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IMPROVED METHODS FOR VISUAL AND PHOTOGRAPHIC BENTHIC SURVEYS

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As funding for field work becomes more competitive, it is increasingly important to produce cost effective quantitative results using calibrated methods. Much effort is devoted to visual and photographic surveys which are routinely employed to determine the density and distribution of animals or other organisms, the type and abundance of biological ground cover, and geological features near or on the ocean bottom. A number of techniques have been developed for estimating the scale of the study site and the size of individual specimens so that the observations can produce quantitative data for numerical analyses and comparative studies.

This paper will review some of the more commonly employed methods and will present recently-developed, laser-based approaches to quantify visual and photographic images. The techniques to be discussed involve the projection of small light spots as fiducials onto the surface to be surveyed, so that the observer or camera can record absolute scale information. Demonstrated applications and proposed methods will be described.

INTRODUCTION

Visual and photographic surveys are commonly used to quantitatively measure the abundance and diversity of benthic biota. A number of studies have shown that photographic methods mitigate some of the major biases associated with traditional physical sampling, i.e., traps, trawls, grabs (Tusting, 1986; Bortone et al., 1992; Barry and Baxter, 1993). For some studies, photography complements mechanical sampling by establishing undisturbed spatial relationships prior to disruption by the sampling method (Emory et al., 1965; Ewing et al., 1967).

A wide variety of methods and techniques have been developed to allow repeatable and comparative studies to be performed. All depend on the establishment of at least one metric scale or dimension on the image to provide a basis for analysis and calculations. The addition of small, inexpensive lasers to these visual/photographic systems can greatly improve the measurement accuracy by providing one or more absolute dimension. For video and film recording, the scale information can be permanently recorded as small bright spots directly on every frame recorded.

TRADITIONAL QUANTITATIVE METHODS

Metric Scale or Grid

The simplest and most direct method is to introduce a scale directly into the scene to be recorded (Owen et al., 1967; Maney et al., 1980; Cassidy, 1991). This can be accomplished by laying a ruler or a frame-like grid on the bottom prior to photographing it. For hard-bottom environments, small flags or other markers can be permanently attached or embedded to denote the boundaries of the study area (Gittings et al., 1990). To further define the boundaries, high-visibility lines are often strung between markers. This approach is accurate and effective for shallow-water sites that will be visited on a repetitive basis. It does require the study site to be carefully mapped and marked prior to the survey work. For random sampling, transects, or other situations where advance delineation of the site is impractical, other methods must be used.

Photogrammetry

Photogrammetry is the science of making measurements using photographic techniques (Wolf, 1983; Newton, 1984). Many of the methods described in this paper can be considered to be photogrammetric techniques. However, the term is usually used to describe a special version of stereo-photography in which measurements are made in three dimensions. A precisely mounted and calibrated pair of cameras record two overlapping images of the same scene under controlled geometric conditions. The images are later processed with a highly-specialized image processor to provide precision measurements from the recorded images. Although this type of photogrammetry is a well-established technique for underwater inspection and measurement, it has only occasionally been used for benthic-survey work because of its complexity and cost (Schuldt et al., 1967).

Most photogrammetric work has been done with film-type cameras, and most commercially available equipment uses 35-mm-format cameras. Recently a video-based system has been developed for undersea photogrammetry (Turner et al., 1991). Although the resolution and accuracy of this system is lower than that obtainable from film recording cameras, the images can be processed on line and the measurements performed in nearly real time.

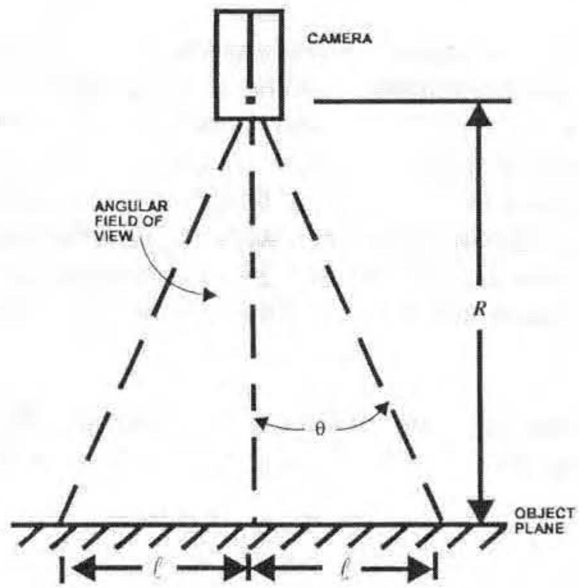


FIGURE 1

Relationships between the camera's angular field of view, range and field of view at the object plane.

Predetermined Field of View

If the angular field of view of a camera and the geometry between scene and camera are known, the size of the photographed area can be calculated and the size of the object within the field of view can be estimated. A simple example is shown in Figure 1 where the camera is viewing a surface normal to the camera's axis at a range of R meters. The angular field of view is determined by the focal length of the camera f and the format size of the film or image sensor (in the case of a video camera) x. The angular field of view can be directly measured by photographing objects of known size at known distances from the camera. Alternatively, it can be calculated from Equation 1 for most cases of interest (Ray, 1984).

$$\text{Angular field of view} = 2\theta = 2\tan^{-1}\left(\frac{x}{2f}\right) \qquad (1)$$

where:

θ = the half-angle as shown in Figure 1
x = the format dimension in mm, and
f = the focal length of the camera lens

For a rectangular format, there are three ways of measuring the size of format: horizontally, vertically, and diagonally. For the common 35-mm camera film, the format is 36 mm horizontally, 24 mm vertically, and therefore, 43 mm diagonally. For video cameras, the diagonal format (diameter of the image sensor) is usually specified and the width-to-height ratio is 4 to 3. The focal length used in Equation 1 is the effective focal length when photographing objects in water. The effective focal length of a lens in water is longer than in air by a factor of 1.33 (assuming a flat view port). For example, a 28-mm lens becomes a 1.33 x 28 = 37-mm, focal-length lens when used in water.

With reference to the geometry of Figure 1, if the range R and the angular fields of view are known, then the dimensions of the photographed area can easily be calculated:

$$\left.\begin{aligned} \text{Vertical field of view} &= 2l_v = 2R\tan\theta_v \\ \text{Horizontal field of view} &= 2\,l_h = 2R\tan\theta_h \end{aligned}\right\} \qquad (2)$$

where θ_V = the half angle of the vertical angle of view, and

θ_h = the half angle of the horizontal angle of view

The size of feature or animals near the object plane, within the field of view, can be estimated by direct scaling with respect to the size of the field of view. This simple and effective approach to quantitative photography has been used since the 1940s. Early systems used a weight to trigger the camera when it made contact with the bottom (Ewing and Vine, 1946; Owen et al., 1967). Harold Edgerton, the pioneer in underwater photography and acoustics, used a sonar system to trigger his camera a predetermined distance above the bottom (Edgerton, 1967). More recently a mechanical frame has been used to accurately position the camera above the bottom prior to photographing it (Cassidy, 1991).

Perspective Grid Approach

If the camera axis is not positioned perpendicular to the scene as in Figure 1, the transformation between the object plane and the image plane is no longer a simple linear one, but is one requiring the solution of equations containing trigonometric functions. Traditionally, the method of obtaining quantitative information from an image produced by a camera aimed forward and downward involves the mathematical generation of a perspective grid that is superimposed over the image to allow metric scaling of the scene photographed (Wakefield and Genin, 1987).

Scientists using the 35-mm forward-looking cameras on the manned submersible ALVIN are provided perspective grids to assist in scaling and size determination from the photographs (D. Foster, personal communications). This method requires that a number of parameters of the camera and its platform be known: the angular field of view of the camera, its height-above-bottom, and the angle of the camera's axis with respect to the surface photographed (Rosman and Boland, 1986). In many cases one or more of these variables is unknown, making quantitative analysis impossible (Rice and Collins, 1985).

Visual and Photographic Surveys

Surveys and censuses are routinely performed by divers or vehicles swimming above the seafloor and observing organisms within a fixed field of view. A number of techniques for obtaining transect data and analyzing it have been developed (Chayes et al., 1984; Boland and Lewbel, 1986; Bortone et al., 1986, 1989; Maney, et al., 1990; Linquist et al., 1992; Barry and Baxter, 1993; Michalopoulos, et al., 1993). Absolute measurement of area of coverage requires a knowledge of the observer's or camera's height-above-bottom. This distance is usually based on an educated estimate rather than an actual distance measurement.

Another visual technique, the point method, requires that a scuba-equipped diver occupy a position on the bottom and slowly turn to scan a circular region of the bottom recording the number of individual fish observed by species during a fixed time interval. The chosen radius is usually 5.6 meters to provide a sample area equal to $\Pi r^2 = 100$ m^2. Fish size is also estimated during these censuses (Bortone et al., 1989, 1992). The size of the circle is estimated using a known-length line deployed on the bottom as a visual reference.

The simple, two-laser range finder (to be discussed in a following section) would allow a direct measurement of range for applications such as these. Laser-based altimeters would facilitate flying an ROV a known distance above the bottom and make it easier to measure uncontrolled variations in altitude during a transect. The basic size-measurement system (to be described) can provide each frame of photographic data with an absolute metric scale so that quantitative analyses can be performed on individual images. The size calibration information also allows variable magnification to be applied to the images so that the scale of each photograph can be normalized. This facilitates the production of mosaics (Steeves and Shafer, 1991) and is being used with computer-assisted image processing (MacDonald, et al., 1992).

LASER-ASSISTED MEASUREMENTS

Camera/Laser Range Finder

A single laser can be used with a camera to obtain an accurate and simple range finder as shown in Figure 2. For this case, the camera's axis must be nearly perpendicular to the surface photographed. The laser must be mounted rigidly with respect to the camera's axis so that the following geometric parameters are known:

y = offset of the laser with respect to the camera's axis, and
R_0 = range at which the laser beam crosses the camera's axis.

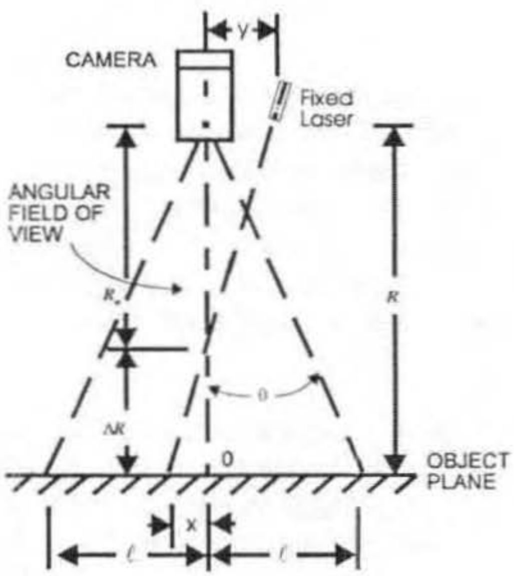


FIGURE 2

The use of a camera and laser to provide a simple range finder.

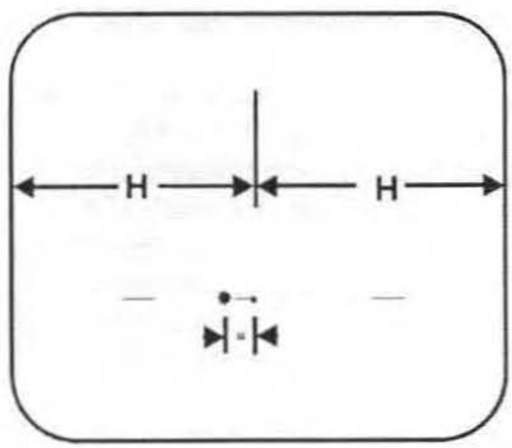


FIGURE 3

The image produced by the camera/laser combination of Figure 2.

In addition, the angular field of view 2θ of the camera must be determined (calculated from Equation 1 or measured). From the geometry of Figure 2:

$$R = R_0 + \Delta R \quad (3)$$

$$\Delta R = R_0 \left(\frac{x}{y}\right) \quad (4)$$

$$l = R \tan \theta \quad (5)$$

For convenience, we define a dimensionless parameter K:

K = ratio between the displacement of the laser beam from the point 0 at the object plane and the half width of the camera's field of view, or

$$K = x/l \qquad (6)$$

The image produced by the camera and laser positioned as indicated in Figure 2 will be as shown in Figure 3, with the light spot displaced to the left of the center of the image. Because of the idealized geometry, the transformation between the object plane and the image plane is again a simple linear transformation. For this special case, K is also equal to the ratio between the displacement of the laser-generated spot and the half width of the image or

$$K = u/H \qquad (7)$$

Combining equations 5, 6, and 7:

$$x = (u/H)\, R \tan\theta \text{, and} \qquad (8)$$

solving equations 3, 4, and 8 for R:

$$R = \frac{R_o}{\left[1 - \frac{R_o}{y}\left(\frac{u}{H}\right)\tan\theta\right]} \qquad (9)$$

The ratio u/H is obtained from the image and the other parameters are obtained from the camera/laser geometry. This method is applicable to video, film, or computer produced images.

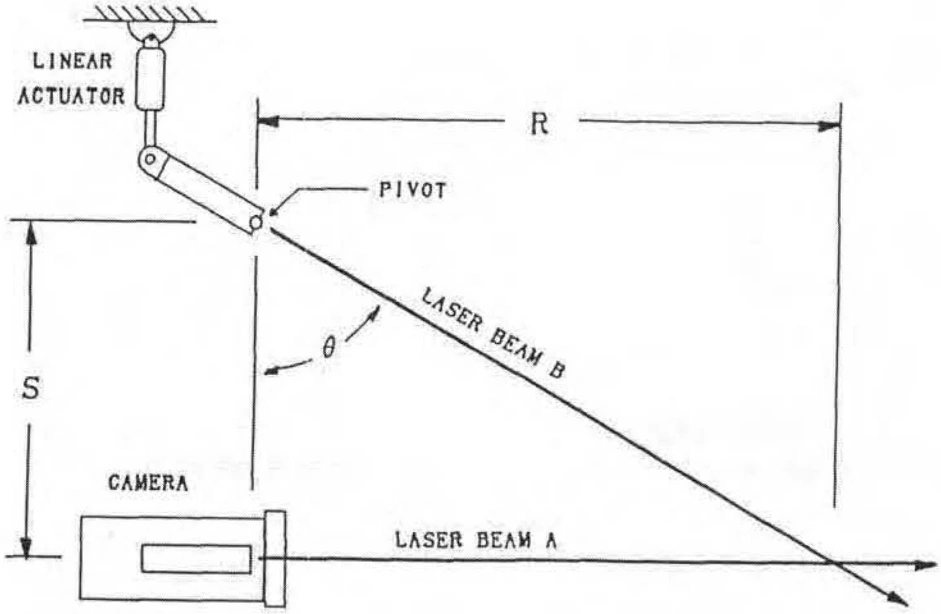
Two-Laser Range Finder

A similar system for determining range using a pair of lasers is shown in Figure 4 (Tusting, 1990).

In this case, one of the lasers is mounted parallel to the camera (or other viewing system), and the second laser is mounted so that it can be pivoted and the angle θ recorded. The moveable laser is adjusted until the two light spots coincide, and the range is calculated from the equation:

$$R = S \tan\theta \qquad (10)$$

This method of measuring range differs from the one described previously in two ways: it is applicable to a situation where the viewing system is a person rather than a camera, and the precise location of the lasers with respect to the camera is not critical.



$$R = S \cdot \text{TAN}\ \theta$$

FIGURE 4

An application of lasers and triangulation to measuring the range from a camera to a target.

Two-Laser Sizer

One of the earliest applications of lasers to underwater measurements involved a pair of parallel lasers to obtain direct size information (Tusting, 1986; Auster et al., 1989; Tusting and Davis, 1993). This method has been widely accepted and recently adopted as a training aid to help divers estimate the size of fish in situ (McFall et al., 1992). The parallel-laser sizer provides a geometric and mathematical basis for much of the following discussion of quantitative photography as it relates to improved survey methods. Therefore, the basic mathematics will be presented in some detail.

The simplest geometry involves positioning a camera perpendicular to the surface to be photographed as in Figure 5. Two lasers are attached to the camera with their axis parallel to and equidistant from the axis of the camera (Tusting, et al., 1989). Two parameters concerning the camera/laser geometry are assumed to be known or measurable:

θ_h = the half angle of the horizontal angle of view, and

x = the spacing between the lasers and the camera's axis.

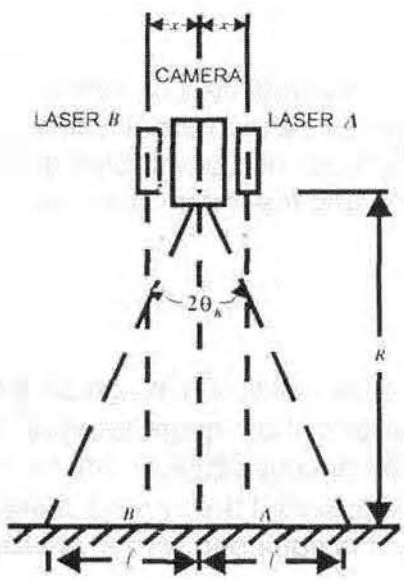


FIGURE 5

A two-laser photographic measurement system

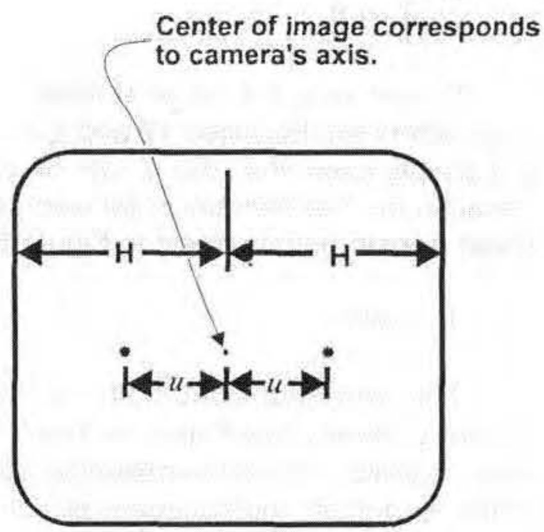


FIGURE 6

The image obtained from the camera/laser system of Figure 5.

In addition, the image format (or ratio of the horizontal to vertical fields) is assumed to be known. We define a ratio K as the fraction of the horizontal field of view spanned by the pair of laser beams as indicated in Figure 5 or:

$$K = \frac{x}{l} \quad (11)$$

Also from Figure 5, it is determined that

$$\tan \theta_h = l / R \quad (12)$$

Combining Equations 11 and 12:

$$R = \frac{x}{K \tan \theta_h} \quad (13)$$

Determining the range R allows the size of the horizontal field of view to be calculated from Equation 12 and also the area viewed since the format is known. For this simple case, the ratio K can be obtained directly from the corresponding image because the transformation between the object plane and the image plane is a simple, linear transformation (refer to Figure 6):

$$K = u/H \quad (14)$$

The dimensions of u and H are arbitrary—inches or cm for an image on a video screen or photographic print or more conveniently, pixels, if an image analysis system is being used. The laser dots also allow objects to be directly scaled from the image in both the vertical and horizontal directions. This is true even if the camera's angular field of view is not known—for example, if the camera is equipped with a variable zoom lens.

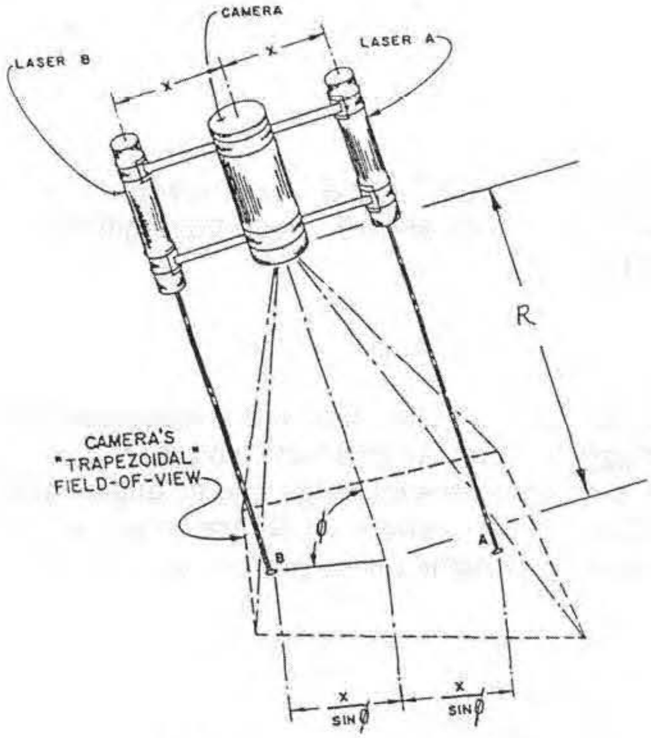


FIGURE 7

A two-laser size measurement system with a perspective view of the bottom

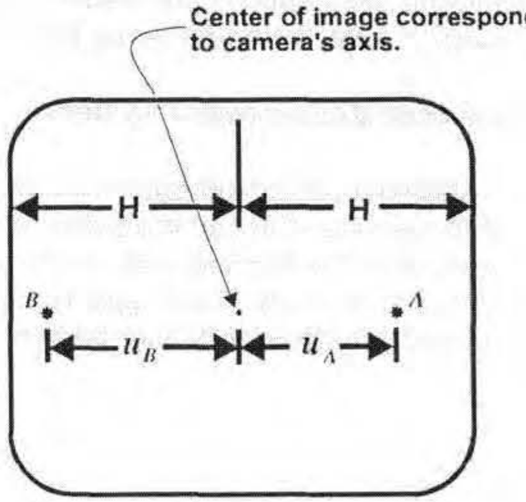


FIGURE 8

The image observed with the camera/laser system of Figure 7. As a result of the nonorthogonality of the camera's axis, the two laser spots are not offset equal distances from the center of the image.

Consider now a more complicated situation, one in which the camera/laser system is tilted fore and aft by an angle Φ. This configuration provides a simple perspective view of the bottom as shown in Figure 7. In this case, the transformation between the object plane and the image plane is no longer a linear transformation. The mathematics is complex and is presented in detail in a readily available paper (Wakefield and Genin, 1987). In this paper, it is shown that a complete dimensional analysis can be performed if the tilt angle Φ and the range R are known. The paper develops the Canadian or perspective grid method of analyzing the image and performing size measurements from the grid generated.

The image corresponding to the perspective view is shown in Figure 8. The rectangular-shaped image corresponds to a trapezoidal-shaped region of the bottom. The light spot marked A results from the intersection of laser beam A with the bottom and similarly for the light spot marked B. The distances u_A and u_B are not equal as in the case of the perpendicular viewing case. In fact, the difference in these two offsets is what allows the range and tilt angle Φ to be calculated (Davis and Tusting, 1991). The equations are:

$$R = \frac{xH}{2\tan\theta_h}\left[\frac{1}{u_A} - \frac{1}{u_B}\right] \qquad (15)$$

and

$$\tan(90-\phi)=\frac{H}{2\tan\theta_h}\left[\frac{1}{u_A}-\frac{1}{u_B}\right] \tag{16}$$

where the various parameters are defined in Figures 7 and 8. A number of simplifying assumptions are made to obtain Equations 15 and 16. For a more general discussion, refer to the paper by Davis and Tusting.

Four-Laser Measurement System

Adding a pair of orthogonally mounted lasers as in Figure 9 allows measurements to be made when the camera's axis is tilted both horizontally and vertically. A discussion of this method and the corresponding equations for range and tilt angles are presented elsewhere (Davis and Tusting, 1991). A comprehensive derivation of the mathematics for this and other laser measurement systems will be published soon.

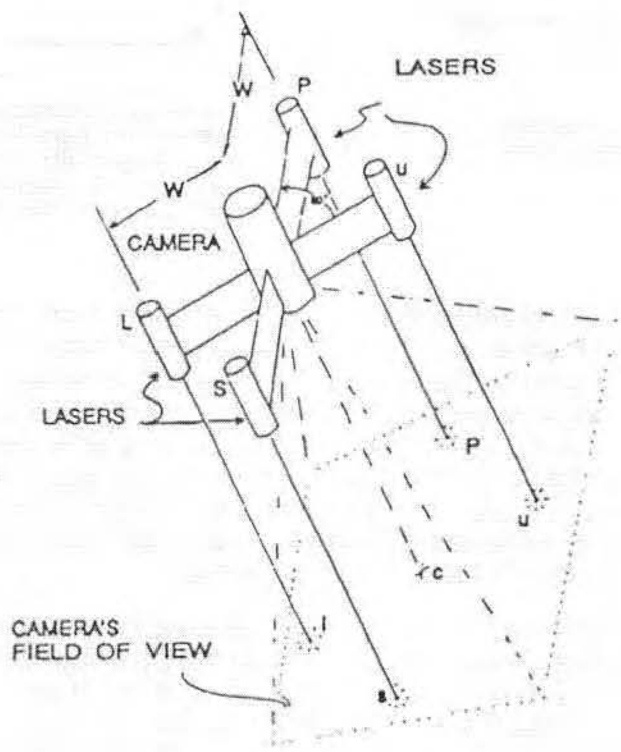


FIGURE 9

Four-laser size measurement system which allows the camera to be tilted in both the horizontal and vertical directions.

The system shown in Figure 9 allows the range to be calculated from two equations—one using the displacements of the upper and lower laser projections, and the second using the displacement of the port and starboard laser projections. A comparison between the two calculations provides an estimate of the measurement accuracy.

DISCUSSION

Lasers can be employed to assist in improving the accuracy of underwater benthic surveys. They can be used in a variety of geometries to measure and record range and distance. Two or more parallel lasers can be directly used to quantify the images obtained from downward looking cameras. Advantages include:

- The measurements are repeatable and calibrated by simple geometry.
- The fiducial marks are visually apparent to the observer at the time the observations are made.
- The calibration data is recorded directly on every image, facilitating later analysis.
- The method is conceptually simple and easy to interpret.

For perspective photography, laser calibrations allow a direct and simple measure of range and tilt so that calculations and perspective grids can be generated on individual frames even if the geometric parameters are changing from frame to frame. For photographic transects made with rapid-cycling, film-recording cameras, the calibration data can be used to correct for uncontrolled variations in height-above-bottom, allowing better mosaics to be constructed with less effort.

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