpness of the final image.

At 25 kHz the attenuation of sound in sea water is approximately 4 db/km. Assuming attenuation is the limiting factor, the maximum range of the system will therefore be of the order of 0.5 km. With an aperture of 10 m, the angular resolution would be ~0.4°, corresponding to a linear resolution of 3 m for each point in the image of a target at maximum range. For targets at shorter ranges, the linear resolution scales accordingly; for example, at a range of 100 m the linear resolution at the center frequency is 0.6 m. A further improvement could be achieved by working at a higher frequency—say 75 kHz—where the linear resolution at a range of 100 m is 0.2 m.

INCOHERENT IMAGING

The first in situ acoustic daylight experiments (phase I) were conducted in the Pacific Ocean off Scripps pier in southern California (Buckingham et al., 1992). The acoustic lens used in the experiments was a parabolic reflector of diameter 1.22 m with a single, low-noise hydrophone at the focus. Thus, the system formed a single beam or "look" direction (Fig. 1A), corresponding to just one pixel of an image. The surface of the parabolic dish was faced with neoprene rubber, which is nominally a perfectly soft (pressure-release) reflector at the frequencies of interest. Rectangular targets, also faced with neoprene, were placed in the beam at ranges of approximately 10 m; noise spectra were recorded with the targets "on" (broadside-on and "off") (edge-on) to the lens, as well as entirely absent.

It is clear from Figure 2 that in the "on" position the targets increased the noise level across the band that is of interest here; the targets were visible in the illumination provided by the naturally occurring ambient noise in the ocean. Even in the "off" configuration, the targets could be "seen," in that they produced higher energy noise spectra than were obtained with the targets absent. Although this single-beam experiment is a far cry from acoustic daylight image formation, the fact that the intensity in a single pixel responded to a target in the beam is the first direct evidence that imaging with ambient noise in the ocean is a physically reasonable possibility. Because the technique works with one pixel, it should only be a matter of technology to extend it to many pixels, and many pixels constitute a genuine pictorial image.

Nominally, the difference between the spectral levels observed with the targets "on" and "off" is 3 db. However, the "on" spectra show some interesting structures, as illustrated in Figure 2, where regions of relatively high intensity or "hot spots" can be seen centered around 10, 22, 33, and 47 kHz. Apparently, the targets exhibited a frequency-dependent acoustic albedo, some frequencies being reflected more strongly than others. This effect can be interpreted as "acoustic color," by direct analogy with optical color. Acoustic color could be displayed as "false" optical color in an acoustic daylight image (just as infrared and ultraviolet satellite images are displayed in computer-generated color), thereby providing visually recognizable information about the acoustic properties of the object space.

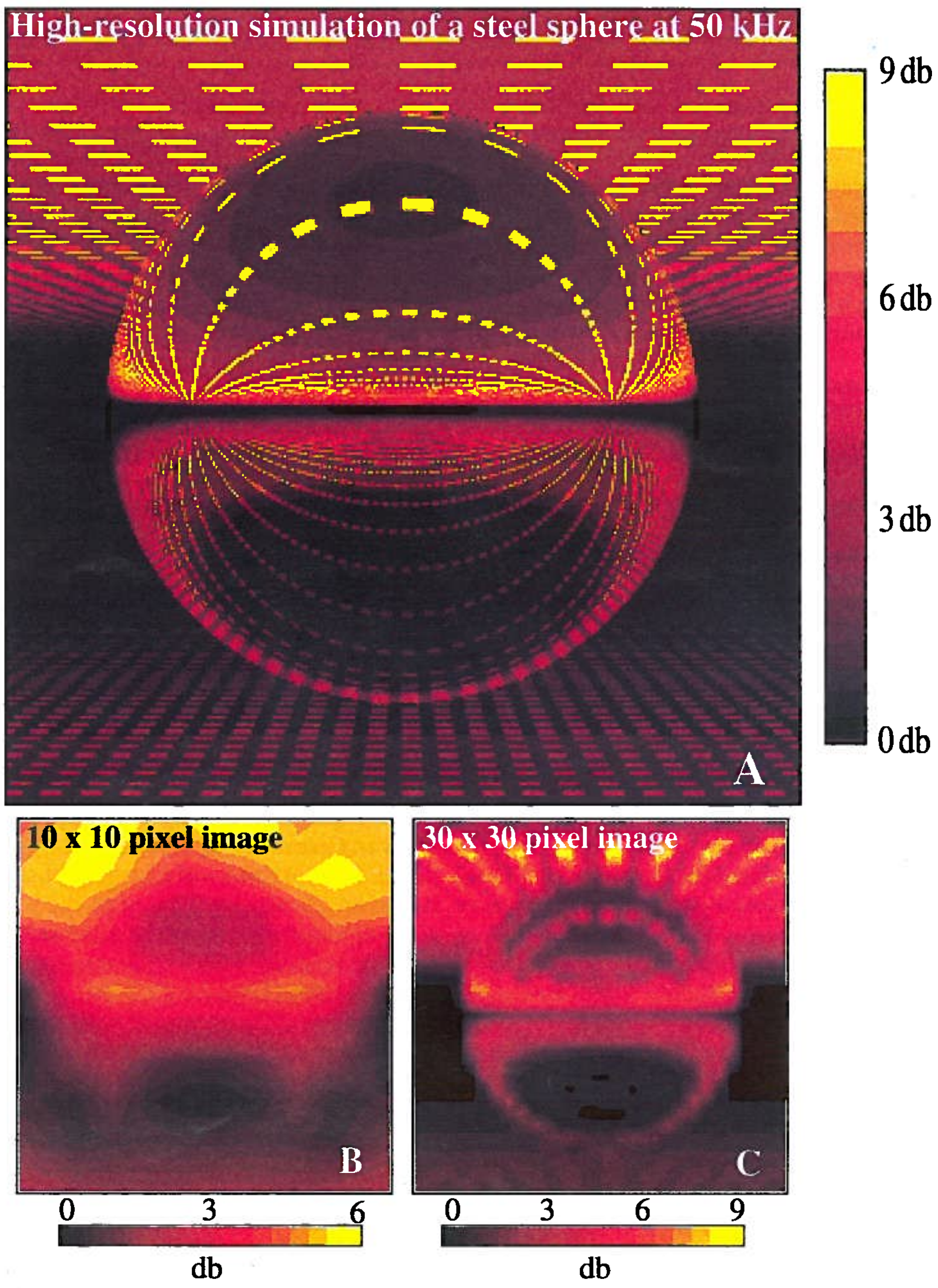

Figure 4. Numerically simulated acoustic daylight image of a steel sphere in shallow water. Breaking waves on the surface are represented as monochromatic sources (bright yellow dashes), with an acoustic frequency of 50 kHz. A: High resolution, with 90 000 pixels. B: Low resolution (phase II), with 100 pixels. C: Intermediate resolution (phase III), with 900 pixels. In all three images, color represents intensity, and dynamic range in each case is indicated by the corresponding color bar.

In a second experiment with the phase I acoustic lens, the neoprene-faced targets were replaced with a vertical screen of bubbles, all of nominally the same size (radius of 0.3 mm). Bubbles are well known to be resonant systems, with a resonance frequency that varies inversely with the bubble radius (Minnaert, 1933). For the bubbles forming the screen, the resonance frequency was about 11 kHz. The bubbles were produced by attaching an air compressor to a hose pipe along which small holes had been pierced with a fine needle. The hose pipe was laid on the seafloor well below the beam of the acoustic reflector to ensure that the bubbles were acoustically quiescent as their buoyancy carried them upward through the beam. (On closure, a bubble undergoes radial oscillations for several milliseconds, during which time it acts as a brief but effective narrow-band source of sound [Longuet-Higgins, 1993]. After the oscillations have decayed, the bubble is in equilibrium with its surroundings and remains mute for the remainder of its existence).

It can be seen from Figure 3 that with bubbles present the spectrum exhibits a pronounced peak centered close to 11 kHz. Because they are quiescent within the beam, this peak cannot be attributed to the initial pulses of sound made by the bubbles at closure, although it is consistent with the resonant nature of the bubbles: each bubble is excited by the incident (broadband) ambient noise and is driven into radial oscillation around the resonance frequency. The bubble then reradiates sound uniformly in all directions (Devin, 1959), the spectrum of which shows a narrow peak centered on the bubble resonance frequency. This scattered field is responsible for the observed peak in the noise spectrum in Figure 3. Because the sizes of the bubbles constituting the screen were almost certainly distributed about the nominal diameter, the observed noise peak is a superposition of individual resonance peaks and hence is considerably broader than the resonance peak of a single bubble. On the basis of these observations, it appears that the spectra shown in Figure 3 constitute further evidence in support of the concept of acoustic daylight imaging.

The phase I experiments, with the single-beam lens, are now complete, and construction of a multielement acoustic lens (phase II) is in progress (Fig. 1B). Again, the lens is a reflector but with the single sensor replaced by an array of 128 hydrophones in the focal surface. The geometry of this arrangement is such that each sensor element corresponds to a single beam, thus providing 128 pixels in the final image. In passing, it is interesting to note that this phase II lens, which forms multiple beams through the geometrical disposition of the dish and transducer array, is an unusual example of sonar system design, although it has an analogue in the long-focal-length mirror lens that is popular for conven-

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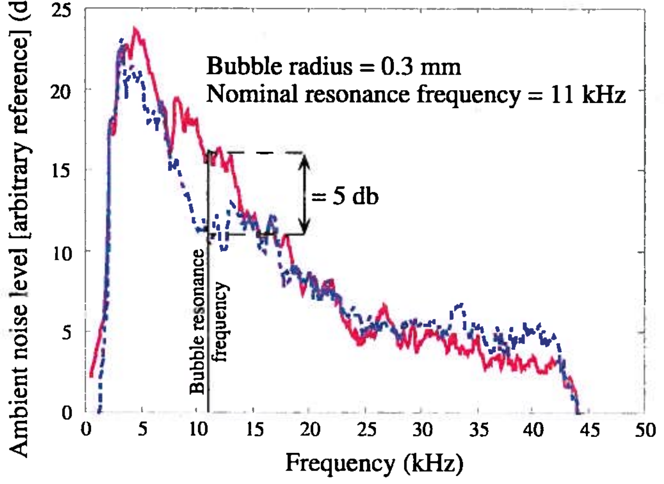

Figure 3. Ambient noise spectra obtained with (dashed blue line) and without (solid red line) the bubble screen as target. Note the peak in the spectrum around 11 kHz when the bubbles are present.

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tional photography. Looking further into the future, the reflector will be replaced with a phased array of about 1000 elements (phase III), perhaps mounted on the hull of a remotely operated vehicle (Fig. 1C). Such a design would provide relatively high resolution images of 1000 pixels and a mechanical "zoom" capability achieved through the mobility of the platform.

Even with as many as 1000 channels, each corresponding to a pixel, it should be possible to achieve a rapid refresh rate in real time, allowing moving images to be created. Acoustic daylight imaging would then be the direct analogue of video photography, giving rise to moving, color pictures originating in ambient sound rather than ambient light.

THEORETICAL MODELING

Although the idea of incoherent imaging with ambient noise is appealing and the analogy with optical imaging provides an intuitive basis for understanding the physical processes involved, it is difficult to quantify the imaging process. Several questions are of interest, including the effect of the anisotropy of the noise on the image. This issue was not clarified by the phase I experiments because of difficulties in measuring the directionality of the noise field, although circumstantial evidence suggests that Scripps pier itself acted as a significant noise generator.

To address the question of anisotropy, a full wave-theoretic analysis (Buckingham, 1993) of acoustic daylight imaging has been developed in which the target is assumed to be a spherical object with pressure-release (i.e., acoustically soft) surface. Concentric with the target sphere is a noise sphere of infinite radius on which the acoustic sources are distributed. The directionality of the noise field is controlled by selecting the area of the noise sphere covered by the sources. The acoustic lens is modeled as a line array of hydrophones at half-wavelength spacing, arranged endfire-on (i.e., radially) to the target sphere. A central feature of the analysis is the derivation of a new, closed-form approximation for the Green's function of the field scattered from the pressure-release sphere. This approximation makes the statistical analysis of the field tractable, allowing a solution to be developed in a form that is easy to evaluate on a desktop computer.

The response of the line array to the scattered field is expressed in terms of a "visibility" function, *V*, defined as the ratio in decibels of the total field (incident plus scattered) to the incident field alone. This is essentially the quantity that was measured in the original phase I experiments. Provided the contrast is sufficient, say, with positive value (front lighting) greater than 3 dB or negative value (back lighting) less than –3 db, the object should be visible against the background.

Theoretically, the visibility is fairly insensitive to the anisotropy of the noise under front lighting conditions, showing values of several decibels, which is consistent with the observations in the phase I experiments. This is encouraging, because it implies that the acoustic daylight imaging technique is robust in that it does not depend critically on the detailed structure of the noise field. Under strong backlighting conditions, the visibility function goes strongly negative (in decibels), indicating that the object is in silhouette. The onset of shadowing, as predicted by the wave-theoretic theory, is consistent with arguments based on simple geometrical (ray acoustics).

NUMERICAL SIMULATION

Whereas the analytical theory provides a quantitative estimate of acoustic daylight imaging, it does not yield simulated pictorial images. To remedy this situation, a numerical model has been developed (Potter, 1993), based on Kirchoff-Helmholtz scattering and a far-field assumption, that simulates the process of acoustic daylight imaging. Objects of various shapes and acoustic properties, illuminated by realistic noise fields, can be handled by the computer code to provide images that should be representative of a working acoustic daylight system.

The object in the foreground in Figure 4A, generated from the model, is a steel sphere with a diameter of 1 m, located in a shallow ocean channel. The perspective is that of an observer, at the same depth as the target sphere, who is looking horizontally along the channel; overhead is the sea surface and below is the seafloor. In this example, the acoustic illumination is provided solely by monochromatic surface sources (bright yellow, parallel dashed lines), with a frequency of 50 kHz, representing one spectral component of naturally generated sound from breaking waves. (Thus, there is no "acoustic color" in Figure 4, in the sense discussed above in connection with Figure 2. The color in Figure 4 represents intensity at a single frequency).

A great deal of visual information about the acoustic properties and geometrical form of the target, as well as the geo-acoustic character of the environment, is contained in Figure 4A. At present, such images are unfamiliar, and the information they contain requires interpretation. However, of all the human senses, vision is the most highly developed, the human eye-brain combination having evolved to become remarkably efficient at recognizing visual cues. As our experience with acoustic daylight images grows, the acoustic messages contained therein, as exemplified by Figure 4A, should become as recognizable as the optical information in a conventional photograph.

In Figure 4A, the intense, bright yellow surface sources can be seen below (dull red), reflected in the bottom. The source lines are mapped as arcs onto the surface of the sphere, thereby giving a visual indication of the shape of the target. If the sphere were pitted or otherwise flawed, then the imperfection would show up as a deformity in the mapped curve; if the object were, say, ellipsoidal, the mapped lines would be correspondingly elongated. These mappings, of course, are specular reflections of the sources in the surface of the target. In the ocean, the actual surface sources would be more randomly distributed than those shown in Figure 4A, but this would not affect the overall level of the illumination significantly, although it would change the detailed structure of the reflections from the target. Nevertheless, shape information could be gleaned visually from these more random mapped reflections in much the same way as in the present example.

Apart from the specular reflections, the shape of the object in Figure 4A is also apparent from subtleties in shading. When the image is first viewed, the shading is perhaps the main factor that identifies the object as a sphere. Shape inferred from shading is, of course, commonplace when one views a photograph, but it is only just being exploited in the latest computer-generated swath-mapping sonar displays (Nishimura and de Moustier, 1993). Acoustic daylight imaging offers shading as a natural, intrinsic feature of the new technique.

The seafloor in Figure 4A has been modeled as a fast-fluid sediment with a critical grazing angle of 28° (for sound incident from above). Thus, noise rays with grazing angles less than 28° are totally reflected from the bottom, whereas rays with higher grazing angles penetrate the interface and are lost to the water column. With such a bottom, relatively little acoustic energy travels upward at grazing angles steeper than 28°. This is indeed evident in Figure 4A from the dark shadow on the lower half of the sphere. The edge of this shadow, which is very sharply delineated, corresponds precisely to the critical grazing angle of the seafloor.

Straight along the channel, on either side of the equator of the sphere, the image is almost black, indicating that very little noise travels horizontally. This is consistent with the fact that most of the energy propagating in the horizontal originates in far distant surface sources and thus is subject to severe attenuation. When we look slightly above the horizon the surface becomes brighter, an effect that continues progressively with increasing elevation, until the nearby, overhead sources appear brightest of all.

In addition to the pronounced shadowing, attenuation, and reflection effects, the image in Figure 4A shows some subtle features that relate to the acoustic properties of the sphere itself. (Although steel is obviously a hard material, the sphere is not a perfectly rigid body, nor is it a perfect reflector of sound). Thus, even this simple example of acoustic daylight imaging contains an abundance of information, making interpretation of the image an interesting and challenging task.

A further factor that complicates interpretation is reduced resolution in real acoustic daylight images. The resolution of the simulated image in Figure 4A is artificially high, at 90 000 pixels, a number that could probably not be achieved in practice. Figure 4B shows the same image but degraded to 100 pixels, which is close to the quality expected of the phase II system currently under construction. No image enhancement has been applied in this case, except for a simple interpolation between pixels which introduces some smoothing. Obviously, the sharpness of the high-resolution image has been lost and the dynamic range has been reduced, but the most prominent features of Figure 4A have been retained. For instance, the dark shadow on the lower hemisphere can still be seen, the bright waistline is apparent, and the shading on the upper half of the sphere is also evident. Nevertheless, it would be desirable to see some improvement in image quality, at least to the level where the shape of the target could be recognized unequivocally.

When the number of pixels is increased by almost an order of magnitude, to 900, corresponding to the

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planned phase III system, the acuity of the image is improved significantly and the dynamic range is retained (Fig. 4C). The target is easily recognizable as a sphere and all the important details in the high-resolution image of Figure 4A are visible with only slight degradation of quality. This degree of fidelity should be achievable with a practical acoustic daylight imaging system.

ACOUSTIC COLOR

Looking to the future, computer-generated color in the display of the phase II and phase III systems will be used to represent the acoustic spectrum in each pixel of an image. With this scheme, the spectral content of a pixel is determined by three factors: the acoustic reflectivity of the corresponding point in the object space (see Fig. 2), the spectral shape of the sources, and attenuation associated with both the medium and the boundaries. Of these, the acoustic reflectivity corresponds to the intrinsic (optical) color of an object as viewed in white light. The noise sources in the ocean are not white but they are broad-band (unlike the monochromatic sources in the artificially generated Fig. 4A), showing a spectrum that rolls off approximately as (frequency)$^{-2}$. Thus, low frequencies predominate in oceanic ambient noise, providing illumination that is acoustically "pink." This shift toward "acoustic red" is further accentuated by attenuation, which increases approximately as (frequency)^{n}, where $n = 1$ or 2, depending on the mechanism involved.

Attenuation does not have a direct analogue in the atmosphere, because light in the visible region of the spectrum is not significantly absorbed. (A related phenomenon is a red sunset, which occurs because blue light is scattered by particulate matter in the atmosphere). In the ocean, on the other hand, even the lowest frequencies will be attenuated over sufficiently long ranges, giving rise to regions of an acoustic daylight image that will appear dark. (Recall that the dark regions on the horizon in Figure 4A are an effect of attenuation.) In applications of acoustic daylight imaging, it may well be possible to turn absorption to advantage since it yields visual information about the acoustic properties of the ocean environment.

GEOPHYSICAL APPLICATIONS

Acoustic daylight imaging has naval, industrial, and geophysical applications; potentially it is useful whenever vision in the ocean is required. In the geophysical arena, an obvious application of the new technique is high-resolution topographic mapping of the seafloor. Assuming that the "camera" was mounted on a mobile platform such as a fish or remotely operated vehicle, allowing it to operate within 100 m of the bottom, a spatial resolution of approximately 0.6 m per pixel could reasonably be expected, with 1000 pixels composing the image. The images would be processed in real time, with a refresh rate of 10 Hz or faster, and would show color characterizing the acoustic properties of the seafloor. In brief, moving, color images of the seafloor would be produced.

Although such performance is for the future, available evidence indicates the feasibility of the technique. An interesting feature of acoustic daylight imaging, which distinguishes it from most sidescan mapping sonar, is its broad-band nature. A frequency bandwidth of over a decade is the factor that allows color to be introduced into the images. Although artificially produced, the color correlates with the frequency-dependent acoustic properties of the object space. Through this color facility, acoustic daylight images of the seafloor may yield, in addition to bottom topography, information on the composition of the basement. For instance, the acoustic reflectivity of a porous sediment is strongly dependent on frequency, whereas that of a consolidated basement is not. The different colors of these two types of bottom material in acoustic daylight images could act as a discriminator, providing an indication of their respective geologic properties.

CONCLUSIONS

Simple experiments in the ocean support the concept of imaging with naturally generated ambient noise, a conclusion that is consistent with theoretical and numerical models of the new imaging technique. Because it provides vision in the ocean, several potential applications exist for acoustic daylight imaging, including geophysical surveying of the seafloor. For two reasons, attenuation in the ocean and reduced angular resolution, the system is effective only over short ranges, of up to about 0.5 km. Within its operating envelope, the acoustic daylight technique should produce images that show (visual) color determined by three factors: the spectral shape of the noise, the degree of attenuation in the ocean, and the acoustic reflectivity of the object space. Because acoustic daylight images can be refreshed rapidly, the final effect should be much like a conventional, moving video image on a television monitor, but with somewhat inferior resolution.

Improvements in angular resolution could be achieved by increasing the aperture of the acoustic lens; apart from being prohibitively costly, such an aperture would make the underwater camera unduly cumbersome. An alternative approach lies with image enhancement algorithms, running in real time to produce images with improved acuity. Automated image recognition is a related problem, which for some geophysical applications may be important; for example, automatic classification of seafloor by topography or geology could prove useful. Neural networks, operating on raw data or extracted feature vectors rather than the acoustic daylight images themselves, may satisfy this requirement. Algorithms dedicated to the enhancement and recognition of acoustic daylight images are currently being considered.

ACKNOWLEDGMENTS

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OFFICERS OF THE DIVISION

Bruce Molnia of the U.S. Geological Survey in Reston (and *GSA Today* Forum editor), is currently president of the Division. Pinar Yilmaz of Exxon Production Research Company, Houston, is first vice-president and will succeed Bruce for a one-year term as president in October 1994. John Oldow of Rice University has just completed a four-year term as our resourceful secretary-treasurer, passing the baton to Fred Simon. As mentioned, Jim Skehan has started his term as second vice-president and will become division leader at the November 1995 New Orleans meeting. I, having stepped down at the Boston (1993) meeting, join Brian Skinner in the ranks of past presidents.

FUTURE OF THE DIVISION

This short article has aimed to give readers some idea of the kinds of things that the International Division has been doing during the four years of its existence. Our future holds prospects of continuing in the same directions and branching out in new ways. Working with other GSA Divisions, which we have done, is an area where additional opportunities certainly exist. I am sure our officers would be glad to hear your suggestions. Field trips to other continents, more work with students visiting North America, and grasping the opportunities that arise as new nations emerge and existing nations become more accessible are all in our dreams.

The Division's diversity embraces some responsibilities that I am beginning to think might be better handled in other ways. Specifically, I refer to the kinds of functions that are filled in many national societies by a foreign secretary. As far as I know, GSA has never had such a person, and the reason may well be that we are a continental and supranational society. Nonetheless, a foreign secretary to deal with national societies on other continents (Antarctica, as always, being the exception) could be very helpful. The kind of person I envisage would be a distinguished senior member of the society, perhaps a past president or officer. He or she would hold office for perhaps five to seven years and work with the president and Council on links with peer societies and international bodies. The key to a foreign secretary's function is continuity in office; a one-year appointee cannot become familiar with the issues, and especially the diverse ways of doing business, which are the essence of international relations. This is an idea that I would like to see discussed widely in the Society. ■