PHOTOGRAPHIC DEVICE FOR ACCURATELY MEASURING FISH

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PHOTOGRAPHIC DEVICE FOR ACCURATELY MEASURING FISH

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ABSTRACT

A photographic measuring device using two cameras and strobe illumination has been developed to improve the accuracy of salmon body measurements in the field. The optical theory is given and the device is described in detail. The technique includes calculating longitudinal distances from photographs. The device is considered accurate within $\pm$ 0.05 centimeters when ideal subjects are measured.

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INTRODUCTION

The photographic measuring device described in this paper was developed to aid the work of the International North Pacific Fisheries Commission. One of the objectives of the Commission is to devise a suitable method of identifying the various races of Pacific salmon so that North American stocks can be differentiated from the Asian stocks. Work to date has shown generally that the differences between the races of salmon are extremely slight. For this reason and others closely related, many aspects of the body characteristics of salmon are being investigated. Among these investigations are bone studies, blood studies, parasite studies, and morphological studies, since one or a combination of these may provide the data needed to characterize the various races (International North Pacific Fisheries Commission, 1955).

In the morphological studies, considerable work is being done on the determination of body proportions and measurements. The taking of accurate measurements, however, from a three-dimensional object such as a fish is difficult. In addition, methods now in use have an indeterminate error due to bias of operators. The problem at hand was to develop a method of taking these measurements by means of photography.

The advantages of photography over present methods of measurement are:

1. The pictures of the fish would form permanent records from which measurements could be checked and rechecked.

2. When fish were needed for measurements that were not contemplated in an original study, these measurements could be taken by the biologist from the many pictures of the fish that would have accumulated over the years instead of his having to wait till the season arrived and then obtaining measurements from only one year's sample.

3. In interpretation of visual characteristics, such as net marks and scale counts, pictures could be analyzed in the laboratory by experts in such analyses.

4. Photography and its associated tools would lend themselves readily to automation, thus tending to minimize human errors and bias of operators.

Because of the potential value of a photographic measuring machine and the need it would fill, the development of such a machine was undertaken. Many factors had to be considered in order to develop a machine that would be useful to U. S. Fish and Wildlife Service field personnel under the variety of conditions under which they must work. Some personnel work on board motor vessels on the high seas, where storms frequently cause an unstable footing for a measuring machine. Others work in canneries, where lighting conditions may make the use of photography difficult. Still others work on spawning grounds, where portability is important, since the base camp may be some distance from the spawning sites. Yet, despite these difficulties, there must be no sacrifice in the accuracy of the measurements.

The objective of this investigation, therefore, was to design a machine that would meet the following qualifications:

1. Give measurements accurate to within ± 0.05 cm.
2. Be fully portable.
3. Incorporate as many automatic features as is possible.
4. Be capable of rapid use in the field.
5. Be rugged.
6. Be not overly expensive.

THEORY

Since a fish is three-dimensional, all of the points on the fish do not lie in the same plane. Consequently, distances between points on the fish are difficult to measure acurately. Although many types of measurements of distance can be made, the present study is limited to longitudinal measurements (fig. 1), as they are the main type now being made by the U.S. Fish and Wildlife Service in the research work for the Commission.

Referring to figure 1, a longitudinal measurement between any two points (P_1 and P_2) on a fish (or any other three-dimensional object) is the distance between the points when they are projected perpendicularly upon the axis of the fish (or object). Since this axis is not accessible, the measurements are made instead between their perpendicular projections (Q_1 and Q_2) upon an orientation line (HJ), which is located parallel to the axis.

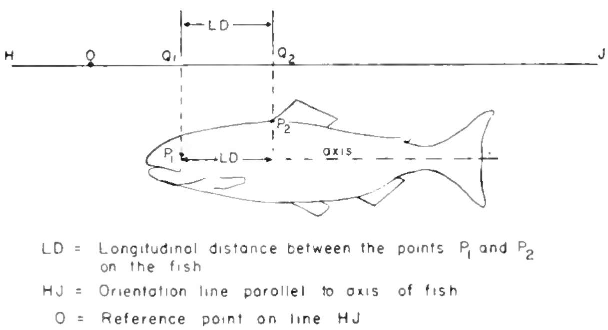


Figure 1.--Illustration of meaning of "longitudinal distance". The longitudinal distance between the points P_1 and P_2 on the fish is equal to $\overline{OQ_2}$ - $\overline{OQ_1}$ on the orientation line HJ.

Photography offers a ready means of projecting P_1 and P_2 upon the orientation line to obtain the points Q_1 and Q_2. The distance Q_1Q_2, however, cannot be measured directly. Instead, each point on the line is located in terms of its distance from some reference point, say 0, on the line HJ; that is, the location of the perpendicular projection of P_1 on the orientation line HJ is $\overline{OQ_1}$, and the location of the perpendicular projection of P_2 is $\overline{OQ_2}$. Then $OQ_1 = \overline{OQ_1} - Q_1Q_2 - LD$.

In locating the perpendicular projection of some point in space, say P_1, upon the orientation line by photography, we find there are two sources of error: (1) parallax and (2) perspective.

Parallax Error

An example of parallax is shown in figure 2. In this figure, point P, which can be any point on the fish, is shown in three different positions above the line HJ. In each case, Q_1, Q_2, or Q_3 represents the location of the perpendicular projection of P upon this line. In only the first case, where P is directly beneath the camera, will Q appear to coincide with P as viewed by the camera. In the other cases, points P_2 and P_3 will appear to be located at P'_2 and P'_3, as illustrated. The distances $\overline{P'_2Q_2}$ and $\overline{P'_3Q_3}$ are the parallax errors.

The problem of parallax can be solved by the use of two cameras. To show how this can be done, we have two considerations: (1) the special case of determining $\overline{OQ}$ (fig. 3) where P is located in the plane HABJ formed by two cameras and an orientation line, and (2) the general case of determining $\overline{OQ}$ (fig. 4) where P does not lie in the same plane with the orientation line but is still in the field of view of the two cameras.

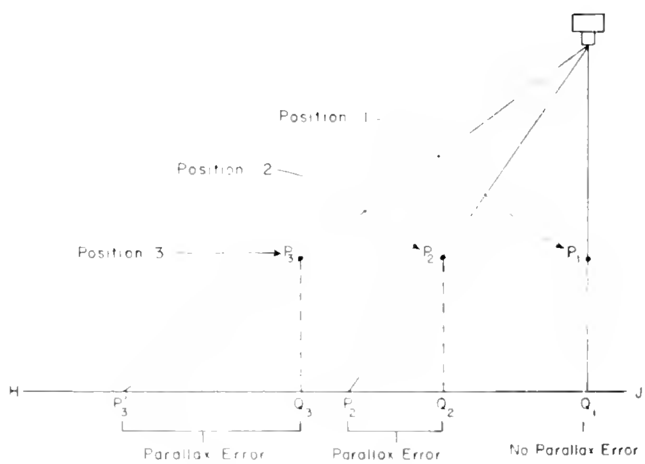


Figure 2.--Examples of what is meant by parallax error.

Special case

In the special case (fig. 3) the following definitions should be noted:

1. Point A is the optical center of the lens of a first camera.

2. Point B is the optical center of the lens of a second camera.

3. Line AB is parallel to the line HJ.

4. Point O is the reference point from which all measurements of distance on the line HJ will be taken.

5. Point P is a point on the fish.

6. Point P lies in the plane HABJ, subject only to the simplifying restriction that $\overline{OF}$ is positive (that F lies to the right of O).

In a picture taken by camera B, point P will appear to be at point F on line HJ. Similarly, in the picture taken by camera A, point P will appear to be at point G on line HJ. Also, we have made D the perpendicular projection of A on the line HJ. The problem now is to derive an equation in which we can use the distances $\overline{OF}$ and $\overline{OG}$ to obtain the unknown distance $\overline{OQ}$. From the fact that figure 3 contains a number of similar triangles, our required equation is easily derived geometrically as follows:

Since triangles ABP and PFG (fig. 3) are similar,

then $$PQ = \frac{(FG)(PT)}{AB}. \qquad (1)$$

but, $$PT = AD - PQ, \qquad (2)$$

so, $$PQ = \frac{(FG)(AD-PQ)}{AB} \qquad (3)$$

simplifying $$PQ = \frac{(FG)(AD)}{FG+AB} \qquad (4)$$

Consider now the similar triangles ADG and PQG.

Then $$\frac{QG}{PQ} = \frac{OG - OD}{AD} \qquad (5)$$

or, $$QG = PQ\left(\frac{OG - OD}{AD}\right) \qquad (6)$$

now, $$QG = OG - OQ, \qquad (7)$$

and substituting (4) and (7) into (6) we have

$$OG - OQ = \left(\frac{(FG)(AD)}{FG + AB}\right)\left(\frac{OG - OD}{AD}\right) \qquad (8)$$

Then $$OQ = OG - \left(\frac{(FG)(AD)}{FG+AB}\right)\left(\frac{OG-OD}{AD}\right) \qquad (9)$$

This reduces to $$\overline{OQ} = \frac{OG\,(AB + OD) - (OD)\,(OF)}{AB + (OG - OF)} \qquad (10)$$

which locates the perpendicular projection of P on the orientation line HJ.

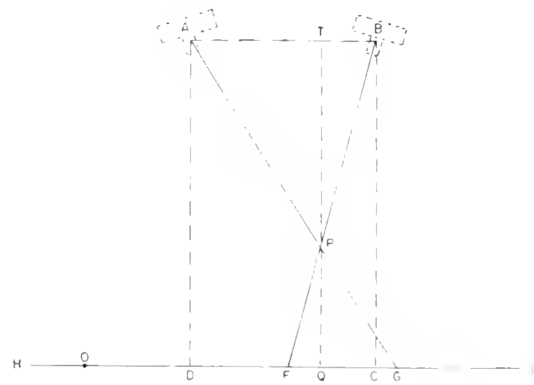


Figure 3.--How a point P in the plane HABJ appears to cameras located at points A and B.

The distances $\overline{AB}$ and $\overline{OD}$ are constants determined by the positions of the cameras in relation to point O on line HJ and to each other. The distances $\overline{OF}$ and $\overline{OG}$ are variables determined by the position of P in the plane HABJ. The value $\overline{OF}$ can be determined from a photograph taken by camera B, and that of $\overline{OG}$ from one taken by camera A.

General case

In the general case (fig. 4), where we wish to determine $\overline{OQ}$ when P lies anywhere in three-dimensional space in view of the two cameras, the following definitions should be noted:

1. In this three-dimensional drawing, line HJ lies on the line formed by the intersection of the perpendicular planes 1 and 2.

2. Line OO' lies in plane 2 and is perpendicular to line HJ.

3. Line AB lies on the line formed by the intersection of planes 1 and 1'.

4. Plane 1 in figure 4 is the same as the plane HABJ in figure 3, except that lines AD and BC have been omitted to simplify the drawing.

5. Plane 1' is in the position plane 1 would occupy if, using the line AB as an axis, plane 1 were rotated through some angle, say alpha α (subject to the obvious restriction that point P' will lie in the field of view of the two cameras).

6. Point P' is the position that point P would occupy if plane 1 were rotated through the angle alpha, and point Q, therefore, is the location of the perpendicular projection of the points P and P' upon line HJ.

7. Point F' is the position that point F would occupy if the line FP were extended as plane 1 rotates through the angle alpha; points G' and H' bear similar relationships to points G and H. From a consideration of figures 3 and 4, we see that the derivation of equation 10, already given, applies to the special case where the angle alpha is equal to zero.

Since P is any point in plane 1, the problem of locating P anywhere in space (anywhere on the fish) now becomes the simple one of showing that equation 10 applies for all values of alpha.

This proof depends upon the fact that changing the value of alpha does not change any of the angular relationships in plane 1; for example, although triangle P'F'G' is larger than triangle PFG for all values of alpha different from 0°, the corresponding angles in these two triangles are identical in size. Similarly, all the other angles in the triangles employed in determining equation 10 also remain constant in size as the angle alpha varies. Therefore, since the derivation of equation 10 depends upon the similarity of the triangles and not upon the size of them, this equation holds for any value of alpha; in short, for any location of P in three-dimensional space. From equation 10, we therefore easily obtain $\overline{O'Q'}$. From figure 4, it is apparent that $\overline{O'Q'}$, is equal to $\overline{OQ}$, the location of the perpendicular projection of P' on line HJ.

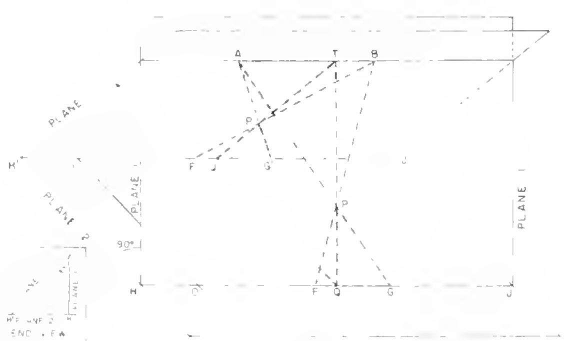


Figure 4.--Locating point Q, the perpendicular projection of P', a point that is anywhere above plane 2 and that lies in the field of view of the cameras at points A and B.

Figure 5.--An example of the error caused by perspective: In this picture, the size of the salmon is greater than that of the fishing vessel because the salmon was closer to the camera when the picture was taken.

The perpendicular projection of any other point in space can be located similarly on the orientation line HJ to give some other value say $\overline{OQ}_2$. The algebraic subtraction of $\overline{OQ}_1$ from $\overline{OQ}_2$ then will give the longitudinal distance between the two points Q_1 and Q_2.

Perspective error

The term "perspective", as used here, is defined as "natural objects as they appear to the eye represented on a plane, such as a picture". Figure 5 illustrates the error caused by perspective; that is, the jumping salmon appears larger than does the fishing vessel since the salmon was much closer to the camera than was the vessel when the picture was taken. Similarly, if two objects of the same size, such as objects A and B (fig. 6), are placed on a flat board or base plane in such a manner that one is at a greater distance from the camera than is the other, they will not appear to be the same size in a picture taken of them.

In the preceding section, we developed equation 10 for eliminating parallax error. This equation was based upon the stipulation that the various projections involved would be free from all other errors. We now see that owing to perspective, this stipulation is not met and that a suitable correction will have to be made for the perspective error as well.

To the camera, all objects appear to be lying in one plane regardless of the actual position of them in space. Hence, for simplicity in the following discussion, we will assume that all of the objects are lying on one plane--the base plane--since that is the one on which they will appear to lie in the photograph.

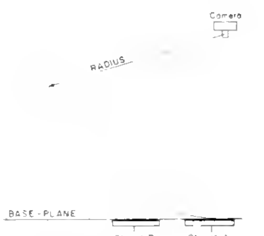
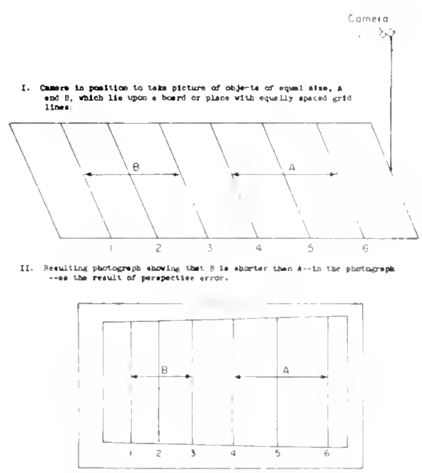


Figure 6 - Illustration showing that objects A and B will not be the same size in a picture taken by the camera, since they are not the same distance from it

The problem of eliminating perspective error is solved by drawing a number of equally spaced, parallel lines (called grid lines) on the base plane. Figure 7 (I) shows such a plane with grid lines 1.5 centimeters apart. Two objects, A and B, of equal length have been placed on this plane, and a camera has been positioned to take a picture of them.

The diagram of the resulting photograph shown in figure 7 (II) illustrates that the grid lines appear to become progressively closer together. Similarly, object A appears to be larger than object B, since object A was closer to the camera than object B was. From our knowledge however, that the distance between the grid lines is actually 1.5 centimeters, we can determine that both objects A and B are 3.0 centimeters long despite the perspective error.

If one end of the object falls between two of the grid lines, as illustrated in figure 8, we must determine the proportionality factor for the distance between the particular lines involved and apply this factor to the measurement of the object in the picture. If, for example, the actual distance between lines 4 and 5 in figure 8 was 1.5 centimeters and the measurement between them, in the picture, was 0.5 centimeters, then the proportionality factor would be $\frac{1.5}{0.5} = 3.0$. Now, if the measurement of A, in the picture was 0.27 centimeters, its actual length would be 0.27 X 3.0 = 0.81 centimeters.



I. Camera in position to take picture of objects of equal size, A and B, which lie upon a board or plane with equally spaced grid lines.

II. Resulting photograph showing that B is shorter than A--in the photograph --as the result of perspective error.

Figure 7.--Illustration showing (1) how perspective error causes two objects of the same actual size to appear to be of different size in a photograph and (2) how the use of grid lines and a knowledge of the distance between them obviates this error.

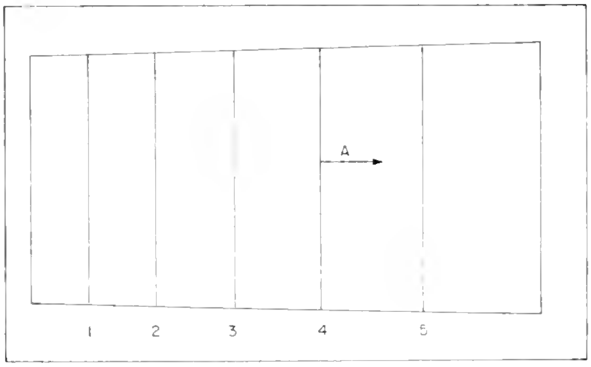


Figure 8.--Picture of an object with one end lying between grid lines.

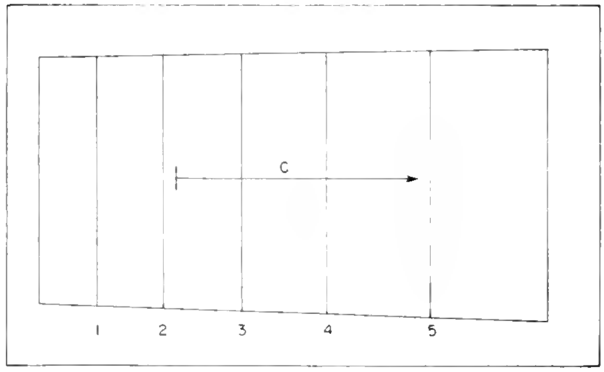


Figure 9.--Picture of an object with both ends lying between grid lines.

To obtain the length of any other object, say C in figure 9, we determine the length of C lying between grid lines 4 and 5 and between grid lines 2 and 3 by the technique used in determining the length of A in figure 8. The length of C lying between grid lines 3 and 4 is determined by inspection. The total length of C then is equal to the sum of the lengths lying between grid lines 2 and 3, 3 and 4, and 4 and 5. The length, therefore, of any object lying (perpendicular to the grid lines) anywhere on the base plane (or appearing to lie on the base plane so viewed in a photograph) can be determined free from the error caused by perspective.

Thus, if the foregoing techniques are used to eliminate errors due to parallax and to perspective, theory indicates that longitudinal measurements of fish can be made accurately by means of photography.

DESCRIPTION OF DEVICE [1/]

Since the design of the photographic measuring device may be altered as further tests dictate, only a general description is given here.

Photographic Measuring Device

The photographic measuring device consists of five major units: (1) the base and the framework, (2) the strobe light and power pack, (3) the camera assembly, (4) the automatic features, and (5) the wiring. All similar parts are numbered so that the machine can be assembled the same way each time.

Base and framework

The "base and framework" (figs. 10 and 11) consists of four sub-assemblies: (1) the base, (2) the legs, (3) the cap, and (4) the cross members #1 and #2.

Base.--The 20" X 48" base was made of a material called "sandwich board", consisting of two, thin sheets of aluminum between which is a core of honeycombed metal. This type of material was chosen because it combines great flexural strength (i.e., resistance to bending) with light weight.

The base was spray-painted with a yellow, metal-etching zinc chromate primer. Parallel grid lines 1.5 centimeters apart and an orientation line perpendicular to the grid lines were then scribed on the base, deep enough to score the metal. The grid lines were then filled with black India ink, and each was numbered according to the total distance in centimeters between it and the zero line.

Legs.--The legs are hollow aluminum tubes with an outside diameter of .628 inches,

1/ The commercial components described in this paper were chosen only on the basis of local availability. There may be many other types that will serve as well.

and a length of 4 feet 5 inches. Each leg has an attached aluminum block that supports the cross members. One end of each of the legs is flattened to fit between two, right-angled bars of aluminum on each corner of the base (figs. 10 and 11).

Figure 10.--Assembled device ready for operation.

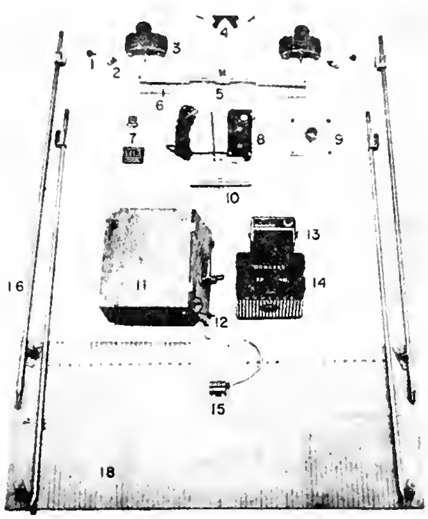


Figure 11.--Exploded view of photographic measuring device. (1) Rubber stops that keep cross member #1 firmly seated in the slots (as shown in Figures 12 and 13); (2) solenoids; (3) cameras; (4) cap and pins that hold legs firmly seated in the receptacles of the cap; (5) cross member #1; (6) adjustment washers that affords adjustment of the endwise rotation of the cameras, (7) buzzer and buzzer battery; (8) strobe light, (9) reflector; (10) cross member #2 with adjustment bolt that affords adjustment of the sideways rotation of the cameras, (11) battery box, (12) switch; (13) flash supply; (14) 6-volt batteries; (15) digital-register; (16) legs; (17) bolts used to attach legs to base, (18) base.

Cap.--The cap is composed of four short lengths of aluminum tubing having an inside diameter equal to the outside diameter of the legs. These short lengths are welded together at appropriate angles and serve as sockets for the four legs. Short pins are used to keep the legs seated firmly in these sockets.

Cross members #1 and #2.--Cross members #1 and #2 are round aluminum tubes of the same diameter as the legs. Figures 12 and 13 shows how cross member #1 is attached to the legs. Cross member #1 is 23 inches long and #2 is 8 inches long. Both members together act as stiffeners for the legs and provide a means of attaching the strobe light between the two cameras.

The cameras are supported by cross member #1, and the cameras can be aimed at any point on the grid by rotating them sideways and endwise, as shown in figures 14 and 15. Square bars on either end of this cross member provide flat surfaces against which the cameras are held by single bolts. Thus, each camera can be rotated endwise with the bolt acting as the axis of rotation. An "adjustment washer" affords a means of fixing the cameras at any position in the endwise rotation. The flat bar attached at right angles to cross member #1 and extending across to cross member #2 can be raised or lowered by an adjustment screw at cross member #2, thus rotating the cameras sideways (fig. 15).

Figure 12.--Picture showing cross member #1 being attached to framework.

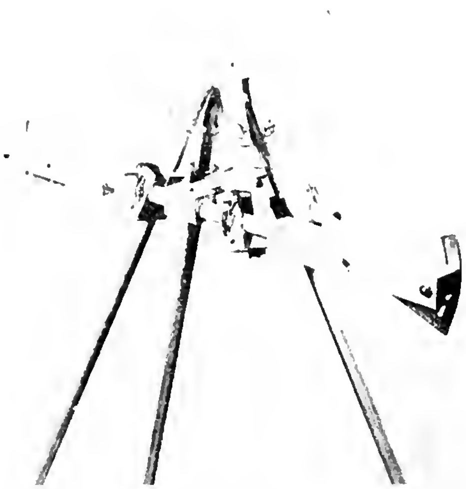


Figure 13.--Picture showing cross member [illegible] after it is attached to framework. Note round, hard rubber stops that keep the cross member firmly seated in the slots, and the short pins that do not allow the cross member to slide back and forth, but do allow the cross member to rotate.

Figure 14.--A double-exposure illustrating the sideways rotation of cameras.

Strobe Light and Power Pack

The strobe light or speed flash used is the "Sunlite II" model manufactured by the Hershey Manufacturing Co., Chicago, Illinois.

The reflector made for this model caused a "hot spot" or area of too much light in the pictures, since it was designed to be used at a greater distance from the subject. Consequently, a flat reflector of our own design was substituted, and this reflector proved to be more satisfactory.

The strobe or speed flash power pack is a part of the "Sunlite II" model. Two 6-volt batteries provide the electrical power to operate the digital-register and the solenoids that trigger the shutters of the two cameras.

Camera Assembly

The camera assembly consists of two "Exakta" cameras equipped with split-image, eye-level viewfinders and f 2.5, 35 millimeter

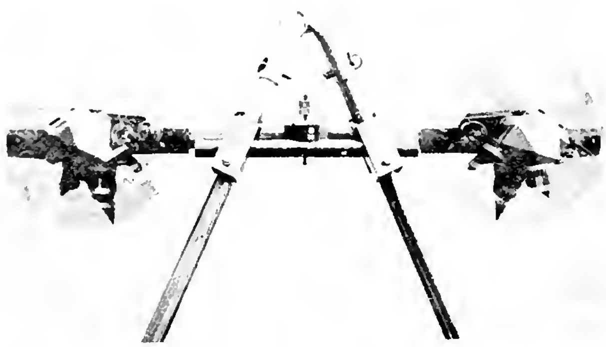


Figure 15.--A double-exposure showing the endwise rotation of the cameras.

Angeneiux lenses and the film.

The "Exakta" is a single lens reflex type camera. The reflex principal allows the operator to see, in a mirror behind the lens, an image of the scene to be photographed. The lever wind feature of the "Exakta" is another valuable time saver. The film used for these tests was Panatomic-X.

Automatic Features

There are four automatic features: (1) The solenoids, (2) the buzzer, (3) the digital-register, and (4) the modified switch.

Solenoids.--The solenoids are necessary to trip the camera shutters simultaneously.

The type used was manufactured by the Heiland Corporation, Denver, Colorado.

Buzzer.--A buzzer was incorporated in the device to warn the operator when one or both cameras were not wound. A common buzzer, operated from a 4-1/2-volt batter was used. The battery and the buzzer were strapped to the strobe light assembly.

Digital-register.--An electrically operated digital-register was placed on the base to number each picture and each fish consecutively so that the left and right pictures could be matched when the films were read. The digital-register used was a Mercury model manufactured by the Production Instrument Co., Chicago, Illinois.

Modified switch.--A modified lever switch was used to trip the solenoids and the digital-register in that order. That is, two contacts were made, one preceeding the other, each time the switch was thrown. In this way, the number on the register was recorded in the picture just before the number changed.

Wiring

The wiring system consists of four circuits: (1) The strobe light circuit, (2) the solenoid circuit, (3) the buzzer circuit, and (4) the digital-register circuit. Figure 16 is a block diagram of these circuits.

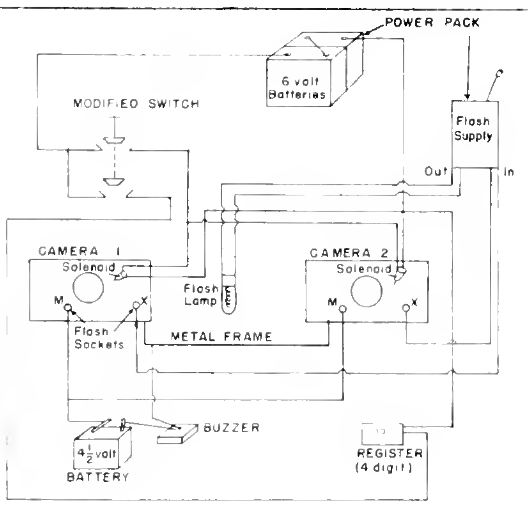


Figure 16 .--Block diagram of wiring system.

The strobe light circuit is connected to the X side of the two cameras. Note that one part of this circuit is the "metal frame"--the device itself. When the shutters of both of the cameras are not cocked, the circuit is closed or continuous because the X contacts in the shutters are grounded through the bodies of the cameras to the metal frame. When the shutters are cocked, however, the circuit is open, or not continuous, because the X contacts are no longer grounded to the "metal frame". If the shutters of both cameras have been cocked, the strobe light can flash only after both shutters have been released or tripped by the solenoids which react almost simultaneously. The shutters were set to remain open 1/25 of a second after the circuit was closed to assure that both shutters were still open when the strobe light flashed.

Now if one camera were to remain uncocked, the strobe light and the camera with the cocked shutter would still operate. In other words, the operator could forget to wind one camera and the mistake would go unnoticed. Because of this the warning buzzer was installed so that when one or both of the cameras were unwound, the buzzer would sound. One side of the buzzer circuit is connected to the M synch of the two cameras, and the other side is grounded to the "metal frame". The circuit is completed whenever either shutter is not cocked.

The solenoid circuit is closed when the first contact is made in the modified switch. The digital-register circuit is closed when the second contact is made. The time delay between making of the two contacts allows the picture [e] taken before the register is advanced. The [swi]tch used is #3004, manufactured by Switch-[cra]ft Incorporated, Chicago, Illinois.

TECHNIQUE OF USE

Determining longitudinal distances be-[twe]en two points consists of three major steps: Taking the pictures, (2) reading the film, and calculating the longitudinal distances.

Taking the Pictures

Taking the pictures consists of three [ste]ps: (1) Assembling the device, (2) loading ... adjusting the cameras and connecting the wire, and (3) aligning the subject parallel with the orientation line and taking the picture.

Reading Film

A microscope with a calibrated stage was used in the normal fashion to determine the film measurements. Two glass plates served to hold the film flat.

The measurements were repeated five times and any measurements obviously in disagreement with the average were not used.

Calculating Longitudinal Distances

The calculation of longitudinal distances consists of three steps: (1) From the left and right pictures, determine $\overline{OQ'}$, the distance from the O line to the perpendicular projection of the first point, say P'. (2) From the left and right pictures, determine $\overline{OQ''}$, the distance from the O line to the perpendicular projection of the second point of measurement, say P''. (3) Subtract the lesser distance from the greater distance to determine $\overline{Q'Q''}$.

Calculation of $\overline{OQ'}$

$\overline{OQ'}$ is calculated from equation 10 (see "Theory"). The use of this equation requires the determination of the distances $\overline{AB}$, $\overline{OD}$, $\overline{OF}$, and $\overline{OG}$ and the insertion of these values in equation 10.

Determination of $\overline{AB}$.--The distance $\overline{AB}$ is a constant. It is the distance between the optical centers of the two cameras (as in fig. 3). The distance between the points on the outside of the lenses, which roughly correspond to the optical centers of the lenses, was measured with a steel tape. This distance was used for the value $\overline{AB}$.

Determination of $\overline{OD}$.--The distance $\overline{OD}$ is a constant. It is the distance from the O or reference line to the perpendicular projection of the optical center of camera A, point D, (as in fig. 3) upon the base plane. The base plane or grid of the photographic measuring device was leveled. A point, judged to be opposite the optical center of the lens, was chosen on the outside of the lens barrel, and a plumb bob was suspended from this point. The distance $\overline{OD}$ was then measured with a steel tape.

Determination of $\overline{OF}$.--The determination of $\overline{OF}$ consists of four steps. (1) From the left film, determine the proportionality factor for the distance between the two grid lines that lie on either side of the first point of measurement (F). (2) Measure the distance from the first point to the nearest line lying to the left of this point (assuming that O line lies to the left also). (3) Multiply this distance times the proportionality factor. (4) Add the distance from the O to the left line to the results of (3) to obtain the total distance from O to F /the position of point P' (the first point) as it appears in the right picture/. Since the distance from the O line to any other line is equal to the number of that line, then this distance can be read directly.

Determination of $\overline{OG}$.--The procedure for the determination of $\overline{OG}$ is the same as that for the determination of $\overline{OF}$ except the left film is used instead of the right film.

Substitution of $\overline{AB}$, $\overline{OD}$, $\overline{OF}$, and $\overline{OG}$ into equation.--To obtain $\overline{OQ'}$, now substitute the constants $\overline{AB}$ and $\overline{OD}$, and the variables $\overline{OF}$ and $\overline{OG}$ into equation 10,

$$\left/ \overline{OQ'} = \frac{\overline{OG}\,(\overline{AB} + \overline{OD}) - (\overline{OD})\,(\overline{OF})}{\overline{AB} + (\overline{OG} - \overline{OF})} \right/$$

Calculation of $\overline{OQ''}$

Since $\overline{AB}$ and $\overline{OD}$ are constants, we need only determine the distances $\overline{OF}$ and $\overline{OG}$ from the right and left film respectively (as explained under "calculation of $\overline{OQ'}$") and then substitute these values into equation 10.

Calculation of $\overline{Q'Q''}$

We have now determined the two distances $\overline{OQ'}$ and $\overline{OQ''}$. If $\overline{OQ''}$ is larger than $\overline{OQ'}$, then $\overline{OQ''} - \overline{OQ'} = \overline{Q'Q''}$, the longitudinal distance between Q' and Q''. And, since Q' and Q'' are the perpendicular projections of the points P' and P'', the distance $\overline{Q'Q''}$ is also the longitudinal distance $\overline{P'P''}$.

PERFORMANCE

The performance of the machine can be considered from the following four categories:

portability, automatic features, efficiency, and accuracy.

Portability

The base of the photographic measuring device used in the tests was not designed to be disassembled. Consequently, the device cannot be considered fully portable. Since making the base in more than one part may introduce further errors, it was decided to test the device in its present form first to have a basis of comparison for any modifications made later.

Automatic Features

Since the device has not been operated without the automatic features, there is no way of determining the degree of added efficiency for which they are responsible. In general, these features were added to accomplish two things: (1) To save time when fish are being measured in the field and (2) to eliminate possible sources of mistakes on the part of the operator. From our experience in using the machine, we feel that all of these features are valuable aids in these two respects.

Efficiency

Taking Measurements

The efficiency of the device under field conditions remains to be tested. However, it can be operated in the field or under laboratory conditions at a greater speed than the methods now in use. Under certain conditions in the field, a greater speed of operation will mean a larger sample of fish measured. In canneries especially, where small boatloads of fish are processed immediately after they are received, time becomes invaluable.

Reading Film and Calculating Longitudinal Distances

Reading the film with the microscope and calculating the longitudinal distances with these readings is tiring and time consuming. The fact that this must be done at all is a disadvantage unique to this photographic method. In methods now used by the Fish and Wildlife Service, the measurements are read directly from the measuring device or from a paper tape upon which the measurements have been stamped or recorded by the device. In the photographic method, four film measurements that have been corrected for perspective are needed to calculate each longitudinal distance.

Accuracy

Design of Tests

The primary objective of these tests was to determine the accuracy of the device in its present form. At the inception of this work, we decided that a tolerance of $\pm$ 0.05 centimeters would be our goal.

A solid aluminum bar was used as the subject instead of a fish. Since a subject of invariable length was necessary so that a comparison of the computed length to the actual length could be made.

Since the length of the subject and the position of the subject on the base may have some effect on the accuracy of the results, tests were made using subjects of different lengths placed at different points on the grid. A bar 25.20 centimeters long was placed in nine positions on the grid for each of three tests - A_1, A_2, and A_3. Figure 17 shows the general location of each of these positions. Similarly, a bar 76.11 centimeters long was placed in six positions on the grid in test B; two positions above the orientation line, two positions on the orientation line, and two positions below the orientation line.

Since the constants used in formula 10 depend upon the positions of the cameras, it follows that the positions of the cameras should always be the same after the device is assembled. This was tested by disassembling and assembling the device prior to each of the three tests - A_1, A_2, and A_3.

Tests A_1, A_2, and A_3, therefore, consisted of 9 negatives from the left camera and 9 negatives from the right camera; one left and one right negative for each position. Test B consisted of 6 left and 6 right negatives.

Test Results

The negatives for test B were read only once because of the short time available. Similarly, the negatives for positions 1, 2, 3, 7, 8 and 9 of test A_1 were read only once. The results are listed in table 1.

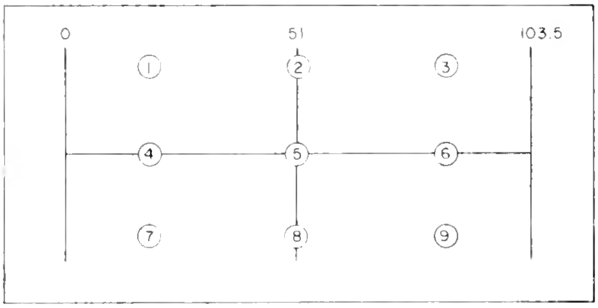


Figure 17.--Illustration showing general location of positions #1 through #9 on base for tests A_1, A_2, and A_3. Most of the vertical grid lines have been omitted to simplify the sketch.

The negatives of positions 4, 5 and 6 (the positions of the bar on the orientation line of tests A_1, A_2, and A_3) were read 5 times by a first reader. The same negatives of test A_1 and A_2 were read three times and those of test A_3 read twice by a second reader. The results are listed in table 2.

Table 1 shows that in test A_1 the range of the errors for all positions was from -0.01 to +0.04 centimeters. In test B the range of the errors for all positions was from -0.03 to +0.04 centimeters. These results indicate that the error for a subject of any length lying anywhere on the grid will not be radically different from a subject of any other length lying anywhere along the orientation line.

The range of all the errors shown in table 2 is from -0.05 to +0.05 centimeters indicating that the positions of the two cameras do not change enough from one assembly to the next to cause an error that greatly exceeds the tolerance limits of +0.05 centimeters. The range of errors for Reader No. 1 is -0.05 to +0.05 centimeters while the range of errors for Reader No. 2 is -0.02 to +0.05 centimeters. In general, the errors obtained by Reader No. 2 were well on the positive side, since only 2 of the 24 readings

TEST	POSITION NUMBER	POSITION ABOVE ORIENTATION LINE			POSITION ON ORIENTATION LINE			POSITION BELOW ORIENTATION LINE		
		1	2	3	4	5	6	7	8	9
A_1	Calculated Length	25.24	25.20	25.21	25.21	25.22	25.23	25.19	25.21	25.22
	Actual Length	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20
	Error	+0.04	0.00	+0.01	+0.01	+0.02	+0.03	-0.01	+0.01	+0.02

TEST	POSITION NUMBER	1	2	3	4	5	6
B	Calculated Length	76.13	76.08	76.15	76.09	76.09	76.11
	Actual Length	76.11	76.11	76.11	76.11	76.11	76.11
	Error	+0.02	-0.03	+0.04	-0.02	-0.02	0.00

Table 1.--Results of test A_1 and test B. All values are in centimeters.

TEST	POSITION	READER NUMBER 1 READINGS					READER NUMBER 2 READINGS		
		1	2	3	4	5	1	2	3
A_1	4	25.18 (-0.02)	25.19 (-0.01)	25.18 (-0.02)	25.19 (-0.01)	25.18 (-0.02)	25.21 (+0.01)	25.25 (+0.05)	25.23 (+0.03)
	5	25.21 (+0.01)	25.19 (-0.01)	25.18 (-0.02)	25.18 (-0.02)	25.15 (-0.05)	25.22 (+0.02)	25.23 (+0.03)	25.23 (+0.03)
	6	25.22 (+0.02)	25.24 (+0.04)	25.23 (+0.03)	25.22 (+0.02)	25.21 (+0.01)	25.23 (+0.03)	25.25 (+0.05)	25.25 (+0.05)
A_2	4	25.19 (-0.01)	25.21 (+0.01)	25.20 (+0.00)	25.20 (+0.00)	25.19 (-0.01)	25.19 (-0.01)	25.24 (+0.04)	25.24 (+0.04)
	5	25.21 (+0.01)	25.21 (+0.01)	25.21 (+0.01)	25.21 (+0.01)	25.21 (+0.01)	25.20 (0.00)	25.24 (+0.04)	25.23 (+0.03)
	6	25.24 (+0.04)	25.24 (+0.04)	25.24 (+0.04)	25.23 (+0.03)	25.25 (+0.05)	25.18 (-0.02)	25.25 (+0.05)	25.24 (+0.04)
A_3	4	25.17 (-0.03)	25.20 (0.00)	25.18 (-0.02)	25.19 (-0.01)	25.19 (-0.01)	25.23 (+0.03)	25.22 (+0.02)	
	5	25.22 (+0.02)	25.18 (-0.02)	25.20 (0.00)	25.18 (-0.02)	25.19 (-0.01)	25.24 (+0.04)	25.24 (+0.04)	
	6	25.25 (+0.05)	25.25 (+0.05)	25.25 (+0.05)	25.23 (+0.03)	25.23 (+0.03)	25.25 (+0.05)	25.25 (+0.05)	

Table 2.--Results for positions #4, 5, and 6 of tests A_1, A_2, and A_3. Each cell contains the computed length of a bar that is actually 25.20 centimeters long. The error or difference between the computed length and the actual length is enclosed in parenthesis. All values are in centimeters.

obtained by this reader were negative. On the other hand, Reader No. 1 had 18 negative readings out of 45. Though neither reader had any errors that exceeded +0.05 centimeters (when rounded to two places) the results indicate that there is a significant difference between readers. Analyzing table 2 by position, it is seen that while the errors for position 4 and 5 are comparable, those of position 4 tend more toward the negative direction than 5. The errors for position 6, on the other hand, tend more toward the positive direction than position 5. This general pattern is shown more clearly in the readings taken by Reader No. 1.

In summary, the results indicate that (1) the magnitude of the error for a subject of any length lying anywhere on the base is in the neighborhood of +0.05 centimeters, (2) though within these limits, there is a slight difference between the results obtained by two readers, and (3) these results were obtained even though the device was disassembled and assembled prior to each test.

Sources of Error

There are many sources of error in the present device and techniques. Some of these sources of error are: (1) the grid lines, (2) the glare, (3) the calibrated knob, and (4) the steel tape used.

Grid lines.--The grid lines were scribed by hand on the base and under the microscope appear quite wavy. In addition, the lines are too heavy.

Glare.--The reflector used does not distribute the light evenly enough and "hot spots" in some areas of the grid cause glare. Whenever the point of measurement falls in one of these "hot spots", the definition of the point is not clear in the negative and misinterpretation of the exact point of measurement can result.

Calibrated knob.--The calibrated knob on the stage of the microscope is undersized. That is, there is room only for every other whole number to be marked. Accurate interpolation to tenths of a number, consequently, is not possible.

Steel tape.--Since the grid lines on the base were wavy and inaccurate, a millimeter steel tape was used to determine the exact measurement between the grid lines. Recently, we had this steel tape calibrated. Though we have not had the opportunity to double-check this calibration, the results indicate that the tape is not accurate.

FUTURE WORK

Many improvements can be made on the photographic measuring machine. The following are a few of the more obvious ones: Portability, automatic features, and accuracy.

Portability

Base

To make the photographic device portable, the base must be made in three parts so that it can be disassembled for easier transporting.

General Design Improvements

Strobe light.--The strobe light now in use was chosen because it was available immediately. Consequently, a search of other commercial models might turn up one that is much smaller in size and weight.

A reflector designed to distribute the light more evenly may improve the resulting pictures.

Power pack.--No attempt has been made to determine the size of the batteries needed, and much smaller batteries undoubtedly could be used.

Cameras.--Two additional features that would increase the efficiency of the cameras would be (1) automatic sequence (self-winding), and (2) large film capacity.

Another possibility is the use of a camera incorporating a sterio-optical lens system. This would reduce the total cost of the device, since one camera could be used instead of two.

Film.--A systematic check of the various types of commercially available films should be made to determine one that is fast, and thus not so sensitive to a wide range of natural light, and yet fine grained to afford great detail. Films should be tested in the photographic measuring machine under various conditions of natural light to determine the best one to use considering the strobe light, fish being photographed, and other related factors.

Automatice Features

The replacement of manual operation with automatic operation is one way in which errors can be reduced and efficiency increased. Since the reading of the film and the calculation of the final measurements are the aspects of this photographic method that need the greatest improvement, serious thought should be given toward improving the present techniques.

One way to increase the efficiency of this operation is to read the film with an automatic film reader. The measurements are automatically punched on IBM cards and the caluclations then can be accomplished automatically by IBM machines. The automatic film reader is a device that projects a large picture of the negative upon a ground glass plate in front of the operator. Manually operated dials on a board in front of the operator move the cross hairs used in taking the measurements, operate a device that punches the information on IBM cards, focuses the film, and does many other operations. Automatic film readers are commercially available.

There may be other means of reading the film, however, and work toward designing such a device is desirable. In any event, IBM cards and machines still can be incorporated to help save time when there are enough measurements involved to make the use of them practical. Until such time, tables can be made to help reduce lengthy calculations.

Accuracy

The photographic measuring device is considered accurate within approximately ± 0.05 centimeters when ideal subjects are being measured.

Experience with the device indicates that the accuracy can be increased by improving the photographic measuring device and by devising a better method of reading the film.

Better definition of the points of measurement can be obtained by (1) changing the color of the background to one that contrasts more with the subject being photographed, (2) eliminating areas of glare by designing a more suitable reflector, thus, increasing the detail in those areas, and (3) having lighter grid lines machined accurately upon the base.

The fact that ideal subjects can be measured accurately does not necessarily mean that fish can be measured just as accurately. Two factors inherent in a fish make this problem difficult. (1) The dimensions of a fish will change by the way the fish is laid down and (2) the body of a fish shrinks as the period of time after death increases. Whether these two factors should be investigated extensively depends on the required accuracy of the fish's dimensions.

It should be noted that the required accuracy of the dimensions of a fish does not necessarily eliminate the need for a greater accuracy in the device, since the error in the fish's body and the error in the device are separate and can therefore be additive. The total possible error can be decreased by decreasing the error in the fish or by decreasing the error in the device.

Other Uses

This paper has described how the longitudinal distance between two points on a three-dimensional object is determined by using two cameras. Other types of measurements might also be useful in separating the various races of salmon. For example, from formula 4 (see "Theory"), it is apparent that we can determine the thickness of the fish at point P (fig. 3) on the fish. Point to point and depth measurements could be determined if suitable formulae for these were developed.

Our experience has indicated that it also may be possible to count the scales on a fish on a photograph.

GENERAL EVALUATION

The many inherent advantages in photography lend great potential to any photographic method that can be used to determine accurately the dimensions of a fish. From our research to date, it is concluded that in this photographic method (1) the theory as set forth in this paper is sound, (2) the device can be made fully portable by designing the base so that it can be disassembled, and by reducing the weight of certain parts of the device, (3) the efficiency of this photographic method can be improved by the design of a better method of reading the film and by incorporating IBM cards and machines or tables to simplify the computations, (4) the device in its present form can be called accurate for some purposes, but that the present accuracy can be increased if necessary, and (5) when the above improvements are made, this photographic method will be a valuable aid in the racial analysis work being carried out by the Fish and Wildlife Service for the International North Pacific Fisheries Commission.

SUMMARY

1. The photographic measuring device described in this paper was developed to aid the work of the International North Pacific Fisheries Commission in differentiating North Pacific salmon stocks from Asiatic salmon stocks by racial characteristics. The taking of accurate measurements of the salmon is a necessary part of this work.

2. The advantages inherent in photography are:

(1) The pictures of the fish would form permanent records from which measurements could be checked and rechecked.

(2) When fish were needed for measurements that were not previously contemplated, these measurements could be taken by the biologist from the many pictures of fish that will have accumulated over the years instead of his having to wait until the next fishing season arrives and then obtain measurements from only one year's sample.

(3) In the case of interpretation of visual characteristics, such as net marks, pictures can be analyzed in the laboratory by one or more persons skilled at such jobs.

(4) Photography and its associated tools promise to lend themselves very readily to automation, thus tending to minimize human error, which in turn minimizes bias of operators.

3. When two cameras are used in determining the longitudinal distance between two points on a three-dimensional object such as a fish, there are two errors involved: (1) parallax and (2) perspective. Theoretically, both of these errors can be corrected.

4. The method of obtaining the longitudinal distance between two points on a three-dimensional object as described in this paper involves the use of the photographic measuring device and the use of a microscope with a calibrated stage.

The photographic measuring device consists of (1) the base and framework, (2) the strobe light, (3) the power pack, (4) the camera assembly, (5) the automatic features, and (6) the wiring.

The microscope was slightly modified by taping two glass plates, one on top of the other, upon the calibrated stage of the microscope. The glass plates serve to hold the film flat when the film is inserted between them.

5. The steps in obtaining a longitudinal distance between two points on a three-dimensional object with this photographic method are: (1) Assemble the device, (2) set cameras and connect wiring, (3) align the subject parallel with the orientation line on the base, (4) take the picture, (5) take the necessary film readings, and (6) compute the longitudinal distance between the two points.

6. The device is not fully portable owing to the fact the the base is not designed to be disassembled.

The degree of efficiency that the automatic features are responsible for has not been determined, but they are considered to be valuable time and labor savers.

More fish can be handled and recorded on film using this device than the methods now in use, but the photographic method has two additional steps. That is, reading the film and computing from the readings the longitudinal dimensions of an object such as a fish. Four film measurements are needed to compute one

longitudinal distance between two points. The methods and techniques used in accomplishing these two additional steps are tiring and lengthy.

The maximum total error of this photographic method for some positions can be as large as ± 0.05 to ± 0.06 centimeters; though after analyzing the sources of error--the grid lines, the glare, the calibrated knob, and the steel tape--we feel that the results can be appreciably improved.

7. Many improvements can be made on the photographic device and the method of reading the film and computing the longitudinal distances. The greatest improvement would be the use of an automatic film reader that punches the film measurements on IBM cards. The cards are then fed to IBM machines that compute the longitudinal distances automatically. A less costly device could no doubt be made, however, by sacrificing certain less needed advantages. Tables also could be used in the place of the IBM card and machines.

8. From our research to date, it is concluded that (1) the theory set forth in this paper is sound, (2) that the device can be made fully portable by designing the base so that it can be disassembled and by reducing the weight of certain parts of the device, (3) that the efficiency of this photographic method can be improved by the design of a better method of reading the film and by incorporating IBM cards and machines or tables to simplify the computations, (4) that the device in its present form can be called accurate for some purposes but that the present accuracy can be improved, and (5) that when the above improvements are made, this photographic method will be a valuable aid in the racial analysis work being carried out by the U. S. Fish and Wildlife Service for the International North Pacific Fisheries Commission.

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