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STUDY OF
AUTOMATIC MEANS OF
DETERMINING THE AGE OF FISH

by

Louis L. Sutro

Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Report No. MITSG 72-2
September 1, 1971

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ADMINISTRATIVE STATEMENT

This report of a "Study of Automatic Means of Determining the Age of Fish" was the result of work performed at the Charles Stark Draper Laboratories, M.I.T., sponsored by the National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Department of Commerce, through contract 14-17-0003-223.

This study demonstrates the feasibility of applying the methodology and technology developed for photo data transmissions in space exploration to the wholly different field of marine biology. The need to recognize, transfer and apply the developments and technology from one discipline to another, regardless of how diverse, is especially important in periods of expanding research effort such as that for effective utilization of the marine resources.

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Alfred A. H. Keil
Director

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ABSTRACT

We have:

1. Studied how a human operator examines a fish scale impression noting that when he is limited to his identifying vision he has to determine age by looking from circulus to circulus, measuring the spaces between and shifting to other circuli when the ones he is examining are defective.
2. Devised a test system using a three-axis manipulator, a microscope, a chain of TV camera and computer, a program that acquires an image and displays a histogram of the gray values in the image, and a program that measures the separation of circuli.
3. Attempted to present half of the fish scale impression on the TV monitor.
4. Looked into other scanners than the TV camera.

We have concluded that:

1. The problem of aging fish is one of measurement and the logical organization of measurements so that they can be interpreted as the age of a fish.
2. The present TV camera is adequate to determine if automatic aging of a fish, beyond an initial setup by a human operator, is feasible.
3. Phase contrast optics are needed to present half of the fish scale impression on the fish scale monitor.

4. A second study now needs to be made of the feasability of a system that automatically determines the age of a fish scale after an operator has inserted a fish scale impression, centered it, focussed it initially and indicated the sector to be searched. Keys to this automatic operation are expected to be, first, multiple servo loops of focus, amplifier gain and detection of edges and their directions; second, the recognition, in three dimensions, of circuli.

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1 THE PROBLEM

Efforts to protect the populations of fish in the waters off our coasts make it increasingly important to learn the ages of those fish and the patterns of their growth. The only way that has been devised to do this is for commercial fishermen to scrape a few scales from the midlines of a sample of each catch and send these to a laboratory where trained personnel view them under high magnification. Of the estimates that they make, they are able to repeat the same estimates about 75% of the time.

To achieve even this degree of reliability, personnel require about nine months of training. A fish scale can be regular, as at the right hand side of Fig. 1. Starting from the center, which was the entire scale when the fish first developed, you observe widely spaced "circuli", and then increasingly narrowly spaced circuli until the spacing becomes wide again. This progression of spacing, from wide to narrow, indicates one year's growth of the fish. Each year's growth is called an "annulus" or ring. There are seven rings on this scale.

The cycle of a year's growth is often interrupted by an unusual close grouping of the circuli called a "check," or the scale may have been injured as appears to have happened at the lower left of Fig. 1. To find his way around these irregularities, a fish scale ager needs training.

Suppose someone of less training were simply to mount each fish scale impression so that its center was on the axis of an appropriate instrument and he were to select a sector of the impression to be examined and adjust the focus. Could the "appropriate instrument" then measure the annual growth of the scale and determine its age?

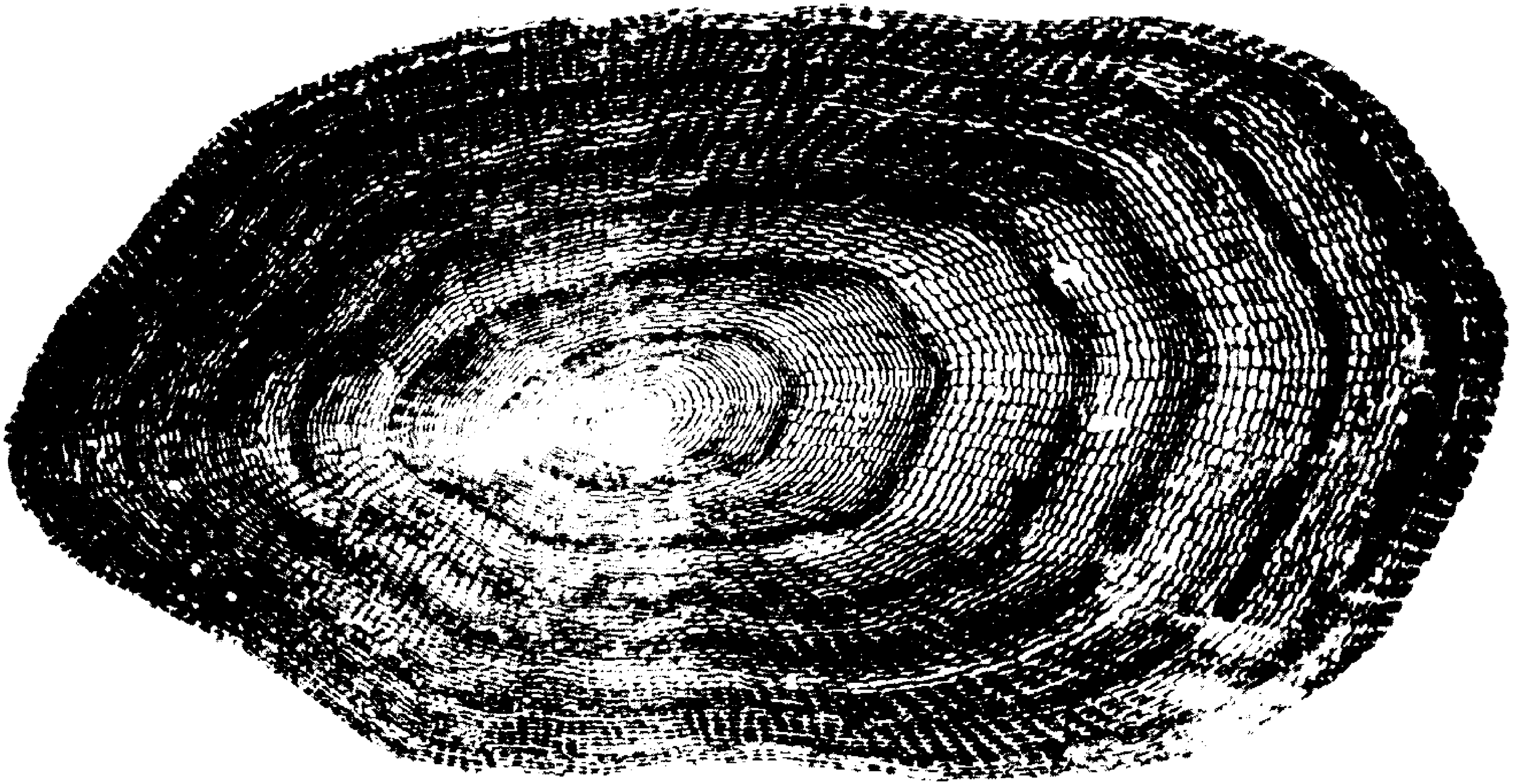


Fig. 1 Photograph of an impression on a rare, near-perfect haddock scale whose actual size is about 1/4". Scale when fish first developed is at center. Widely-spaced circuli are summer growth; closely spaced circuli are winter growth. Thus, the fish from which this was taken was 7 years old. Only the right hand quarter of the scale was exposed to water.

2 FROM SPACE TO FISH

During the peak years of preparation for the exploration of space (1965-1970) a system was built at the Draper Laboratory to try methods of interpreting the scene before a television camera so as to make decisions about that scene. This was a departure from most of the picture processing then carried out in laboratories all over the world. The assumption of that picture processing was that nothing could be done about the scene being pictured. It was only to be interpreted.

The Draper Laboratory approach was to develop equipment that could act upon the environment to move through it, pick up a piece of it or otherwise change it. This required that the computer or computers be light, small enough and of low enough power to be carried on a vehicle of considerable operating range. The place where this was expected to be used was the surface of Mars(2).

Figure 2 shows the test system and its binocular TV camera. Figure 3 shows one of the possible configurations the system was expected to evolve into. Here there were to be two TV cameras functioning binocularly and each camera would have both a central high-resolution view and a peripheral low-resolution view.

Available funding permitted completion of a library of software for the test system and the design of one light-weight, low-power computer. Most important, it permitted a concept to develop of the interaction of a TV camera and computer with their environment. Whereas most picture processing uses a picture as the memory of the scene, the new system would use the scene as the memory, looking at it again or moving in for a closer look when it needed more information.

Into this framework of a design concept and a test system came the opportunity in September 1970, to look into the problem of examining fish scales to determine the age of the fish from which they came. Study of this problem makes it possible to test the validity of concepts on earth that are not likely to be tested on Mars for some time to come. These concepts come from observations of animals who recognize objects by interacting with them. More will be said about this approach in Section 4.

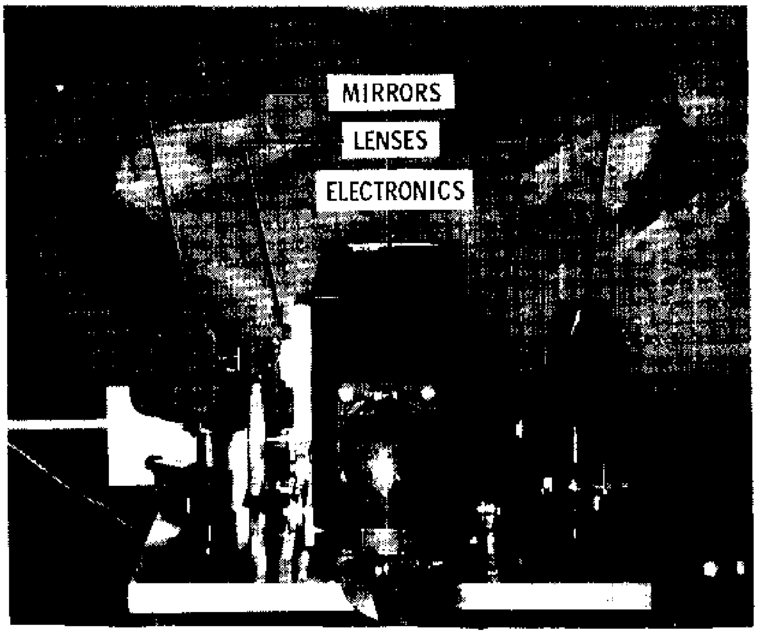


Fig. 2 Equipment for simulating light-weight, low-power hardware.
(above) camera-computer chain for simulating visual computers.
(below) binocular, or stereo TV camera.

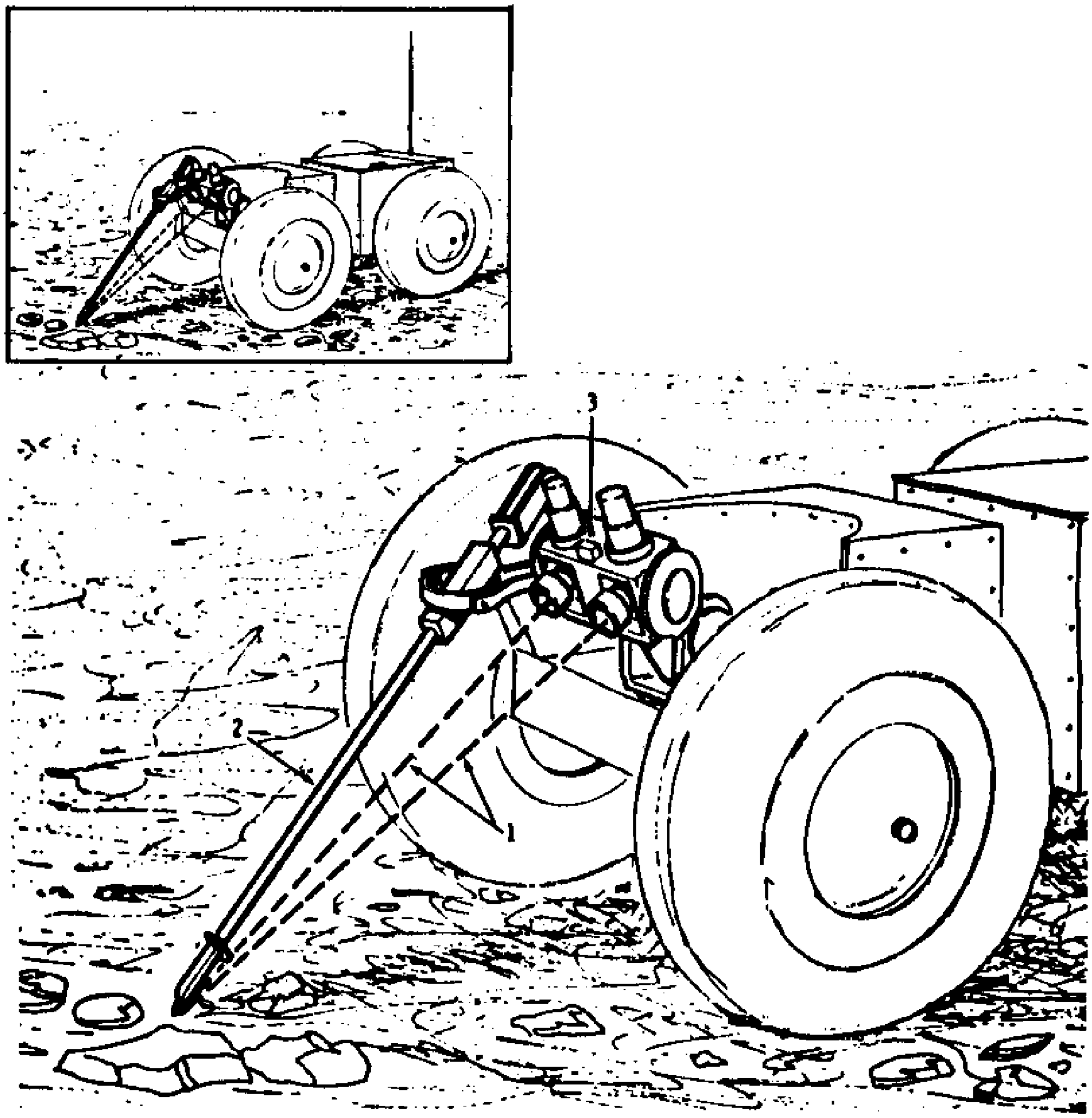
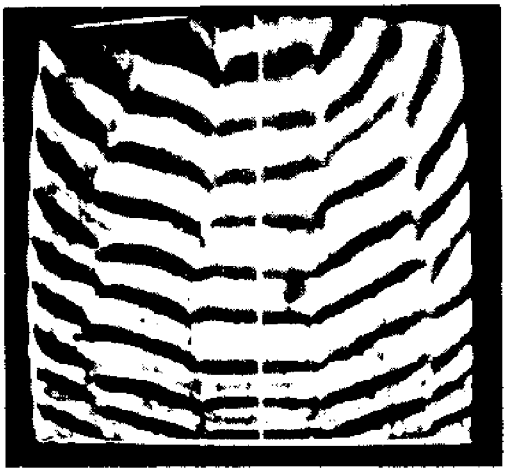
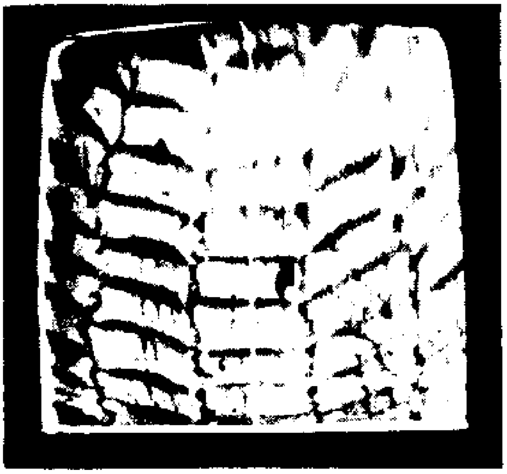


Fig. 3 Possible configuration of a Mars rover. Binocular camera views scene along lines of sight (1). While hand and arm (2) feel, and accelerometers (3) detect inclination.



(a) Where relative Z-axis setting was 0.



(b) Where relative Z-axis setting was 0.0017".

(c) Where relative Z-axis setting was 0.0028".

Fig. 4 Photographs of monitor scope when circuli No. 37 through 40, viewed through 40X magnifier and positioned between the top and bottom white lines, were focused in the three positions indicated.

3 APPROACH TO A SOLUTION OF THE PROBLEM

A human ager of fish locates rings of growth, and then identifies within each ring widely-spaced circuli as contrasted to narrowly-spaced ones. In doing so, he is employing two separate functions of human vision: locating and identifying.(1)

The ager of fish quickly locates the outer edge of the first ring, identifies wide and narrow circuli there, locates the next ring, identifies its outer edge and so on. The ager counts each ring as he proceeds, thus determining the age of the fish. Thus the human ager uses his locating and identifying functions together.

Automation has been achieved of only the identifying function. This automated procedure, called "pattern recognition," consists, first, of the detection of features; second, of the grouping together of these features into patterns; and third, recognition of these patterns. Pattern recognition usually does not include the change of focus that must be made to explore a fish scale impression. Nearly all work in the field of pattern recognition begins with a picture, usually a photograph, and then proceeds to devise algorithms for extracting features and patterns.

Human vision shows us that there is far too much information in any scene to be taken in with a single glance. Instead, the eyes focus on objects of interest at different depths in the visual field. Likewise, there is too much information in the scene to be captured by a single photograph. Instead, let's enable our camera to view a scene as we do, by equipping the camera to focus at different distances.

Figure 4 shows the result of having a TV camera look at the impression of a haddock scale this way. Figure 4a shows a portion of the impression when the camera lens is focussed to achieve maximum contrast between the leading edges of the circuli (black bars) and the spaces between. Calling the focus setting for this picture 0, the focus settings for the next two pictures are 0.0017 inch and 0.0028. As the lens is focussed deeper into the impression, the leading edges of the circuli appear thinner (Fig. 4 b) and radial lines appear that are evidently impressions of radial valleys. In Fig. 4c, the leading edges of the circuli have almost disappeared, while the valleys are now very evident.

In Fig. 5 an artist has pictured the structure of a haddock scale. He was aided in making this drawing by electron micrographs as well as by the photographs of the scanner monitor in Fig. 4. The ramp-like leading edges of circuli appear dark in Fig. 4 a because light passing through the prism-shaped clear plastic is refracted from the optical axis, as shown in Fig. 6. The leading edges appear to be continuous bars in Fig. 4a because the narrow spaces between the ends of circuli (Fig. 5) fail to be reproduced in the impression.

The leading edges of circuli have been detected automatically, as we report in Section 6, and the ends of circuli (valleys) have been detected by pencil and paper analysis. Automatic interpretation of inter-circuli distances has been performed as we report in Section 10. Automatic interpretation of a fish's age can be made from this data. The problem is to organize equipment to do it as fast as human beings, namely once per minute.

Note in Fig. 1 that at the inner edges of rings, focussing is such that both circuli and valleys can be seen at once as in Fig. 4b. At the outer edges of rings, focussing is such that only circuli can be seen as in Fig. 4 a. The reason is that circuli at the inner edge of a ring (spring growth) are taller than those at the outer edge of a ring (winter growth).

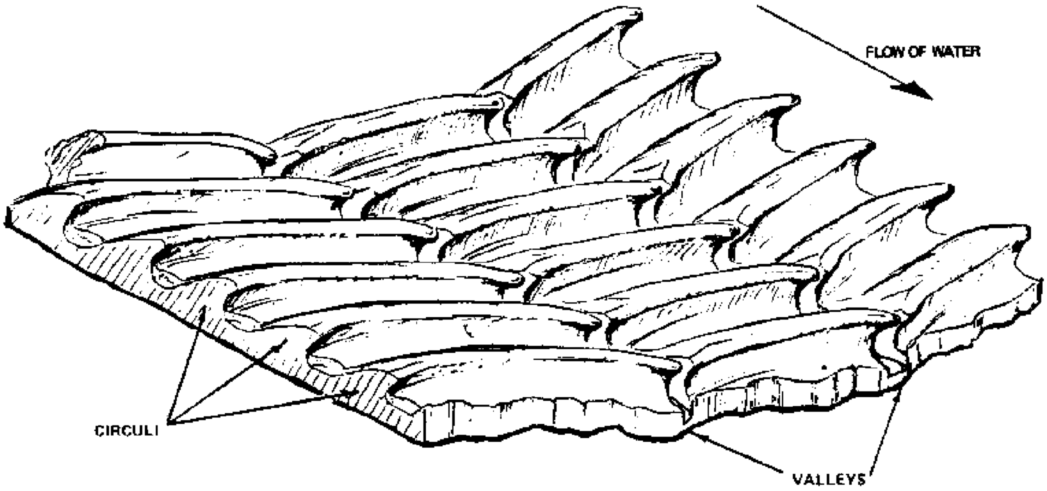


Fig. 5 Parts of three columns of circuli in a haddock fish scale as pictured by an artist.

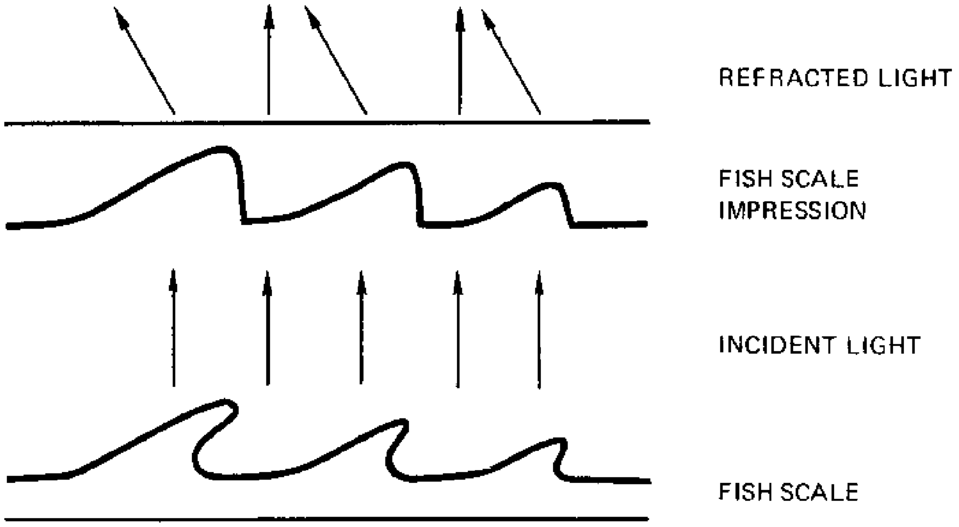


Fig. 6 Why circuli of fish scale appear dark. Light is refracted from its original direction by prism-shaped parts of the impression. Note that shape of the impression does not correspond directly with that of the fish scale.

As you look at a fish scale impression, your orienting vision appears to latch on to the rings. These are usually marked by darkening at their outer edges because of the narrower spacing of circuli there (see Fig. 1). Your identifying vision identifies circuli wherever your eyeballs stop or fixate. Since only identifying vision has been automated so far, he who inserts the fish scale impression into the machine we design will use his locating vision to select the part of the fish scale impression to be searched. We refer to this as "the sector to be searched" because a sector includes the center of the fish scale impression.

The machine we design must employ repeated identification to examine a fish scale impression automatically, analyze it and determine its age. A machine can employ a strategy of discovering the sequences of widely spaced and then narrowly spaced circuli that represent a year's growth. Just as if it were climbing a ladder when there are other ladders to shift to, so should the device be able to climb circuli, shifting sidewards to another circulus when one proves incapable of analysis. After each identification of a circulus, the machine should be able to measure the distance radially from the previously identified circulus. From the sequence of changing measurements, it should be able to detect in a nearly perfect scale, like that in Fig. 1, cycles of growth, age. Analysis of imperfect scales should follow when the computation equipment is large enough to store special cases and test imperfect fish scale impressions rapidly.

4 PRESENT TEST SYSTEM - AN OVERVIEW

Everything we want to do with a fish scale is already being done by trained human operators. In Section 5 we describe human behavior in aging fish. Here we will describe the computation that takes place in the human visual system and how our test system imitates it.

Identifying vision is computation that takes place in four principal stages in animals such as ourselves. These stages are:

1) Detection of contrast
2) Detection of edges and lines
3) Extraction of features
4) Recognition of objects by grouping together features, either by moving the eyes, or by shifting attention during one fixation of the eyes.

Following this approach, we organized our test system as shown in Figs. 7 and 8. At the left of each illustration is the fish scale impression which the microscope objective projects on the face of the scanner (TV camera). The picture acquired by the scanner is both displayed on the scanner monitor and read, in part, into the computer. The programs IMAGE and AGING take the first and fourth of the above steps to discover an object in only the crudest sense of that word. The second and third steps were skipped because the process of thresholding which is employed detects edges directly. This is the "oldest and most widely used method of edge extraction"(3).

All parts of the test system in Fig. 7 and 8, except the microscope, were developed for NASA to provide a means of evaluating camera-computer systems being considered for a landing on Mars.(2) The purpose of such systems was to reduce the amount of information acquired on Mars for transmission back to earth. One method explored was to detect edges and form a line drawing. Hence the program LDRAW, described in Section 10.

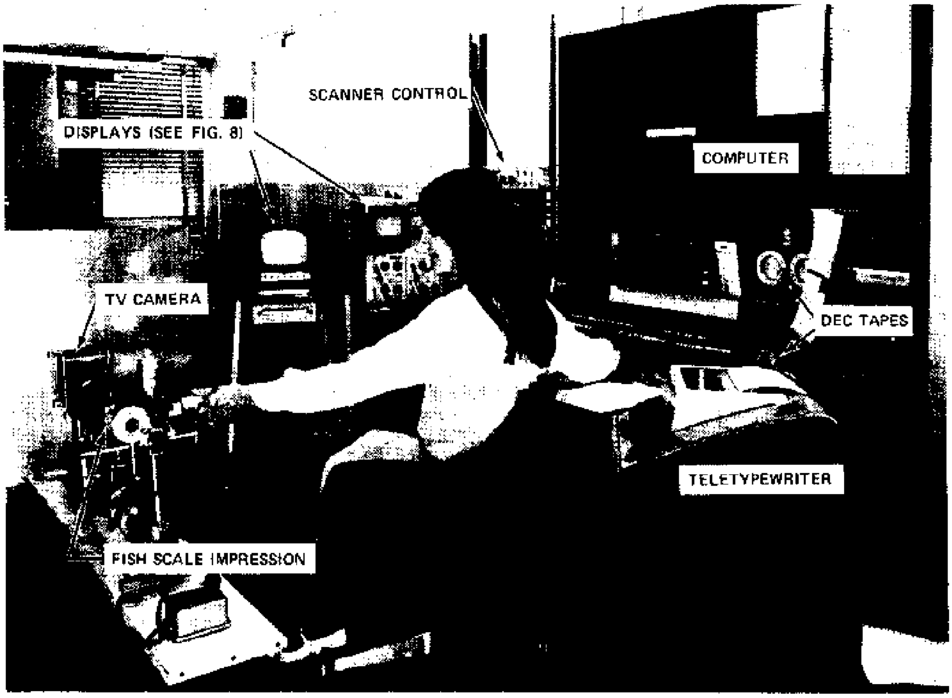


Fig. 7 Laboratory setup in which operator manipulates microscope and computer while watching displays.

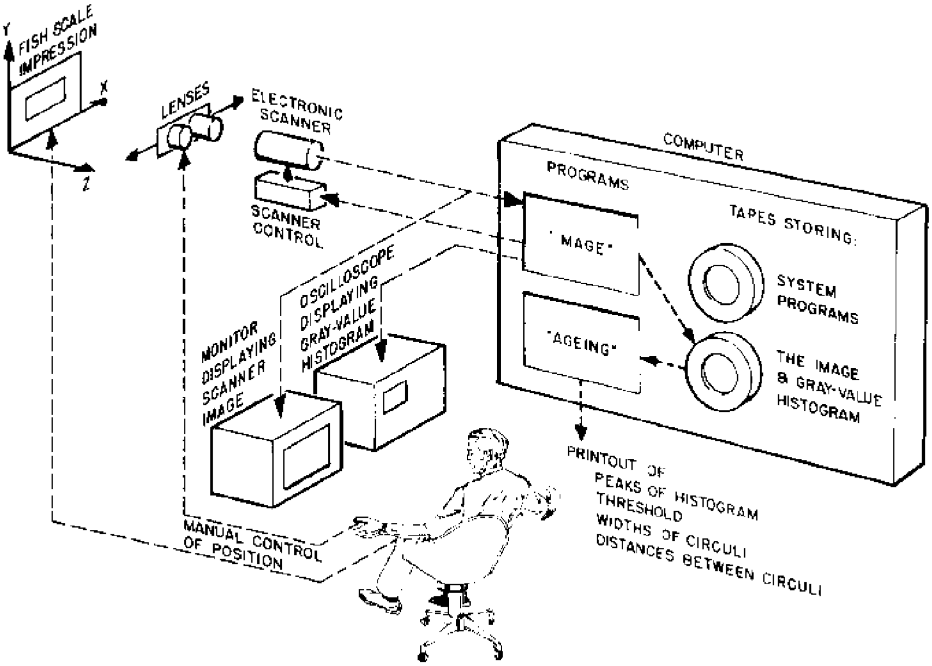


Fig. 8 Diagram of test setup.

5 AGING OF FISH BY A HUMAN OPERATOR

Preparatory to aging a fish, a technician at the laboratory of the NMFS at Woods Hole presses one scale at a time into cellulose acetate butyrate, 0.02 inch thick, which he has softened by a drop of thinner. He then covers the impression by another layer of acetate so that dust or dirt will not accumulate. He places this impression in a microfilm reader which can enlarge it to an image 2 feet by 2 feet.

Section 4 described what the human operator looks at and the information he appears to acquire. Let us now consider the sequence in which he acquires this information. While no two agers of fish follow exactly the same sequence the following appears to be representative.

1) He finds the center of the fish scale.

2) Scanning from the center outward, he looks for borders between densely-packed circuli (winter growth) and loosely packed circuli (spring growth).

3) If each border is unambiguous, he can skip from one to another, counting as he goes.

What enables him to skip in this way is his locating vision which detects the presence of these borders so that he can aim his identifying vision at them. Lacking locating vision, the operator must follow a different sequence, starting with step 2. Assuming that his line of search is vertical, he must:

2') look for top and bottom of the circulus

3') follow these along first to one end of the circulus, then the other, seeking information at several settings of focus,

4') digest this information in an attempt to recognize a circulus. Failing to recognize one he may try again or shift to the side seeking a circulus there.

5') Each time he recognizes a circulus he needs to measure the radial distance outward from the previously recognized circulus.

6') As he measures these circuli, he needs to compare their separations with one another, seeking cycles of annual growth.

In both of the above sequences the operator needs to draw on his memory of spacings of circuli that are different from the simple progression from wide to narrow that is the ideal year's growth.

6 THE PRESENT TEST SYSTEM--HOW IT WORKS

The test system is a first step toward automating the human operations described at the end of the last section.

The operator in Fig. 7 holds the x-axis micrometer. By manipulating this and the y-axis micrometer (Fig. 9), he can bring any circulus of the fish scale into the field of view of the scanner. By adjusting the z-axis micrometer, he can bring into focus any of the details shown in Fig. 4.

Figure 10 shows the fish scale impression attached with scotch tape to an aluminum plate which is attached to the 3-axis system just described. Figure 10 also shows the nominal 15x microscope objective that formed the image displayed in Fig. 11. As will be explained in Section 8, this objective provides a linear magnification of 40x. This allows only 4 to 6 circuli to be examined in the center half of a TV frame as shown in Fig. 11. If the number of circuli is approximately 120, as in Fig. 1, $\frac{1}{24}$ th of the area that has to be examined to determine age is examined in each TV frame.

When this lens is replaced by a nominal 5x whose linear magnification is 15x, 8 to 10 circuli can be examined (see Fig. 13). These are $\frac{1}{12}$ th of the radius of the fish scale in Fig. 1.

The scanner shown in Fig. 9 is a Colorado Video Inc. Model 501 Data (TV) Camera which is designed to be operated with a digital computer. A control system for this camera, built partly by Colorado Video Inc. and partly by Draper Laboratory, occupies the relay rack behind the operator's head in Fig. 7. This control system counts the 512 lines that are scanned by the TV camera and 512 positions on each line. It intensifies TV lines Nos. 128, 256, and 384, the first and third of which are called "limits of sample" in Fig. 11. The control system also intensifies the position on each horizontal line that is being read into the computer, thus forming the vertical white line shown in Fig. 4 and 11. This

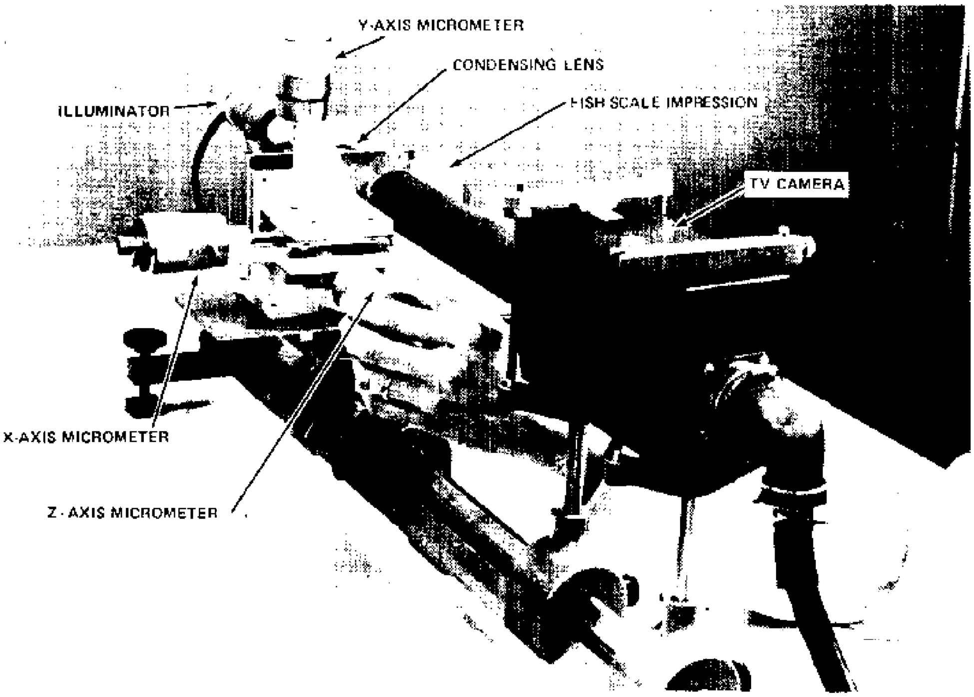


Fig. 9 Microscope and TV camera on lens bench.

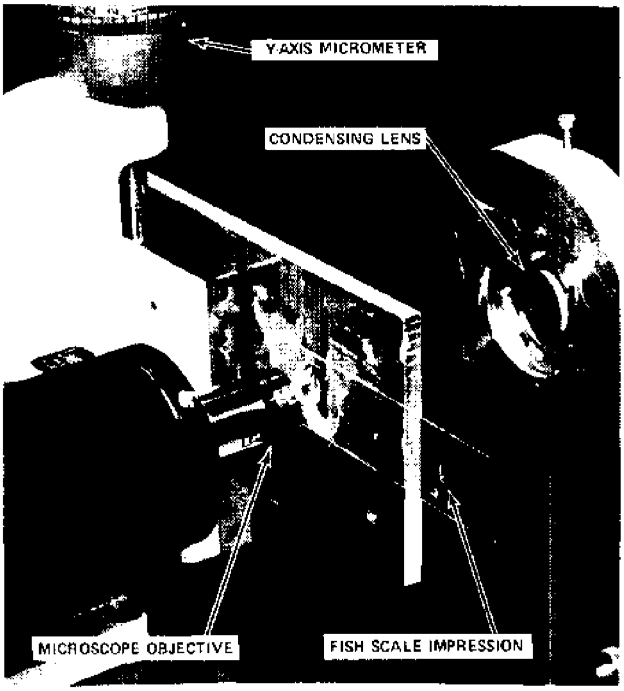


Fig. 10 Microscope objective, fish scale impression and condensing lens.

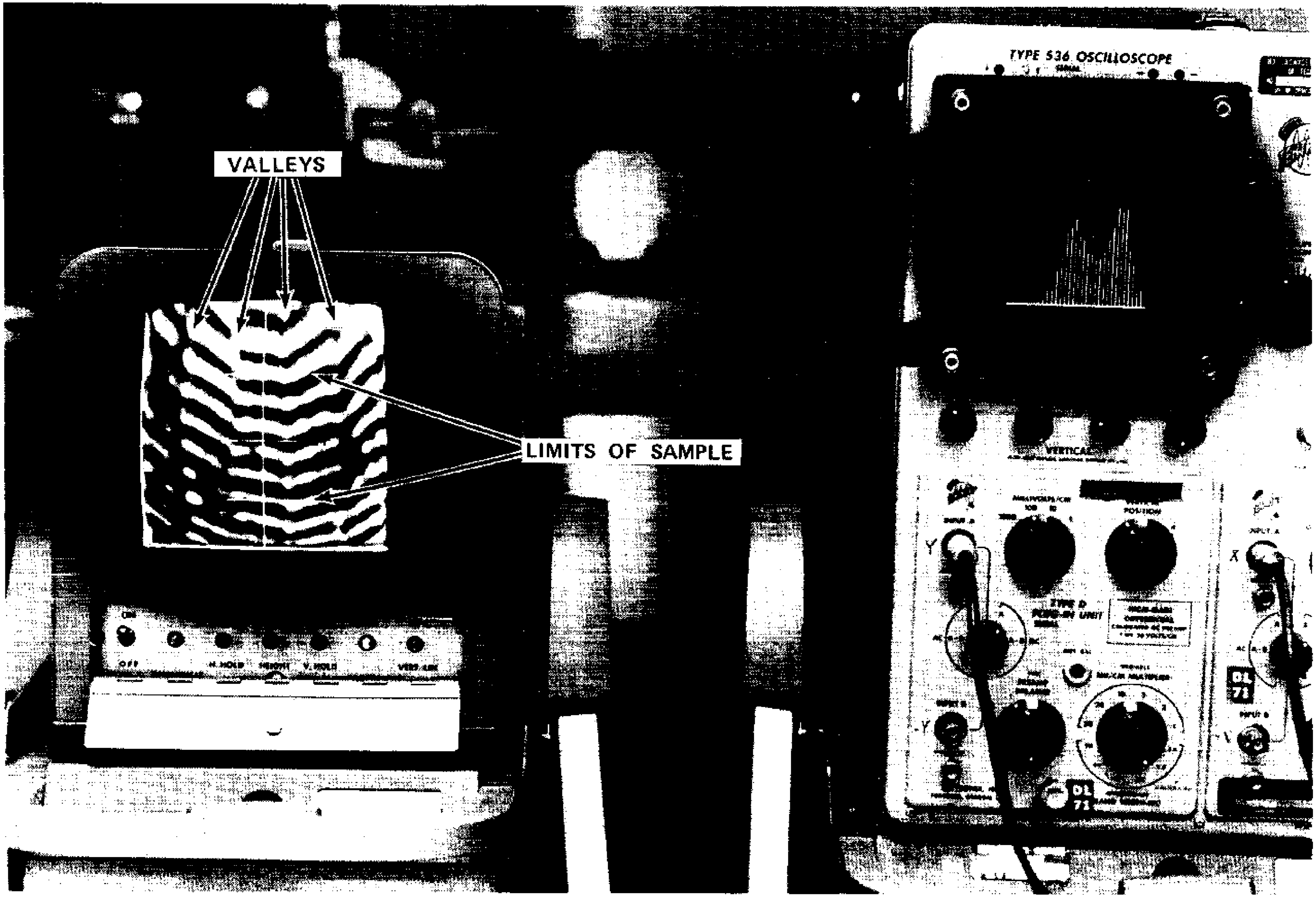


Fig. 11 Displays of fish scale impression at left, gray-value histogram at right.

method of sampling the TV image at a rate slow enough to be read into the computer is called "slow scan". The area sampled in the tests reported here was always 256 lines high by 10 columns wide (see Fig.12). Tests show that the 384 central lines can be taken, but not the full 512 because of distortion at the edges of the frame of the camera. Similarly, the central 384 positions of each line can be taken.

The computer of the test system is a Digital Equipment Corp. (DEC) PDP-9 with 8,000 words of core memory and two DEC tape units. The computer, of course, does only what its program tells it to do.

The program IMAGE, written for the Mars landing study, directs the camera control to read the tall, narrow image one point at a time and to convert each point of the image into a 5-bit word. With 5 bits there are 32 possible values of gray. The program counts the number of each gray value in the acquired image and displays these numbers as bars in a graph or histogram, shown at the right of Fig. 11. If the histogram does not display two distinct peaks, the operator refocusses the lens by adjusting the z-axis micrometer and runs the program again. He repeats this sequence until two distinct peaks are displayed. Sometimes it takes the operator one try, sometimes 8 or 10, but he has always been able to acquire the two peaks.

The left hand peak represents gray values of the dark leading edges of circuli and the right hand peak represents values of the light areas between circuli. The histogram of Fig. 11 is unusual in the uniformity of the peaks and depth of the trough between them.

A new program called AGING finds the midpoint between the two peaks in the histogram, which is then used as a threshold. It converts all gray values equal to or greater than the threshold to 1's, all values equal to or below the threshold to 0's. This is called "automatic cartooning."

Each band of 0's represents the width of a circulus between the limits set by the threshold. The program determines this width and the distance between centers of circuli, and prints out this information, as shown in Fig. 15. If requested to, the computer will print out all of the gray values in the tall, narrow image, and the bands of 1's and 0's in the cartoon of the image.

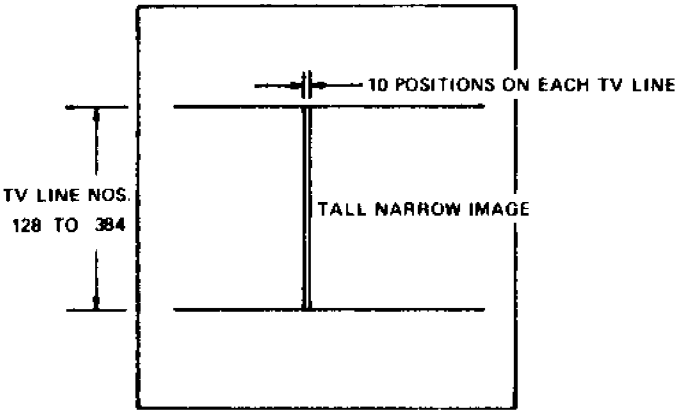


Fig. 12 Dimensions of image read into the computer for tests described in this report.

7 ADJUSTMENTS PERFORMED BY THE OPERATOR

The operator of the test system adjusts one micrometer to focus the microscope and two more to select the part of the path across the fish scale to be examined.

A fourth adjustment the operator may have to make is to rotate the fish scale impression by loosening the Scotch tape that holds it to its mount (Fig. 10) and reattaching it in a different position. Rotation is often needed so that the direction of search from circulus to circulus will remain vertical. An alternative is to tilt the direction of search, which we think is more difficult.

The fifth adjustment is of the gain of the video amplifier, to center the gray-value histogram on a scale of 1 to 32. Usually this has to be adjusted after each change in a micrometer setting.

8 RESOLVING POWER OF LENS AND SCANNER

The optical resolving power is determined by the lens and the electronic scanner. In most of the tests of this system, automatic cartooning, that is, separation of the image into light and dark areas, was desired. For this, high resolution was required to achieve an accurate measurement of the width of each light and dark band. Highest useful resolution for this scanner is achieved by a lens of 40 diameters magnification (called 15 x) which images a square area of the fish scale

0.01 inch high and wide

onto an area on the face of the camera tube 0.4 inch high and wide. The TV camera resolves this image into 512 lines, so the smallest distinguishable height or width in the image is

$$\frac{0.01''}{512} = 0.00002''$$

which is two hundred-thousandths of an inch or 0.5 micron.

To show that more circuli could be distinguished, a lens of 15 diameter magnification (called 5 x) was used for the measurements pictured in Figs. 13 and 14. At this magnification with the equipment set up as described, the valleys between circuli can not yet be distinguished automatically. More tests will be run.

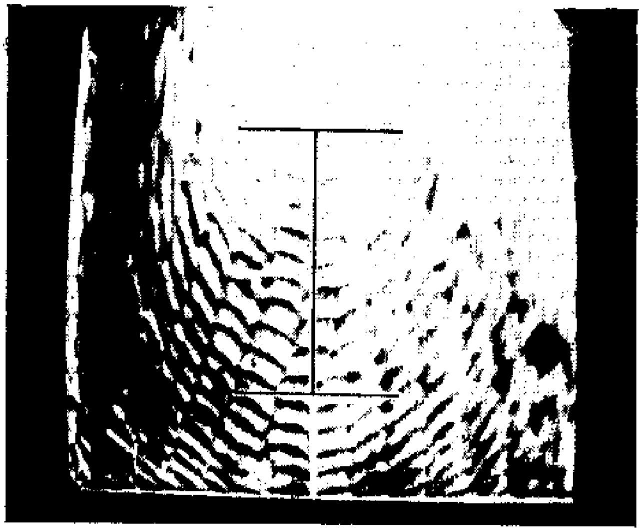


Fig. 13 Photograph of monitor scope display of nine circuli between boundary lines, here drawn black.

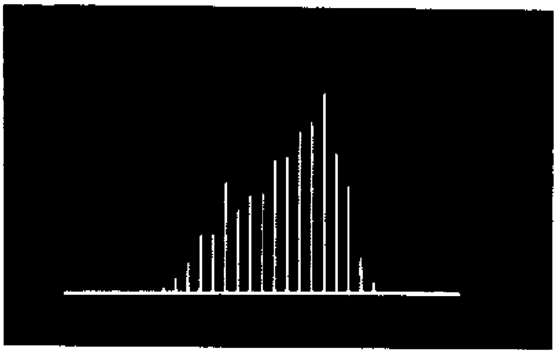


Fig. 14 Gray-value histogram of tall, narrow image including vertical line shown black in Fig. 13.

9 RESULTS OF TESTS OF IDENTIFYING

Human operations in aging fish, as explained in Section 5, can be divided into locating and identifying. While it is desirable to automate both functions, it appears necessary to get along with automation of only the identifying function in the immediate future.

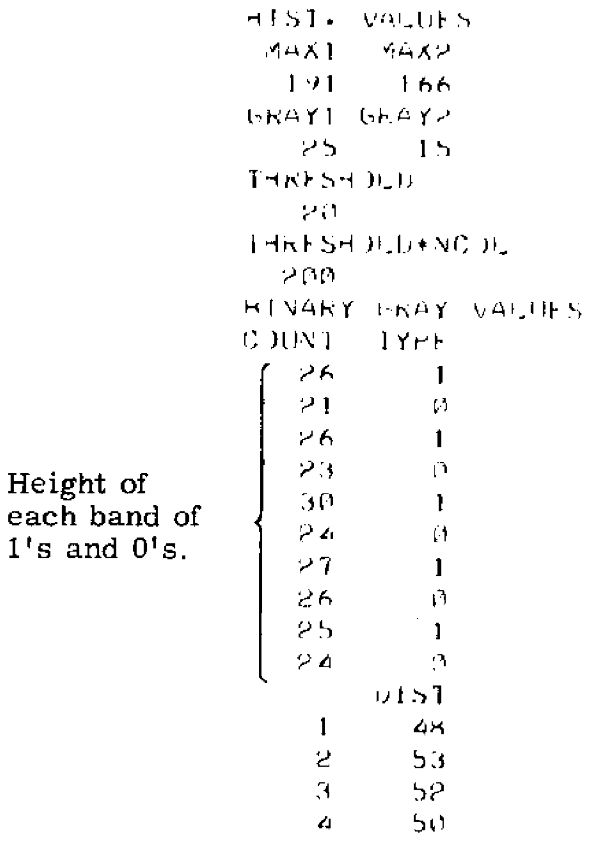
Results of tests of identifying take two forms. The first is the computer printouts of the kind presented in this section. The second is the conclusions in Section 11.

Figure 15 is a computer printout of the results of analysis by the program AGING of first the gray-value histogram, shown at the right in Fig. 11, then of the tall narrow image that includes the vertical white line in the monitor display of Fig. 11. Before examining that figure it is important to recall that the tall narrow image contains 10 columns, 256 lines high, or a total of 2560 points.

As shown in Fig. 15, AGING finds that the largest number of any gray value in the histogram of Fig. 11 is 191 (MAX1) at a gray value of 25 (GRAY1). The second largest, at least five gray values away, is 166 (MAX2) at a gray value of 15 (GRAY2). AGING picks as THRESHOLD the midpoint between peaks, namely, the gray value of 20. It multiplies THRESHOLD times the number of columns (NCOL) to get the threshold that it applies to the sum of the readings on each line, namely 200. It then translates each of the 256 sums into a 1 or 0, depending upon whether it is greater or less than 200. The result is a table or cartoon (not shown in Fig. 15) of bands of 1's and 0's and a few "stray" 1's and 0's. AGING will print this cartoon if requested to.

AGING considers a band of three or less anomalous elements residing in a uniform block to be "stray." It changes these anomalous elements to agree with the block. AGING then forms a revised cartoon which it will print if requested to.

Examining the revised cartoon, AGING counts the height of each band of 1's and 0's, forming the table shown in Fig. 15. Finally, it measures the distances (DIST) between centers of bands of 0's. The four distances printed at the bottom of Fig. 15 are the intercirculi distances along the vertical white line in Fig. 11 between the "limits of sample." The measurement is in TV lines. Multiply by 0. 00002 to get inches, by 0. 5 to get microns.



```
HIST. VALUES
 MAX1   MAX2
  191    166
GRAY1 GRAY2
   25     15
THRESHOLD
   20
THRESHOLD*NCOL
  200
BINARY GRAY VALUES
COUNT  TYPE
  26      1
  21      0
  26      1
  23      0
  30      1
  24      0
  27      1
  26      0
  25      1
  24      0
       DIST
   1     48
   2     53
   3     52
   4     50
```

Fig. 15 Printout of results of computer's examination of image that includes the vertical white line in the monitor display of Fig. 11.

10 COMPUTATIONAL TECHNIQUES AVAILABLE FOR AN AUTOMATIC SYSTEM

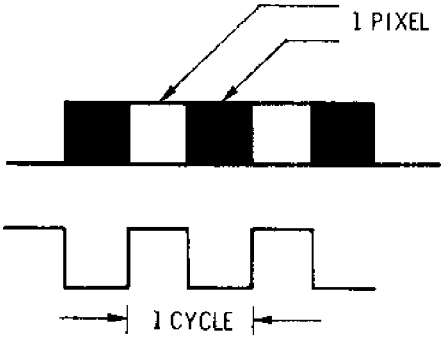
Three computational techniques are available to detect the edges of a circulus when they are in focus and the edges of valleys when they are in focus. All of these techniques can be derived from the concept of spatial frequency. For example, in any one line in which the electron beam sweeps the camera tube of our test system, there are presently 256 useful positions, called "pixels" for picture elements. As Fig. 16 shows, the highest spatial frequency that can be detected is 0. 5 cycle per pixel the lowest 1/256 cycle per pixel.

One computational technique is thresholding which we do not propose for future work because it does not facilitate automatic focussing. A second is the Fourier transform(5) which requires a larger amount of computation than we think is necessary.

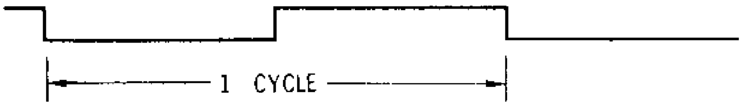
The third technique Rosenfeld calls "nonlinear edge detection"(6). Figure 17 shows the filters employed by our version of this technique. The filter in the upper left of Fig. 17 detects 0. 33 cycles per pixel because one out of three pixels is not sensed (see Fig. 16c). There is a column of 0's there to permit centering the filter on that column. The top center filter detects 0. 2 cycle per pixel, the top right 0. 14.

The program which performs the operations of Fig. 17 is called LDRAW because it was intended to reduce the appearance of a scene such as that of Fig. 18 to the coarse line drawing of Fig. 19.

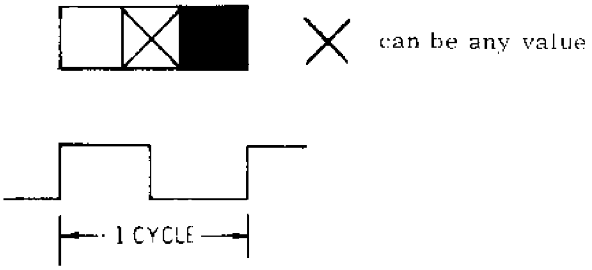
The operations performed by LDRAW are represented by the equation shown in Fig. 17 if a special meaning is given to the ★. The special meaning is that each of the arrays of numbers in Fig. 17, which we call a "filter", is convolved with a submatrix of the image that measures nine pixels (picture elements) by nine pixels. Three such limited convolution sums are formed of each 9 x 9 area, then the



a. The highest spatial frequency is caused by alternately light and dark pixels.

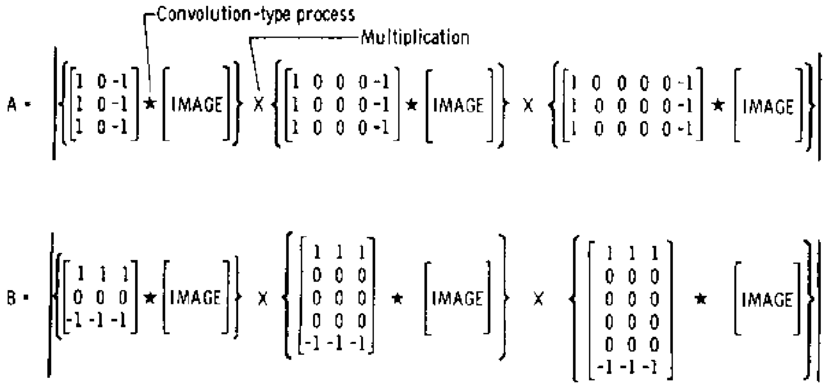


b. The lowest spatial frequency that can be detected with the present test system is one cycle per 256 pixels, or 1/256 cycle per pixel.



c. The highest spatial frequency detected by LDRAW is one cycle per 3 pixels.

Fig. 16 Diagrams of patterns of pixels and the spatial frequencies they communicate.



$$A = \left| \left\{ \begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix} \star \begin{bmatrix} \text{IMAGE} \end{bmatrix} \right\} \times \left\{ \begin{bmatrix} 1 & 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 & -1 \end{bmatrix} \star \begin{bmatrix} \text{IMAGE} \end{bmatrix} \right\} \times \left\{ \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 & 0 & -1 \end{bmatrix} \star \begin{bmatrix} \text{IMAGE} \end{bmatrix} \right\} \right|$$

$$B = \left| \left\{ \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} \star \begin{bmatrix} \text{IMAGE} \end{bmatrix} \right\} \times \left\{ \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} \star \begin{bmatrix} \text{IMAGE} \end{bmatrix} \right\} \times \left\{ \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} \star \begin{bmatrix} \text{IMAGE} \end{bmatrix} \right\} \right|$$

$K\,(A+B)$ = Output for each position in the image

Fig. 17 Operations performed on each submatrix of the image by LDRAW.

sums are multiplied together. A convolution sum is formed by multiplying each number in the filter by the corresponding gray value in a submatrix of the same size, and then summing the product. Only if all frequencies sensed are non-zero is there an output. Noise of one or two spatial frequencies is thus not detected.

Each convolution sum is a pixel of a new image, such as that in Fig. 19 which is a coarse-line drawing formed by LDRAW from the image of Fig. 18. Sharpness of edge is indicated by lightness of gray on a scale of 1 to 64. When the sharpness of edge exceeds what can be plotted, LDRAW truncates it at 64. The remaining flat top accounts for the coarseness of the drawing. The program MXFND finds the center of each coarse line, as shown in Fig. 20. The displays of Figs. 18 to 20 are presented by the program PICT.

Note that far more information is acquired by the filters of Fig. 17 than is presently retained. They detect individual frequencies which we will employ in an automatic focus program. They detect direction of the gradient from dark to light or light to dark which we will employ to find the edges of circuli.

Figure 11 illustrates circuli which appear as continuous bands. If an attempt is made to determine age automatically by measuring the distance between adjacent bands of circuli without first finding the ends of individual circuli, this distance measurement might, by accident, follow up a radial valley where circuli may be absent or appear very fat (see Fig. 11). Evidently the ends of circuli have to be determined.

Valleys exist in a fish scale impression at the ends of circuli, but a different focus (z-axis micrometer) setting than that which gives the highest contrast for viewing the centers of circuli. These intermittent valleys extend radially from the center of a fish scale. We have always found them below the points where the circuli tend most to look like continuous bands (see Fig. 4).

LDRAW can detect the edges of the circuli in Fig. 4a and the edges of the valleys in Fig. 4c. Professor Azriel Rosenfeld of the

Fig. 18 Mars-like scene.

Fig. 19 Coarse-line drawing formed from the image of Fig. 18 by LDRAW.

Fig. 20 Fine-line drawing formed from the image of Fig. 19 by MXFND.

University of Maryland helped us write it. We call it LDRAW because we used it initially to make a line drawing of a scene (Fig. 19). Rosenfeld has described his own program to detect edges in Ref. 6. Modifications need to be made both to LDRAW and to the test system that will employ this program. The modifications needed for the program will make the filter area greater, for the detection of more gradual changes in gray level, and capture direction-of-edge information that is now discarded. The test system needs to be modified to increase the number of gray levels from the present 32 to 64 or 128.

11 CONCLUSIONS

11.1 General

The work reported here shows that the problem of aging fish is one of measurement and the logical organization of measurements so that they can be interpreted as the age of a fish.

The method employed in detecting edges - thresholding - made it possible to tie a system together, but it required more human participation than is desired. The operator had to select the course followed by the computer across the fish scale impression. To relieve the operator of this chore, the computer must find the outline of each circulus, while at the same time adjust the focus, and choose a course across the fish scale. The program LDRAW can detect the tops and bottoms of circuli when the z-axis (focus) setting is chosen for highest contrast across horizontal or nearly horizontal edges. It can detect ends of circuli when the z-axis setting is chosen for highest contrast across vertical or nearly vertical edges. Adding more and larger filters to LDRAW will make the detection more reliable.

11.2 Locating Vision

Locating vision(1) enables a human being not only to find the rings in a fish scale impression but also to find areas of damaged circuli. From this information he can select the sector to be searched automatically.

In the laboratories of the NMFS, an operator looks at an enlargement of a fish scale impression in a microfilm reader to make these decisions. We have explored the possibility of erecting on the scanner monitor an image of the outer half of a fish scale impression. Figure 21 shows what could be achieved through an Elgeet 3-inch TV camera lens. Since only part of the desired detail appears, we plan to try other optical systems, particularly phase contrast.

Locating vision differs from identifying vision by using the peripheries of the visual field, especially when the eyes are in motion. We locate rings in a fish scale, as our eyes dance about, almost without trying. No computer can do this yet because no one has tried to make it do so. We think it can be achieved, but it will take a research effort. This will be an extension of the modelling of the vertebrate nervous system we have under way.(4)

11.3 Different Scanner Not Yet Needed

Let us consider whether the present scanner is adequate. The immediate need is not to find the best possible equipment but to demonstrate that adequate equipment can be organized to determine the cycles of growth and age of fish automatically. The TV camera presently employed is adequate for that.

Fig. 21 Haddock scale impression televised through 3-inch lens and displayed on TV monitor.

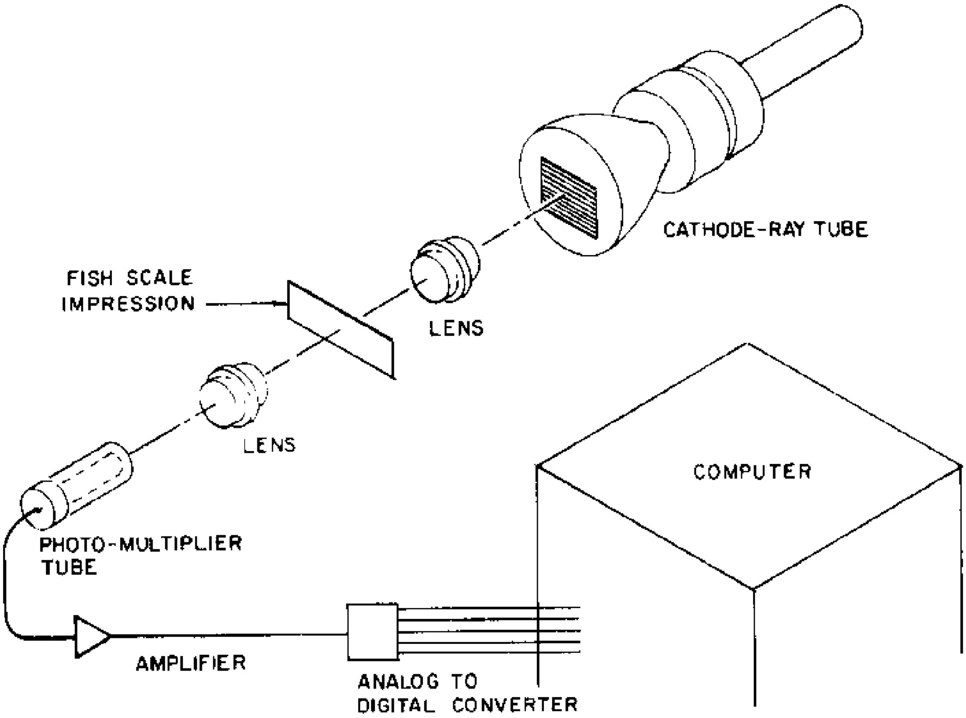


Fig. 22 Flying-spot scanner consisting of cathode-ray tube, lenses and photo-multiplier tube.

For the fast automatic system that will be wanted after feasibility has been demonstrated, is there a scanner preferable to a TV camera? There are two possible directions to pursue: one is to build or acquire a scanner that could view all of the fish scale impression at once, and the other is to accept as adequate the area of the fish scale impression presently scanned and concentrate on providing the best scanner of this area.

Going in either direction, expert opinion converges on a flying spot scanner.(7) This consists of a cathode ray tube, the tip of whose electron beam (flying spot) traces lines which are imaged on the fish scale impression. A second lens projects the illuminated spot on a photomultiplier (see Fig. 22).

The fish scale impression of Fig. 1 has approximately 120 circuli. If four are imaged on 256 TV lines, as in the example of Figs. 1 and 15, then

$$\frac{256}{4} = 64 \text{ TV lines}$$

are needed per circulus and

$$64 \times 120 = 7680 \text{ TV lines}$$

are needed to examine the entire scale.

11.4 Feasibility Study Needed

Five manual operations need to be replaced by program-controlled servos: Displacement in x, y and z directions and in rotation; and control of the gain of the TV-camera amplifier. The program LDRAW, or its equivalent needs to be revised to indicate the spatial frequency of the edges of circuli and the direction of these edges. The z-axis (focus) servo can then be slaved to a program that traces the outlines of a circulus in terms of spatial frequencies in different directions. The output of this program will be fed to a new AGING program that will automatically measure the separation of circuli recognized in this way. Feasibility of such multiple-loop servo systems and such a hierarchy of programs can be determined by operating a test system this way.

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