NAVAL POSTGRADUATE SCHOOL
Monterey, California

TECHNICAL REPORT

Image Enhancement Software for
Underwater Recovery Operations
– *User's Manual*

William J. Partridge
Charles W. Therrien

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Rear Admiral R. W. West, Jr.   Dr. Harrison Shull
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ABSTRACT

This report describes software for performing image enhancement on live or recorded video images. The software was developed for operational use during underwater recovery operations at the Naval Undersea Warfare Engineering Station. The image processing is performed on an IBM-PC/AT compatible computer equipped with hardware to digitize and display video images. The software provides the capability to provide contrast enhancement and other similar functions in real time through hardware lookup tables, to automatically perform histogram equalization, to capture one or more frames and average them or apply one of several different processing algorithms to a captured frame. The report is in the form of a user manual for the software and includes guided tutorial and reference sections. A 'Digital Image Processing Primer' in the appendix serves to explain the principle concepts that are used in the image processing.

TABLE OF CONTENTS

A. GENERAL

The "Menu" software package is a menu driven program which provides real time continuous video image processing using lookup table modification techniques. It also provides limited non-real time single frame enhancement capability. Control of the routines in "Menu" varies from manual (requiring operator input to make an adjustment) to automatic or "hands-off" operation. The processing routines were chosen to provide maximum effectiveness in situations where the images' pixel values are limited to a relatively small region of the total gray scale range. Typically this would include images of objects which have actual small variations in shading or those whose contrast has been reduced by obscuration or dim lighting.

B. EQUIPMENT REQUIRED

The following equipment is required to use the "Menu" program:

- IBM Personal Computer AT, XT, or PC[1] or 100% compatibles with Extended Graphics Adaptor card and monitor.

- Imaging Technology PCVISIONplus Frame Grabber card with standard cable.[2] (NOTE: The older model PCVISION Frame Grabber will not work.)

- Analog video monitor (such as SONY Trinitron[3] Model 1271Q).

- Video source (camera or video tape player).

C. SIMPLE SETUP

The PCVISIONplus Frame Grabber User's Manual provides all the information required to place the Frame Grabber into operation. Here is a much condensed version of that procedure with some helpful hints to ease the way.

1. Getting the Board Ready

Figure 2-1 on page 2-2 of the Frame Grabber Manual shows the jumper locations on the board and Table 2-1 on page 2-3 tells how they are configured from the factory. There are three position functions to be concerned with:

- Since an EGA card is needed to run "Menu" the memory base address must be changed on the Frame Grabber board. Address D0000 is recommended since this is the default value in the software. To change to address D0000 simply insert a jumper at location J8. If other than D0000 is chosen it should be noted for entry each time "Menu" is run.

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[1] Trademark of IBM.

[2] Trademark of Imaging Technology Inc.

[3] Trademark of SONY

- "Menu" has a default register base address of 100. To change the FrameGrabber board insert a jumper at location J11. Again, if 100 is not used, the chosen value will have to be entered each time "Menu" is run.

- If an AT host is being used a jumper is required at location J20. If an XT or PC is being used no jumper should be installed at J20.

2. Installing the Board

Pages 3-1 through 3-3 of the FrameGrabber Manual provide a detailed description for installing the board. A summary is as follows:

- Turn off and unplug the computer and periphials.

- Remove the cover.

- Place the board in any open slot where it fits and install screws.

- Reinstall cover.

- Plug in and turn on computer.

3. Cable Installation

Page 3-5 of the Frame Grabber Manual shows how to connect the cable. Here's the bottom line:

- Plug the rectangular female connector on the cable into the top connector protruding from the board.

- Connect the white labeled BNC connector to the video source output.

- Connect the green labeled BNC connector to the 'line' input (not the 'green' input of the red, green, blue connections).

- Do not connect the red- or blue-labeled cables.

4. Running the Diagnostics.

Page 3-10 of the Frame Grabber Manual describes the procedure for running the diagnostic software included with the Frame Grabber. Since the factory configuration has been changed as described above, the command < configure> will have to be entered followed by the register base address (100) and the memory base address (D0000). The diagnostics take several minutes to run so be patient. As stated in the manual, system memory or other devices mapped into the same memory space or register addresses will cause some tests to fail.

D. LET'S TRY IT OUT

This is an introduction to the "Menu" program. It let's you walk through some of the features of the program; sort of a hands-on familiarization. If you are not familiar with some of the concepts described in this section, or with digital image processing in

2

general, you should probably have a look at the Primer which is included in this document as an appendix. It explains the neccessary ideas in just a few pages.

Now turn on your source (camera or VCR) and video monitor to let them warm up. On your computer go to the directory where you want to keep the program and copy 'menu.exe' there.

1. **Load the Program**

To get started simply type the word 'menu' followed by <enter>. No <enter> is needed for any selection from here on out unless otherwise noted. The menu should now be displayed on the computer monitor. If you are not using the memory base address (D0000) and register base address (100) as described in paragraph C above, hit 'K' to change setup and follow the instructions on your monitor.

2. **Live Action**

Menu selection 'E' provides continuous acquisition and display of the incoming real time video images. Hit 'E' and you should see live action from your camera or VCR (if you're using a tape make sure you press the play button first).

3. **Take a Snapshot**

Now let's freeze the action. Hit 'F' for snap. This acquires and displays a single frame. You should see a stop action snapshot on your video monitor. The image is also stored now in framegrabber memory A, the default memory chosen when you started up.

4. **Take Two Snapshots**

Now hit 'D' for display memory B. Take another snapshot with the 'F' key. The second snapshot is now displayed on the monitor and stored in framegrabber memory B. Try going back to memory A (the 'C' key) to make sure the first snapshot is still there. Note that we are using the display memory keys and not the select memory keys to perform these operations. More on select memory later when we start storing images.

5. **All Black**

Let's erase one of our snapshots. Display memory B (the 'D' key) and then hit the 'G' key for screenclear(0). This clears the screen and framegrabber memory B to black or intensity level zero.

6. **All White**

While still in memory B hit the 'H' key for screenclear(255). This erases the screen and memory B to white or intensity level 255. Darker gray shades have lower intensity levels while lighter shades have higher intensity levels.

7. Put Your Snapshot in the Photo Album

Saving an image to disk is analogous to putting your snapshot in a photo album. You should still have an image in frame memory A. If not, use the display mem A and snap routines to get one. Now hit the 'A' key to select memory A. This selects memory A for data manipulations or storage. For our purposes we have selected the image data in memory A to store on disk. Now hit the 'I' key and you will be asked to enter an image name. Type a name (e.g. 'image') to store the image on the current disk and directory or path and name (e.g. 'a: image') to store it in a different place. Then you'll be prompted for a comment. You may give it a label or simply type 'none' (note that < enter > is required for each of these inputs). The disk drive selected should make some noise and your snapshot is safely tucked away in the "photo album" (i.e. the image file is written to the disk).

8. Open the Album to See Your Snapshot

Let's see if the image was really saved. First erase both frame memories as described in paragraph 5 or 6 above. Then select a memory using 'A' or 'B'. Now hit the 'J' key. Type the image file name (followed by < enter >) to read the image from disk. The image should appear on the video monitor. If it does not, display the memory you selected (the 'C' or 'D' key) and the image will appear.

9. Simple Processing

Now let's process real time video images using some simple lookup table modification techniques. Hit the 'L' key - its called analysis, but really it just lets you see how your image is being changed. The graph you see on your computer monitor is the current lookup table. The horizontal coordinate represents input pixel values and the vertical represents output values.

On the top of the computer monitor screen are the current options available for selection. The snap ('F') and grab ('G') options work the same as on the previous menu. Try them! Now try the invlut ('I') option and see how the lookup table changes (the blue line is the current lookup table and the green is a reference linear lookup table line). The effect on the image is just like looking at the negatives of a photograph, except that we still have live action. Now hit the 'L' key for linear lookup table. We are back to unprocessed live images.

Keys 'P' (logarithmic) and 'A' (absolute value) also modify the lookup table. You can experiment with these functions to see the effect on the real time image and their corresponding lookup table shape.

4

10. Histogram Equalization

Now for the most powerful of our lookup table modification routines. Hit 'E' for equalize. You now are given two choices, default and rectangle. This determines which portion of the image will be used to do the processing. Most of the time you will probably use the default mode but let's try rectangle now just for fun. Hit 'R' for rectangle. On the video monitor you will see the live images being displayed with a rectangle overlaid. Now hit 'Num Lock' on your keyboard. Using the '2', '4', '6', and '8' keys on the number pad (the ones with the arrows) you can move the rectangle around on the screen. The corner numbers ('1', '3', '7', and '9') are used to change the size of the rectangle. If your image had a large white or black area in which you were not interested, it would lessen the impact of the equalization routine on the area of interest. So you would frame the area of interest with the rectangle. After you have placed the rectangle where you want it, hit 'S' for stop.

Now you have to choose between manual or automatic update. Try manual update first. Hit the 'M' key. The image will equalize, the new lookup table is plotted, and live action continues using the new lookup table. In this mode, as you notice the contents of the image changing you can hit the 'U' key and equalization will occur again.

Let's go back now and try the default rectangle parameters. Hit 'C' to change parameters. Now hit 'D' for default and 'C' for continuous update. You are prompted for time between updates in seconds. Enter any number 2 through 9. The computer will perform a new equalization at the interval you specify. This is intended for situations where the contents of the image are changing often and you don't want to have to remember to update. When you have seen enough updates hit 'S' for stop.

11. Before and After

Let's look at some histograms and see whats happening when we equalize. Hit the 'H' key for histogram. Again, you may choose between default or rectangle to specify a portion of the image. Hit 'D' for default. Now hit the 'L' key for computation of linear lookup table histogram. After the "COMPUTING HISTOGRAM" indicator goes away hit 'M' for computation of modified histogram. When the indicator goes away this time hit 'D' to display the linear lookup table histogram. This is the information used to perform the equalization. The image on the video monitor is the unprocessed version. Now hit 'E' to display the modified histogram. The video image is enhanced and the "spread out" histogram is displayed. As you toggle back and forth between 'D' and 'E' you can see graphically how equalization lets us use the full range

of intensity levels and the corresponding enhancement of contrast on the image. Convinced? Hit the 'S' key and let's try something else.

12. Modifying the Lookup Table

Hit the 'N' key. Now we'll go again to the number pad with 'Num Lock' on. Using the corner keys ('1', '3', '7', and '9') we'll change the slope of the lookup table by moving the top or bottom of the curve. To shallow out the lookup table use the '9' key to move the top to the right and the '1' key to move the bottom to the left. Notice that enhancement to the live images changes as you modify the curve. When you are finished hit 'S' to stop and the resulting lookup table is shown. If you were to develop a "favorite" lookup table which you think you might want to use again, there is a way to save it in the computer. We'll talk about that later.

13. Draw Your Own Lookup Table

Now hit 'M' to perform another form of manual lookup table modification. We'll do this by drawing lines. Using the number pad with 'Num Lock' on move the pointer on the computer monitor by hitting the '2', '4', '6', and '8' keys. This will move it one pixel in the direction of the arrows on the keys. The next key clockwise from each of these will move it in the same direction ten pixels . (e.g. The '1' key moves the pointer in the same direction as the '2' key only faster.) When the pointer is at a location where you want the line to begin hit 'B' for begin line. Then move the pointer to a location where you want the line to end and hit 'E' for end line. Now hit 'D' to draw the line and your change will take effect on your image. You may draw other lines to connect segments and build a whole new lookup table. To get rid of the clutter just hit 'S' and then reenter the routine by hitting 'M'.

Now hit 'P' to put a pointer on the live video image. To move the pointer use the number pad keys in the same manner as you did to move the pointer on the computer monitor described above. Notice on your computer monitor that the position of the pointer and the intensity level are displayed. One possible use of this capability would be to find the intensity level of an object in the image and use the draw lookup table routine to change all pixels with that intensity to another level. Again, if you were to draw a really good all-purpose lookup table, you could save it with a routine which we'll describe later. Hit 'S' to exit the video monitor pointer routine and 'S' again to exit the modify routine.

Finally, let's go back to the main menu to see the lookup table storage/selection routines and try some single frame (frozen) processing. Type 'S' to exit the analysis function.

14. Storing and Retrieving Your Favorite Lookup Tables

Remember that lookup table you designed using the modify routine a while ago? Here's how you can save it for future use. Hit the 'M' key. Type in a name (e.g. 'mylut' or 'a: mylut'), hit enter, and the values are saved. To get it back hit the 'N' key to read the lookup table values from disk. Again, type in the file name followed by enter and your lookup table will take effect.

15. Piggyback Lookup Tables

The framegrabber board has two sets of lookup tables, one as the image is put into frame memory and one as the image is output to the monitor. Up to this point we have only used the output lookup table. Now we'll modify both sets to achieve a different result. Hit the 'P' key to select the input lookup table. Then go back to the analysis routine ('L') and do a histogram equalization. Everything still looks the same as the last time we equalized , including the video image, but this time the computed values went into the input lookup table. Now exit the equalization and analysis routines to get back to the main menu. Hit the 'O' key to select the output lookup table. Then go back into analysis. You may now use any of the lookup table modification routines (e.g. invlut, abslut, etc.) and you will get a "piggybacked" lookup table effect on the image. To get back to normal, hit 'L' to linearize the output lookup table. Go back to the main menu and select and linearize the input lookup table. Note that when you use this procedure, always put values derived by equalization into the input lookup table or the equalization will be based on already modified data.

16. Zoom

Now hit the 'R' key to start the zoom function. On the video monitor you can see the rectangle we saw before. Using the number pad with 'Num Lock' on you can move the rectangle with the '2', '4', '6', and '8' keys in the direction of the arrows on the keys. The size of this one is fixed at approximately one quarter of the screen, since we will be expanding the image to four times the original. Move the rectangle to the portion of the image you wish to zoom in on and hit 'S'. The expanded image is displayed. Notice that some resolution is lost from the original because we are "zooming" digitally as opposed to changing the focal length of the camera lens. Hit 'M' to get back to the menu. Now you can process the "zoomed" image using the fixed image processing routines described below.

17. Unzoom

To return to a normal image after using the zoom routine and performing any fixed image processing hit the 'R' key. It is essential that this be done when you are finished with a "zoomed" image or the zoom parameters will interfere with other routines.

18. Sharpen

Snap an image by hitting the 'F' key or by using the zoom routine (the 'R' key). Then hit 'S' to sharpen it. If you watch closely you can see the sharpening occurring on the displayed image.

19. Low Pass Filter

Snap or zoom another image and then hit 'T' to call the low pass filter routine. This function is designed to remove high frequency noise from a fixed image. Again, looking closely you can see the change occurring.

20. An Edge Detector

One more time, snap or zoom an image. This time hit the 'U' key to perform a Sobel Edge Filter. Note the interesting display of the image's edges on the video monitor.

21. Image Averaging

Hit the 'V' key. Then enter the number of image frames you want to average together. This number may be limited by the amount of disk space you have available (2 is a good number to start with). When the average image is displayed you should notice that objects which passed across the field of view during the operation have faded away. The more frames you average, the less visible these objects will become. Image averaging is very effective at eliminating transient noise, but requires a stable platform for the source.

To exit the program hit the 'W' key.

E. QUICK REFERENCE LIST

This list presents the program's options in the order they appear with a brief description of their output.

1. **A for select mem A**

Selects framegrabber memory A for storing or reading an image to/from disk.

2. **B for select mem B**

Selects framegrabber memory B for storing or reading an image to/from disk.

3. **C for display mem A**

Selects framegrabber memory A for acquisition of image from camera and displays memory A on the monitor.

4. **D for display mem B**

Selects framegrabber memory B for acquisition of image from camera and displays memory B on the monitor.

5. **E for grab**

Continuously acquires image frames from source and displays on video monitor. Uses framegrabber memory designated by 'display mem' function.

6. **F for snap**

Acquires a single frame from source and displays it on the video monitor. Uses framegrabber memory designated by 'display mem' function.

7. **G for sclear(0)**

Clears screen and memory to intensity level 0.

8. **H for sclear(255)**

Clears screen and memory to intensity level 255.

9. **I to store image**

Stores contents of selected memory to disk. Prompts input of filename (including path if desired) and comment.

10. **J to read image**

Reads image from disk file to selected framegrabber memory. Prompts input of filename (including path if desired).

11. **K to change setup**

Allows change of software memory base address and register base address. On screen instructions and example inputs provided.

12. **L for analysis**

Displays lookup tables and histograms. Performs equalization and lookup table modification routines. Options as follows:

    a.   m = modlut

       Modifies lookup table by drawing lines. Places pointer on video monitor. Move pointer to desired start point and end point using 'Num Lock' on and number pad

keys '2', '4', '6', and '8' for down, left, up, and right respectively. Use keys '1', '7', '9', and '3' for faster movement down, left, up, and right respectively.

  (1)   *b = beginline.*   Marks beginning of line.

  (2)   *e = endline.*   Marks end of line.

  (3)   *d = drawline.*   Draws line and enters new values into lookup table.

  (4)   *p = pointer.*   Places pointer on video monitor. Gives pointer location and pixel intensity level of that location on computer monitor. Use same method to move pointer as for line drawing routine above.

  (5)   *s = stop.*   Exit lookup table modify routine.

 b.   *n = mod2 lut*

Changes slope of existing lookup table and implements results. With 'Num Lock' on use number pad keys '1' and '3' to move bottom of curve left and right respectively. Use '7' and '9' keys to move top of curve left and right respectively. Hit 's' to exit this routine.

 c.   *h = histogram*

Computes and displays histograms for images processed with linear and modified lookup tables. Snaps images before and after processing and allows for comparison.

  (1)   *d = default.*   Selects default portion of image for histogram computation (approximately 90% of image).

  (2)   *r = rectangle.*   Displays rectangle superimposed on image on video monitor. Change portion of image used for histogram computation by altering rectangle size and location. With 'Num Lock' on, use number pad keys '2', '4', '6', and '8' to move rectangle down, left, right, and up respectively. Use '1' and '3' keys to increase and decrease height. Use '7' and '9' keys to increase and decrease width. Hit 's' to exit rectangle routine.

  (3)   *l = com linhist.*   Computes histogram of image processed by linear LUT. Displays "COMPUTING HISTOGRAM" message until done.

  (4)   *m = com modhist.*   Computes histogram of image processed by modified LUT. Displays "COMPUTING HISTOGRAM" message until done.

  (5)   *d = dis linhist.*   Displays histogram computed above using image processed by linear lookup table. Unprocessed image shown on video monitor.

  (6)   *e = dis modhist.*   Displays histogram computed above using image processed by modified lookup table. Processed image shown on video monitor.

  (7)   *s = stop.*   Exit histogram routine.

10

d. e = *equalize*

Performs histogram equalization with update on command or automatically at specified intervals. Displays resulting lookup table after each update.

(1) d = *default*. Selects default portion of image to use for equalization (approximately 90% of image).

(2) r = *rectangle*. Allows use of rectangle to specify portion of image to be used as described in histogram rectangle routine above (paragraph 12.c.(2)).

(3) c = *continuous update*. Selects automatic update of lookup table at specified intervals. Prompts for desired interval. Hit 's' to exit equalization routine from this mode.

(4) m = *manual update*. Selects lookup table update on command.

(a) u = update— Performs new equalization and updates lookup table.

(b) c = changeparam— Returns to default/rectangle portion of image options for changing parameters.

(c) f = freezeframe— Acquires and displays a single frame (snap).

(d) g = grab— Continuous acquisition and display of image frames.

(e) s = stop— Exit equalization routine from this mode.

e. l = *linlut*

Sets lookup table to linear values. Results in unprocessed image.

f. i = *invlut*

Sets lookup table to inverse values. Produces a negative image.

g. p = *loglut*

Sets lookup table to logarithmic values. Increases image brightness.

h. a = *abslut*

Inverses intensity levels greater than 127. Reduces image brightness.

i. g = *grab*

Continuous aquisition and display of image frames.

j. f = *freeze*

Aquisition and display of a single frame (snap).

k. s = *stop*

Exit analysis routine.

13. **M to store lookup table**

Stores contents of selected lookup table to disk. Prompts input of filename (including path if desired).

14. **N to read lookup table**

Reads lookup table values from disk to lookup table they were stored from. Prompts input of filename (including path if desired).

15. **O to select output lookup table**

Selects the output lookup table to perform modifications on and for display in the analysis routine. When used in conjunction with 'P' (select input lookup table) allows for processing through two modified lookup tables.

16. **P to select input lookup table**

Selects the input lookup table to perform modifications on and for display in the analysis routine. When used in conjunction with 'O' (select output lookup table) allows for processing through two modified lookup tables.

17. **Q for zoom**

Enlarges chosen area of image. Provides moveable rectangle to select area for zoom. With "Num Lock" on use number pad keys '2', '4', '6', and '8' to move rectangle down, left, right, and up respectively. Hit 'z' to stop rectangle and fix/zoom image. Hit 'm' to return to main menu.

18. **R for unzoom**

Returns image to normal state.

19. **S for sharpen**

Sharpens fixed image using a high pass filter. May be used on zoomed image.

20. **T for low pass**

Performs a low pass filter operation on a fixed image. Reduces high frequency noise. Blurs the image. May be used on zoomed image.

21. **U for edge detector**

Performs Sobel edge detector operation on a fixed image. Displays detected edges. May be used on zoomed image.

22. **V for image average**

Averages specified number of image frames and displays results. Prompts input of number of frames to average.

23. **W for framegrabber off and exit program**

Terminates program.

APPENDIX A.   DIGITAL IMAGE PROCESSING PRIMER

A.   GENERAL

This appendix provides the reader with some background on the basics of digital image processing. It describes the makeup of a digital image, including the concept of pixels and how gray level shading is accomplished. It also describes the histogram, a basic tool in the analysis of a digital image. Finally it introduces the lookup table, which is the primary image processing tool used in the "Menu" program.

B.   THE DIGITAL IMAGE

Think about a black and white photograph. Suppose you were to overlay a grid on it which is 512 squares across by 512 squares down. The picture is divided into 512 x 512 = 262,144 tiny squares. Each square is called a pixel. Now look at an individual pixel to see what color it is. If it is black it will be assigned the lowest number, intensity level 0. If it is white it will be assigned the highest number, intensity level 255. Different shades of gray will be assigned intensity levels between 0 and 255, with lower numbers for darker grays and higher numbers for lighter grays. Once the image has been broken up into pixels and each pixel has been assigned an intensity level, it is said to be digitized. It's intensity levels are then stored in order somewhere in the computer. In the case of the framegrabber it is placed into frame memory (either A or B) for processing and/or passing on to the monitor.

C.   THE HISTOGRAM

Now let's look at our digitized image and count how many black pixels (intensity level 0) are in it. Then we'll count the dark, dark grays (intensity level 1), the dark grays (intensity level 2), and so on, all the way up to the whites (intensity level 255). When we are finished we will have analyzed the image with respect to gray level content. A plot of this gray level content is called a histogram. A histogram is normally plotted as a bar graph, with the intensity levels (0 to 255) plotted across the bottom, and the number of pixels which have each intensity plotted as a vertical bar (see figure 1). The "Menu" program has a routine which allows you to compute and display the histogram of an image. The histogram values are also used in an important lookup table modification technique, the histogram equalization.
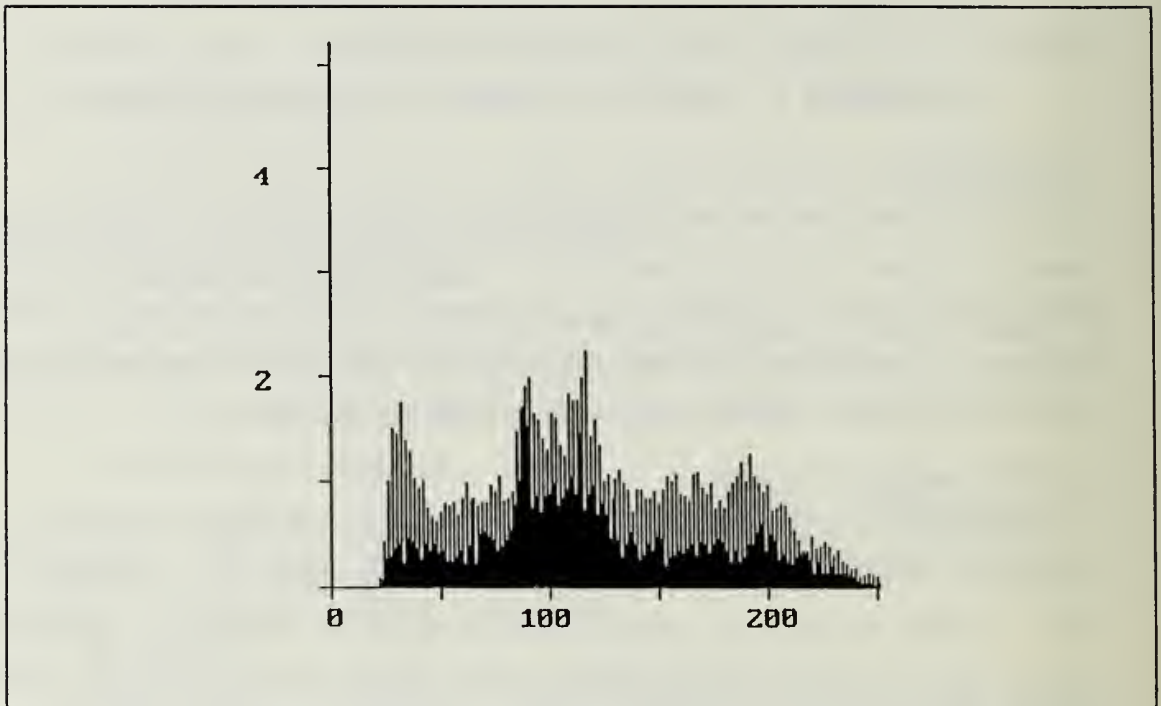
Figure 1. Example of Histogram

D. THE LOOKUP TABLE

A lookup table provides a way to change all pixels of a particular intensity level to another intensity level. The table has 256 possible input values (one for each possible gray level in the original image) and a corresponding output value for each input. Lookup tables are normally plotted graphically with the input values across the horizontal axis and the corresponding output values on the vertical axis. A lookup table whose output values are the same as it's input values will not change the image and is called a linear lookup table. It plots as a straight line from the lower left corner to the upper right corner of the lookup table graph as shown in figure 2.

An inverse lookup table changes black pixels to white, white pixels to black, and in between values to their difference from 255. The image processed through the inverse lookup table looks like a photographic negative. We refer to it as a "negative" image. The inverse lookup table plots as a straight line from the upper left corner to the lower right corner of the graph as shown in figure 3.

A lookup table stretch is performed by setting low and/or high valued intensity levels to zero and stretching the reduced input range of values to a full scale output range.
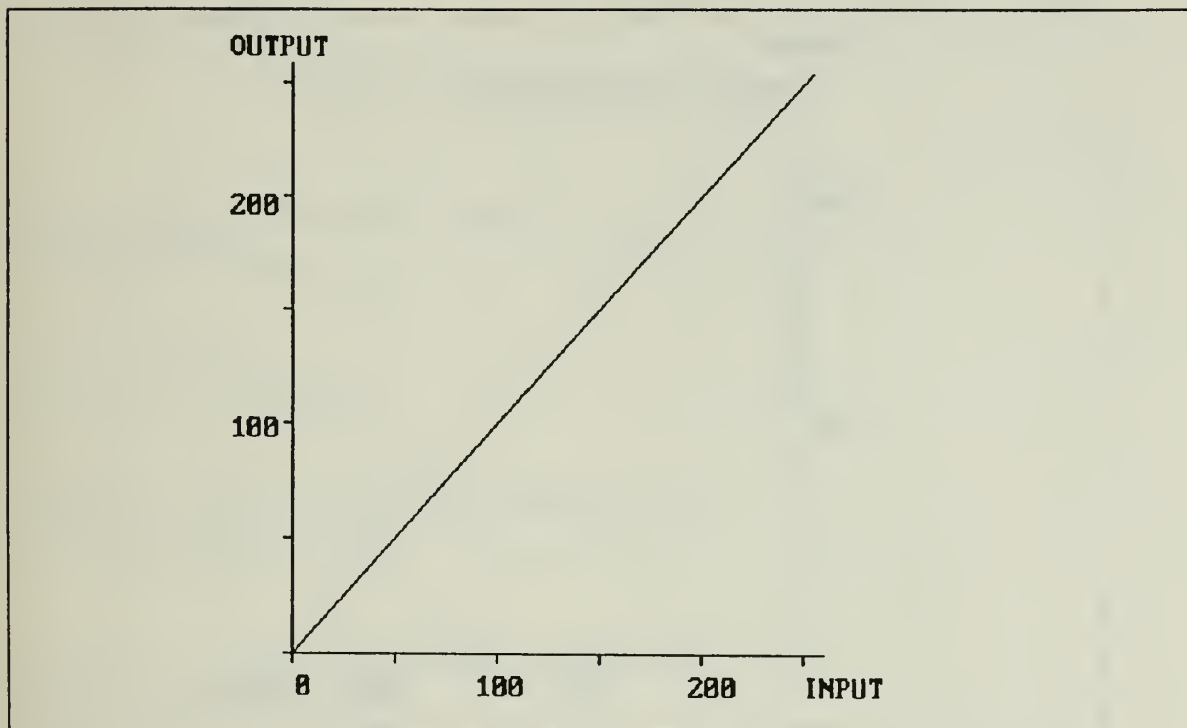
Figure 2. A Linear Lookup Table

The resulting graph is a straight line with a steeper slope than our original linear lookup table (see figure 4) and the image will have overall enhanced contrast; the steeper the slope, the greater the contrast, but for a smaller range of input values.

A more powerful, nonlinear form of stretching the lookup table is the histogram equalization technique. It performs localized stretching of the lookup table by detecting the areas of the histogram which have few or no pixel counts and using them to stretch high pixel count areas across. Histogram equalization is a very efficient means of contrast enhancement. The "Menu" program is based primarily on lookup table modification techniques and provides the user with the capability to modify the lookup table in many different ways including those described above.
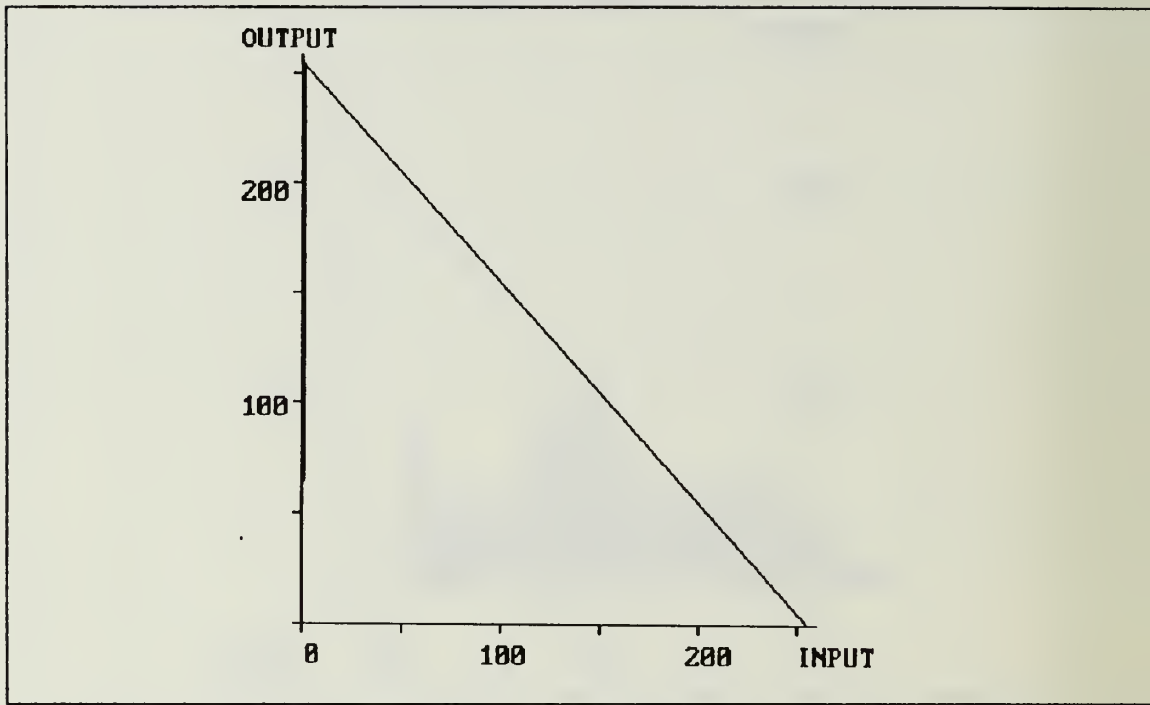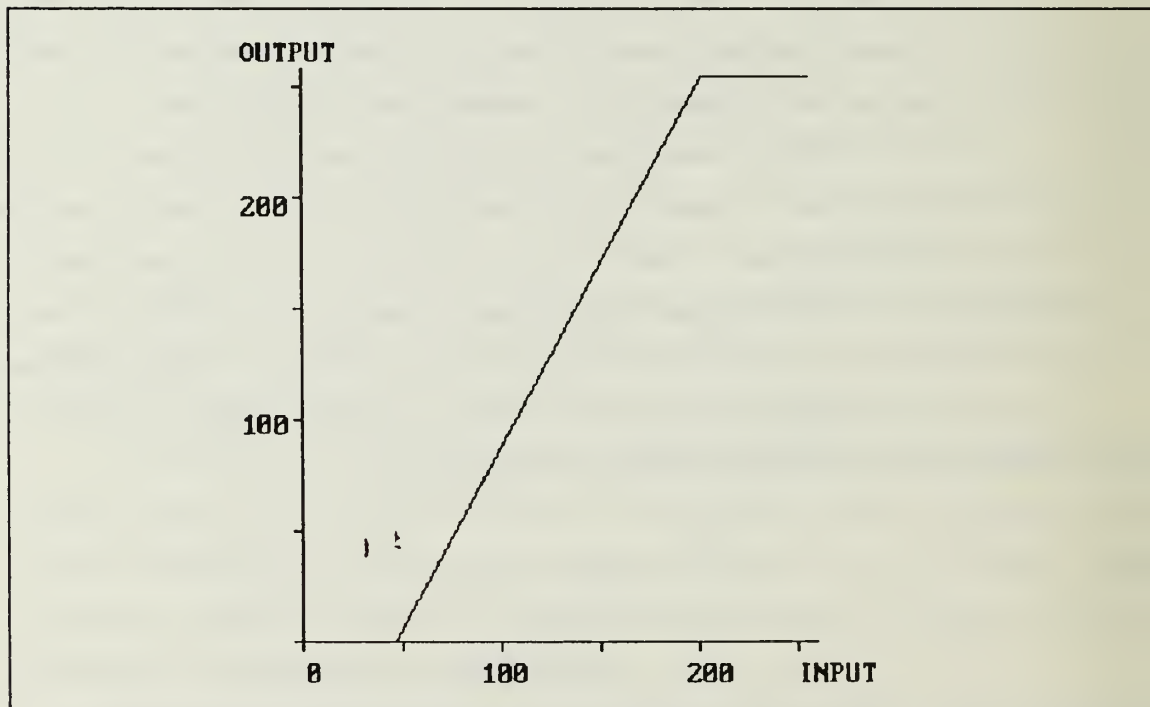
Figure 3. An Inverse Lookup Table

Figure 4. A Lookup Table Stretch

16

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