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# Color Image Processing and Object Tracking Workstation

Robert B. Klimek
*Lewis Research Center*
*Cleveland, Ohio*

and

Michael J. Paulick
*Baldwin-Wallace College*
*Berea, Ohio*

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# NASA

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# COLOR IMAGE PROCESSING AND OBJECT TRACKING WORKSTATION

Robert B. Klimek
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

and

Michael J. Paulick
Baldwin Wallace College
Berea, Ohio 44017

## SUMMARY

This report describes a system for automatic and semiautomatic tracking of objects on film or video tape which was developed to meet the needs of the microgravity combustion and fluid science experiments at NASA Lewis Research Center. The system consists of individual hardware components working under computer control to achieve a high degree of automation. The most important hardware components include a 16-mm film projector, a lens system, a video camera, an S-VHS tapedeck, a frame grabber, and some storage and output devices. Both the projector and tapedeck have a computer interface enabling remote control. Tracking software was developed to control the overall operation of the system. In the automatic mode, the main tracking program controls the projector or the tapedeck frame incrementation, grabs a frame, processes it, locates the edge of the object being tracked, and stores the coordinates in a file. This process is performed repeatedly until the last frame is reached. Three representative applications of the system are described. These applications represent typical uses of the system and include tracking the propagation of a flame front, tracking the movement of a liquid-gas interface with extremely poor visibility, and characterizing a diffusion flame according to color and shape.

## INTRODUCTION

Historically, the analysis of moving objects, whether they are flame fronts, particles, droplets, or fluid interfaces, has been done manually, usually by measuring features of an image projected on a wall. This manual analysis was tedious and suffered from many shortcomings, including poor accuracy and poor repeatability. The smoothness and reflection of the wall or projection screen was a problem, as was the stability of the projector and the poor lighting conditions. Since all the measurements were performed by hand and by eye, repeatability was always questionable. For most people, the worst part was the length of time it took to analyze a film.

More recently, film analysis was performed by projecting the image onto an internal viewing screen—an improvement over projection on a wall. The movement of objects was tracked manually with a cursor moved by the operator. The latest models even incorporated a personal computer (PC) serial interface for downloading the data. However, several shortcomings remained. The cursor was still operated by the scientist and was still dependent on the scientist's eyesight and judgement on that particular day. It was not a problem for a couple dozen frames, but after a couple hundred the operator's fatigue undoubtedly became a factor, and the reliability of the operator's judgement diminished.

The Color Image Processing and Object Tracking Workstation (Color Imaging Workstation, or CIW) was designed to overcome these deficiencies. It was designed to be fully automatic, thus removing some of the guesswork from the analysis as well as reducing the tedium of analyzing a large number of

frames. Because the image is converted to digital format, it can be processed digitally, improving the image and enabling easier detection of edges. At times it may be preferable for the user to locate the object manually with a mouse rather than have the computer do it. The CIW allows this. All of the image processing that can be performed in the automatic tracking mode can still be performed in the manual mode, at the user's discretion.

The CIW was developed and is being used by the Space Experiments Division of the NASA Lewis Research Center primarily for combustion and fluid science studies. The system is composed mostly of separately purchased components that were integrated in-house. The software to control the overall system operation as well as data acquisition and tracking was also written in-house. The CIW consists of two systems equipped with hardware and software for tracking objects on 16-mm film. The Comtal/ LW-Athena based system is the older system for which most of the current object tracking software was developed. The Matrox-Vanguard system has a newer and more advanced film transport system and has just recently become operational. Most of the software developed on the Comtal/LW-Athena system has been ported over to the Matrox-Vanguard system. Therefore, the operation and procedure for film-based tracking is the same. Each workstation is made up of a number of separate components performing a specific task. The Matrox-Vanguard system currently consists of only the film transport system (projector), a video camera, a PC, and the Matrox MVP-AT frame grabber. The Comtal/LW-Athena is a more extensive system, encompassing many more components as will be seen later in this report.

For this reason, the report describes primarily the Comtal/LW-Athena system. Its main purpose is to convert 16-mm film or video frames to digital image format with minimal image degradation. Once in digital form, the workstation can be used to process the image digitally, whether to increase contrast, to extract certain colors from the image, or to enhance the visibility of a particular feature of interest in the image. A measurement package allows the user to measure the image, including line lengths and areas. The image then can be annotated with headings and labels. All of this is done with menu-driven software. Finally, the image can be printed on a color printer.

## SYSTEM DESCRIPTION

The CIW includes several discrete components as illustrated in figure 1. The following two sections briefly explain the signal flow in the system diagram. The system can track objects on either 16-mm film or VHS/S-VHS tape. The Film Analysis System section describes the components used when 16-mm film is analyzed, and the Video Tape Analysis System section describes the components used when a video tape is analyzed. Both are actually part of the same CIW, with the only difference being whether the frame grabber gets the video signal from the tapedeck or the video camera.

### Film Analysis System

The film image is projected by an LW-Athena 4500 projector through a Laird multiplexer lens system where the field lens creates an areal image in the gap between the two lenses. The video camera lens is focused on the areal image, thus capturing the scene on film. This method of projecting and imaging the film is considered superior to the one commonly used in less-expensive systems where the image is projected and the video camera lens is focused on a ground glass plate.[1] The use of an areal image avoids the color distortion and speckly image degradation associated with ground glass.

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[1] It is not, however, better than the video camera focusing directly on the film, as is done with some of the latest systems.

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A Sony DXC-3000, a three-chip CCD camera, separates the image into three color components and converts them into analog electrical (video) signals that are fed into the camera CCU (camera control unit). The CCU (not shown in fig. 1) performs some analog processing and can be used to adjust the video signal so that it is optimum for a given set of image conditions. The CCU outputs separate red, green, and blue (RGB) video signals into the image processor, which digitizes the video image. The camera head rests on an Oriel two-axis translation stage that can move the camera along the x and y axes of the image. The translation stage can be used with the zoom lens to enlarge areas of film that are not near the center of the frame.

The image processor is a Comtal/3M Vision Lab II-T with a spatial resolution of 512x480 pixels and a color resolution of 24 bits. The image processor consists of three ISA-type cards that reside in a personal computer. The image can then be altered (enhanced preferably) using the software available. The image processor then converts the image back to an analog video signal and outputs it to a video monitor, a Conrac 7241. Two hardcopy output devices are connected to the system: the Kodak XL-7700, a high-quality color printer, and a lower quality Seiko CH-5303 thermal wax printer. The image can be stored either on the computer's hard disk, a 44 MB per cartridge Bernoulli drive, or for a large amount of data, on an optical disk drive. The PC controls the operation of the projector in the automatic and semiautomatic object-tracking modes. The projector can also be controlled manually.

## Video Tape Analysis System

The tapedeck (Panasonic 7300) can be used in exactly the same way as the projector and a video camera combined. The image processor readily accepts the tapedeck output. The tapedeck, by using a commercially available PC interface, can also be automatically incremented under the PC control. VHS as well as S-VHS tapes can be analyzed. Once the image processor grabs a frame from the tapedeck, it can be enhanced, displayed on a monitor, or output to a printer in the same way as a film image. For a more detailed explanation of the individual components described, refer to appendix A.

## OBJECT TRACKING SOFTWARE

Probably the most important and useful aspect of the CIW is its capability to track objects from film or video automatically or semiautomatically. These objects can be flame fronts, moving liquid droplets, or liquid interfaces, just to name a few. In addition, the system can be used for studying other phenomena, such as the characterization of object shape or color.

## Track1

A program named "track1" was developed to track objects. This program was written specifically for the type of problems encountered in many of microgravity-based combustion and fluid science studies. Some of these problems may be related to color nonuniformity, poor contrast, noisy signal, uneven background illumination, changes in the edge characteristics with time, or reflection from the container window.

This general program evolved from several predecessors, each designed to tackle only one of the problems mentioned. A large emphasis was placed on keeping the program and the user interface as simple as possible. The program features an interactive input screen to simplify the input of parameters, and the user-specified selections are stored in a small auxiliary file so that the next time track1 is executed it

can simply accept the previously selected configuration. The user specifies an area of interest (AOI) containing the edge to be tracked. This is done with a PC mouse. The length of steps the object moves from frame to frame determines the size of the AOI, thus a judicious selection of shape and size of the AOI is needed. The tracking can be performed in two modes, the automatic or the semiautomatic mode.

In the automatic tracking mode, the program increments the projector or the tapedeck by one or more frames, grabs a frame, performs the selected image-processing operations within the AOI, locates the edge, stores the edge location coordinates in a file, and centers the AOI around the newly found edge. This process is repeated in a loop until the last frame specified is reached. In the semiautomatic mode, the program performs all steps as in the automatic mode except locating the edge. The user specifies the edge by moving a cross hair around the screen via a mouse.

Some of the more important features of track1 are

- Projector or tapedeck control (incrementation)
- Lowpass, highpass filtering
- Edge detection
- Line and area histogram equalization
- Video frame averaging
- Film or tape frame averaging
- Thresholding
- Red, green, blue, or intensity color space tracking
- Spatial and temporal scale factors
- Relative and absolute coordinates

For a more detailed explanation of the menu input screen and its input fields, refer to appendix B.


Utility Programs

Several useful utility programs, described in more detail in appendix C, were developed to help determine tracking parameters. The first one is called profiles. It is a line profile program intended for interactively studying and exploring edges or boundaries of objects to be tracked. When the profiles program is executed, a white line is displayed (in the overlay plane) representing the location under which the profile is taken. This line can be moved and rotated with a mouse or incremented in one-pixel steps with the PC's arrow keys. The color modes can be switched between red, green, blue, intensity, and hue. By pressing the left mouse button and incrementing the film in the background, with the left button continuously depressed, the profile can be visualized live. By interrogating the boundary in question, the user can get an intuitive feel for the level of thresholding to be used and for the types of processing steps needed. This is required for input into track1 program.

The second important utility program is track0. This program is nearly identical to the track1 program except that no tracking is performed. The track0 program menu interface is missing all input fields related to object tracking. The purpose of this program is to allow the user to try different processing options (e.g., frame averaging and histogram equalization) in the same sequence and conditions as would be done with track1 program. The results can then be examined to see if the selected criteria were appropriate: that is, was the edge indeed located as the user intended?

The third utility program is the scale program. The user measures a known length in the image (usually a scale or a ruler) by using a PC mouse and inputs the units of that length to the program. The

program calculates the pixel scale factor that can be used as input to the Scale Factor option in the track1 program.

The last important utility program is Image Pro (by Media Cybernetics). It is a full menu-driven image-processing package. It can be used in conjunction with the other programs to measure and annotate the image.

## EXPERIMENTAL APPLICATION

Three experimental tests were chosen to demonstrate the usage and the capabilities of the CIW. Each of the tests was quite different from the others, employing a different set of processing functions and tracking criteria.

The first application involved tracking a propagating flame over a thin cellulosic fuel. The flame spread was fairly uniform, and the flame was clearly visible. The tracking was straightforward. The second application involved tracking a very low visibility fluid interface, which presented a much greater challenge. The liquid-gas interface was nearly indistinguishable from the background. A significant amount of processing was necessary for the computer to find the interface. The third and final application dealt with color (hue) characterization of a gas jet flame issuing from a nozzle. The hue of the flame suggested regions where particular combustion species or soot was located. This process did not involve tracking a moving object but the tracking of color shifts on a stationary object.

### Flame Spread

This droptower experiment involved the study of flame propagation over a thin solid material (ashless filter paper) in microgravity. The flame motion was linear, and the viewing conditions were not difficult, with a dark background and a bright flame clearly visible (see fig. 2). The solid surface sample was perpendicular to the plane of the paper so that the flame was viewed on edge. A small wire ignitor was located at the right end of the sample. From the ignitor, the flame propagated from right to left until the sample was fully consumed. The flame spread velocities were studied as a function of oxygen concentration and total pressure. The leading edge of the flame was the primary reaction zone in which the combustion proceeded with a distinct blue color. Processes in this region are believed to control the rate of spread. Depending on pressure or the oxygen concentration, the blue combustion region may only be partially or weakly visible. The blue component was the parameter used in the tracking process.

The first step in the tracking process was to observe the blue component line profile (using the profiles program described earlier) across the leading edge of the flame (fig. 3). As can be seen from the height of the profile curve in figure 3, the flame can be easily distinguished from the background, and thus very little image processing was needed. A 3x3 convolution lowpass filter was employed to smooth out any noise spikes, which do occasionally occur and may yield an erroneous reading. The last step was to select a threshold level on which the exact location of the flame edge would be based. The threshold was selected just above the background noise level, ensuring that the very first and faintest occurrence of the flame was detected.[2] Figure 4 shows a typical flame propagation test run.

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[2] Care must be exercised so that the selected threshold holds for the full range of flame travel. If the flame brightness varies with position, the tracking analysis may have to be split into several sections, each with a slightly different threshold, or another edge detection processing technique, such as gradient filtering, may have to be employed.

## Low-Visibility Liquid-Gas Interface

The second application chosen was the tracking of surface settling motion of an aqueous ethanol solution in a partially filled container. The visibility of the meniscus was extremely low as can be seen on the outside of the rectangular AOI in figure 5. The meniscus appears beneath the surface of the fluid because in the absence of gravity the fluid climbs the walls of the container, thus making the meniscus appear below the surface in the side view. The line profile through the unprocessed interface (fig. 6) revealed that the fluid interface could not be clearly distinguished from the background. The film grain noise was on the same level as the fluid interface itself. In this condition, the meniscus location was impossible to track. Several image frames were manually processed with the Image Pro package to get a rough idea of the processing required. It was possible to improve the image considerably with several image-processing operations. With the use of track0 and some of the other utility programs, four operations were found to be particularly important. They are listed in the following paragraphs in the order in which they were performed. All of the image processing was performed within a 100x50-pixel AOI that can be seen in figure 5. For improved visualization, the unprocessed AOI as well as the results of the four processing steps were plotted as a three-dimensional surface in figure 7.

The first processing step dealt with increasing the signal with respect to the noise. A closer study of the film revealed that the film grain noise was random from frame to frame, and therefore, the signal-to-noise ratio (S/N) could be improved with frame averaging. The number of frames used in the averaging process was kept low, compared with the 400 frames/sec at which the original event was filmed, to avoid any blurring problems due to the movement of the interface. Nine was found to be an effective and sufficient number of frames for averaging, above which the S/N improvement was limited. Other similar experiments performed with ethanol solutions required as many as 14 frame averages. The effect of frame averaging is illustrated in figure 7(b).

The frame averaging helped immensely, but some noise still persisted (fig. 7(b)). The AOI was low-pass filtered with a 5x5 convolution filter to reduce the noise level further. This filtering caused the remaining noise spikes to be averaged in with the neighborhood data. The smoothing effect of a lowpass-processed fluid interface is shown in figure 7(c).

The lowpass filtering cleaned up the noise in the image very well. However, because of the uneven background illumination, the intensity levels of the fluid interface were higher at the left side of the AOI than at the right side, as can be seen by the slant of the surface in figure 7(b) and (c). This prevented the program from correctly finding the center of the interface. Even though a substantial amount of noise was eliminated, the fluid interface was still very weak (faint), making identification of the interface still difficult. The technique that increased the image contrast the most was a histogram equalization. This technique attempts to remap the intensity levels uniformly over the entire available intensity range. However, the area histogram equalization only accentuated the problem of the uneven background illumination, making the slant in the intensity levels across the AOI (fig. 7(c)) even more pronounced. This problem was overcome with a line histogram equalization perpendicular to the fluid interface (vertical). That is, a line histogram equalization was performed on each column of pixels in the AOI. The effect of this equalization is shown in figure 7(d).

A lowpass filter was employed once again to smooth out any leftover noise spikes that could be generated spuriously by the histogram equalization. This final step used a 3x3 convolution lowpass filter and is shown in figure 7(e). A line profile across this resultant interface area is shown in figure 8. It is easy to see that tracking the processed interface can be much easier than tracking the unprocessed one in figure 6. The surface settling motion tracked automatically by the processor is shown in figure 9. The vert-

ical lines indicate missed points where the interface could not be correctly identified. The settling history of figure 9 reveals high-frequency oscillations due to the release mechanism of the particular drop tower, whereas the lower frequencies are the resonant frequencies for the liquid surface.

### Flame Color Characterization

The third application chosen was the characterization of methane diffusion flame colors. The flame properties, including color and color distribution, depended heavily on the amount of oxygen supplied. The colors indicated distinct combustion regions in which different combustion reactions proceeded. Each color also indicated the temperature and the amount of soot present.

A decision was made to perform the color characterization in the hue-saturation-intensity (HSI) space with only the hue component used in the analysis. This greatly simplified the analysis since only one component was needed to describe the color instead of three, as is the case in RGB space. The hue color range of $2\pi$ rad was divided evenly into six or more segments, and each segment was assigned a color (pseudocolor). A program was written to generate the flame region contour lines. This was done by locating the pseudocolor boundaries and storing the boundary coordinates in a file so that the pseudocolor outline could be graphed for a quantitative analysis. Figure 10 shows the unprocessed flame in the center, the pseudocolored version on the left, and the flame boundary contours on the right.

## CONCLUDING REMARKS

The Color Image Processing and Object Tracking Workstation (Color Imaging Workstation, or CIW) has become an important tool in film and video tape analysis. The automation of the system removes much of the tedium of tracking objects manually as was done in the past. Moreover, much of the guesswork has shifted from the operator to the computer, improving the accuracy and reproducibility of the measurement. Since the image is converted into a digital format, a more sophisticated tracking analysis can be performed. Digital image processing can be employed to enhance the visibility of features being tracked, thus allowing the tracking of objects that would have been nearly impossible before. The CIW also can be used for work other than tracking object movements, such as color characterization (discussed earlier in this report) or measuring the progression in the change of an object's size.

The use of the CIW has increased significantly since its introduction, and as more specialized software is developed, its use will undoubtedly increase further.

## ACKNOWLEDGMENTS

# APPENDIX A

## INDIVIDUAL COMPONENTS

An explanation of the individual components in figure 1 is given here. Also where pertinent, a mention is made on where and how the component fits in the overall system.

### 16-mm Analysis Projector

The LW-Athena 4500 performs all standard analysis projector functions. The PC interface, which allows remote control of the projector, was built by Comtal Corp., also the provider of the image processor. It uses LPT2, the second parallel port, to implement the interface.
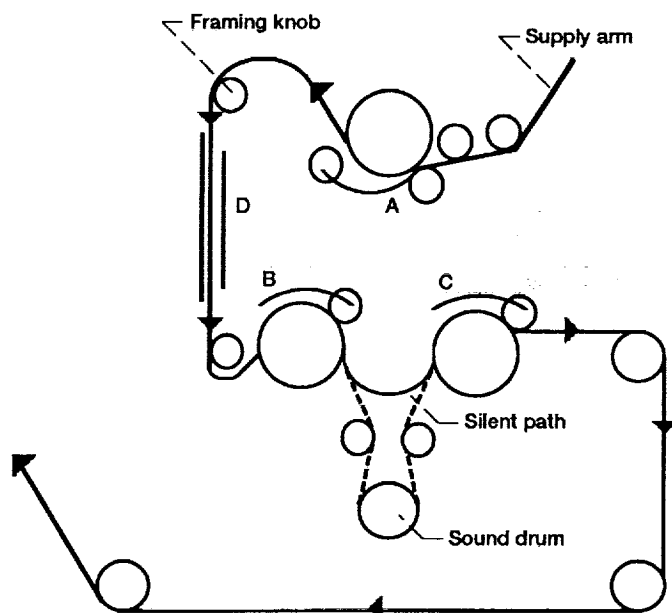


Threading Procedure

(1) Turn the power on so that the claw pins are retracted.
(2) Press the FWD (forward) button and then the Motor Stop button.
(3) Place the film on the supply arm and the empty reel on the takeup arm.
(4) Open the sprocket clamps A, B, and C and the aperture gate D.
(5) Thread the film according to the diagram. Be sure the film perforations fit on the teeth of the sprockets.
(6) Close the sprocket clamps A, B, and C.
(7) Be sure the film is between the guide rails of the aperture.
(8) Close gate D.
(9) Attach the film to the takeup reel.
(10) Press the FWD button; press the Single Frame button several times to check for the correct film transport operation.

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## Lens System

The Laird 5645 multiplexer is distributed by LW-Athena under Athena's name along with the projector and the pedestal. It consists of a mirror and a biconvex lens system onto which the frame is imaged. The multiplexer can accept an image from a slide projector mounted opposite to the analysis projector. Currently, it is set up for single-input operation only.

## Video Camera

The Sony DXC-3000 camera head with CCU-M3 is the camera control unit. The video signal is input to the CCU, which can be used to process the signal by adjusting the color gains. In this manner, it can be used as a color preprocessor.

The video camera lens is a Fujinon VCL-1012BY zoom lens. The zoom can enlarge the film image without a loss of resolution. It can be operated either automatically or manually.

## Two-Axis Translation Stage

The two-axis translation stage, from Oriel, is intended to be used in conjunction with the camera zoom lens. When the lens is zoomed in on an object not in the center of the film, the translation stage is incremented to bring the object into view.

## Tapedeck

The Panasonic 7300, a VHS/S-VHS deck, was selected for its excellent remote frame control capability and for the stable image it produces when in pause mode. A computer interface allows the tapedeck to be operated remotely, including single stepping one frame at a time. When the deck is set into pause, the vertical resolution drops in half because only a field is output. The tapedeck fills in the blank lines with the previous line. Most researchers can live with this limitation since most processes (objects) being tracked move horizontally and thus are not affected by the vertical resolution decrease.

## Video Monitor

Conrac 7241, a high-resolution monitor, can accept RGB or NTSC color input. The monitor can also operate in 30-Hz interlaced or 60-Hz noninterlaced signal modes. Currently, it is set up for a 60-Hz noninterlaced signal mode, compatible with the image processor.

## Optical Disk Drive

The LaserDrive 810 has a capacity of 400 MB per cartridge. These cartridges are write-once read-many (WORM) optical disk drives so that the data cannot be physically erased from the disk, only from the directory.

## Bernoulli Disk Drive

The Iomega Bernoulli Box II has a capacity of 44 MB per cartridge. The Bernoulli cartridges are erasable (read/write) with access times comparable to those of a hard disk.

## Kodak Color Printer

The high-quality color printer, model XL-7700, is used where the best image quality is required. The XL-7700 communicates with the PC via a general-purpose interface bus (GPIB) interface. The prints cost $5 a piece, so printing should be used with discretion.

## Seiko Color Printer

The thermal wax printer, model CH-5303, is an average-quality hard copy output device. It complements the XL-7700 since the cost per print is only about 25 cents.

## Color Image Processor/PC

The image processor, which is a Comtal/3M Vision Lab II-T with a resolution of 512x480 pixels, is a true-color processor (24-bit RGB). It is composed of three boards occupying slots in the computer chassis, and as such it is not physically separated as indicated in figure 1. All image processing is performed by the on-board processor (rather than by the AT processor), and all data transfers are performed on a high-speed internal bus. The AT bus is used only for communication between the processor and the PC. The image processor digitizes the RGB video signals at 30 frames/sec, and the image-processing operations are performed separately on each of the three color buffers with the software available. The image processor converts the digital image back into an RGB video signal (60-Hz noninterlaced) so that it can be displayed on a video monitor. The 60-Hz noninterlaced standard greatly reduces screen flicker and is commonly used in the medical imaging industry. The computer is an IBM compatible ALR 286.

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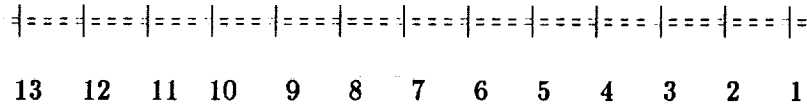
Vision Lab II-T internal slot layout viewed from the back.

Slot Description

(1) Disk controller
(2) Bernoulli card
(3) Optical drive controller
(4) Monochrome monitor/parallel port adapter
(5) Serial/parallel card (COMM1, COMM2)
(6) Second serial/parallel card port (used to control the LW-Athena projector)
(7) 286 card (CPU)—1-MB memory
(8) Empty (not usable because of the cable from the CPU card)
(9) Display processor (DPI) (Comtal/3M)
(10) Expansion memory (DPC) (Comtal/3M)
(11) Frame processor (FPI) (Comtal/3M)
(12) GPIB-AT card (communicates with the Kodak XL-7700)
(13) Empty (not usable)

# APPENDIX B

## MAIN OBJECT TRACKING SOFTWARE—Track1

Track1 is the main program on the CIW for tracking objects on film or video tape. The following sections explain how to execute the track1 program and describe its menu input screen and its individual input fields.

### To execute track1:

- Type **track1**
- Input information to the menu interface. Use arrow keys or tab key to move between fields.
- Press **F5** to begin processing, **ESC** to abort.
- Locate the edge to be tracked by rubberbanding a box (AOI) around the edge using a mouse.
- To start tracking, press the center mouse button (or the left button if you are using a two-button mouse).
- Press **ESC** to stop tracking.

### Track1 Menu Interface

When the track1 program is executed, the first thing the user sees is an interactive input screen or menu interface, prompting for input. This section explains the menu interface in detail. The menu interface input screen is shown below as it appears on the computer screen.

```
Datafile Name   [                    ]

          Input Mode   (R,N)      [N] = NTSC
          Color   (R,G,B,I)       [R]
     Lowpass Filter   (Y,N)       [Y]              Kernel Size   (3,5)     [3]
    Highpass Filter   (Y,N)       [Y]
     Roberts Filter   (Y,N)       [Y]
       Sobel Filter   (Y,N)       [Y]
   Histogram Equal.   (Y,N)       [Y]              Type   (N,H,V)     [N]
     Lowpass Filter   (Y,N)       [Y]
    Threshold Value (1-255)     [128]
      Edge Location   (A,M)       [A]         Tracking Side   (L,R,T,B)     [L]
                                              Type of Tracking   (1,2)     [2]
    Frame Step Rate  (1-25)      [05]
          Frame Speed Factor  [0001.000]
                 Scale Factor  [0001.000]
    Screen Coordinates   (Y,N)   [N]
Average Acquired Frames  (Y,N)   [Y]      Number   (2-25)     [3]
   Average Media Frames  (Y,N)   [Y]      Number   (2-9)      [5]

      <ESC> = Quit Program      <F5> = Begin Tracking
```

The individual input fields from the menu interface input screen are described in detail in the following list. Note that all filtering processes use convolution filtering and that all image-processing operations are performed on an AOI.

Datafile Name [ ]

The Datafile Name is the name of the file to which the resultant tracking data are written. A directory path may be included.

Input Mode (R,N)

The Input Mode is the video signal input to the frame grabber.

- R selects RGB mode. Selecting R initializes the program for film-projector operation.
- N selects NTSC mode. Selecting N initializes the program for tapedeck operation.

Color (R,G,B,I)

The Color option controls which color plane is to be processed; that is, which color is involved in the tracking process.

- R selects the red color plane.
- G selects the green color plane.
- B selects the blue color plane.
- I selects average intensity of the three color planes;
  $I = (R + G + B)/3$.

Lowpass Filter (Y,N)

Selecting this option causes the AOI to be lowpass filtered. It is generally recommended to lowpass filter the image before other operations are performed to reduce the chance of error due to spurious noise spikes.

Kernel Size (3,5)
- "3" selects a 3x3 kernel.
- "5" selects a 5x5 kernel. This causes a more severe smoothing effect.

Highpass Filter (Y,N)

Selecting this option causes the AOI to be highpass filtered.

Roberts Filter (Y,N)

This option will cause the Roberts gradient edge detect filter to be executed on the AOI.

Sobel Filter (Y,N)

This option will cause the Sobel (unsharp masking) edge detect filter to be executed on the AOI.

Histogram Equal. (Y,N)

Selecting this option will perform histogram equalization on the AOI.

Type (N,H,V)
- "N" selects an area histogram equalization.
- "H" selects a horizontal line histogram equalization.
- "V" selects a vertical line histogram equalization.

Lowpass Filter (Y,N)

This second Lowpass Filter option is the same as the 3x3 lowpass filter option mentioned earlier. It is included to smooth the results of any previous operations, as a final step before thresholding.

Threshold Value (1-255)

The Threshold Value is a number (gray level) from 1-255 that represents a cutoff on which the tracking is based. All of the image processing is done only to more clearly differentiate the edge from the background, so that the threshold can be set more easily. Each pixel intensity value is compared with the threshold value. If a pixel intensity is lower than the threshold value, then the pixel is set to 0; otherwise, the pixel is set to 255.

Edge Location (A,M)

This option controls the type of edge detection used to locate an edge.
- "A" selects automatic edge location. The computer scans the AOI, searching for an edge that meets the threshold criteria.
- "M" selects manual edge location. In this mode, the user can place a small cross hair on the edge with a mouse.

Tracking Side (L,R,T,B)

The Tracking Side is the side of the object where the tracking cross hair will be placed. It is usually the direction in which the object to be tracked is moving.
- "L" selects the left side.
- "R" selects the right side.
- "T" selects the top.
- "B" selects the bottom.

Type of Tracking (1,2)

This option controls the movement of the tracking box on the screen when automatic mode is selected.
- "1" selects one-dimensional tracking. The tracking box will move along the x or y axis only (but not both) depending on the Tracking Side selected.
- "2" selects two-dimensional tracking. The tracking box may move in any direction within the boundaries of the screen.

Frame Step Rate (1-25)

The Frame Step Rate is the number of frames to increment after each frame is processed. For example, selecting "2" will cause every other frame to be processed. This number must be from 1 to 25.

Frame Speed Factor [0001.000]

The Frame Speed Factor is basically a time-scale factor. The Frame Speed Factor is multiplied by the frame number, and the result is written to the data file. Thus, if the film was recorded at 100 frames/sec, the user may choose to enter a Frame Speed Factor of 0.01, and all frames will be numbered in terms of time in hundredths of a second. A Speed Factor of 1.0 will cause the frame number to be written to the data file.

Scale Factor [0001.000]

The Scale Factor is a length scale factor used so that the position data can be recorded in user units. The Scale Factor is the measure in actual units which equals one pixel on the screen. It is multiplied by the position data, and the result is written to the data file. A Scale Factor of 1.0 will cause the position data in pixels to be written to the data file.

Screen Coordinates (Y,N)

    If Screen Coordinates are selected, the position data will be recorded in the actual screen coordinates. If Screen Coordinates are not selected, relative coordinates will be used for the position data, referenced to the first point in the data set. This function is affected by the Scale Factor.

Average Acquired Frames (Y,N)

    Average Acquired Frames refers to averaging of video frames. The frame grabber will acquire (grab) the same film frame multiple times and average them. This reduces random noise generated by external sources, such as vibration of the projector or the analog-to-digital (A/D) conversion.

    Number (2-25)

        This refers to the number of times the frame grabber will grab a single film or tape frame.

Average Media Frames (Y,N)

    Average Media Frames refers to averaging film or video tape frames. This process should only be used with very slow moving objects since it can blur the image.

    Number (2-9)

        This refers to the number of media frames to be averaged together.

APPENDIX C

UTILITY PROGRAMS

Three main utility programs are presented. These utility programs were developed to help determine some of the parameters needed as input to the track1 program. Each utility program performs a specific task and should be used as needed. This section demonstrates how each utility program is executed and briefly explains the various input options. A very important utility program, track0, has been omitted from this section since it has a user input screen very similar to that of track1, which was explained earlier.

Profiles

This utility generates a line profile.

To execute:

- Acquire an image; the image should be displayed on the monitor.
- Type **profiles**.
- A box outline appears on the monitor screen. This is the location where the profile graph will be displayed. Using a mouse, position the box where desired. Press the center button.
- Answer the prompt "Enter parameter to be plotted (r,g,b,i, or h)"-the parameters in parentheses stand for red, green, blue, intensity, and hue respectively.
- Position the line by moving a mouse. Follow the instructions on the screen for stretching and rotating the line.
- Press the center (or left) button to exit.

Scale

This utility generates a scale factor that can be used by the track1 program. The value of the scale factor is equivalent to a unit length of one pixel. This utility only needs to be executed if the coordinates of the tracked object are to be in real units instead of pixels.

To execute:

- Acquire an image that contains a known length, such as a ruler.
- Type **scale**.
- Follow the screen directions for moving and stretching a line. Press the center button when done.
- Answer the prompt "Enter actual length of line:" type in the length over which the line was stretched, in user units.
- The program output: "one pixel = x.xxx", where the x.xxx is the scale factor. It is to be input to the track1 Scale Factor option.

Image Pro

Image Pro is a menu-driven true-color image-processing software package. It interacts with the image processor thus enabling display of live video or single-frame capture. Once the image is captured,

it can be processed or enhanced with the various image-processing functions the package has to offer. A list of some of the capabilities follows:

- Annotation of images including graphic primitives, such as lines, rectangles, and circles
- Measurement package—can measure in pixels or in calibrated units; measures straight-line lengths, free-hand line lengths, area measurements, x and y coordinates, and ASCII file storage
- A selection of image-processing functions including
  - Convolution filtering
  - Thresholding
  - Histogram equalization
  - Contrast stretching
  - Color extraction
  - Color alteration
- Learn mode—can record keystrokes and play them back later

The Image Pro manual, concisely and sometimes graphically, illustrates all steps needed to accomplish the desired operation. Also, there is an introduction section that explains many of the basic image-processing operations.

<u>To execute:</u>

- Type i (this batch file starts Image Pro).
- Move the mouse cursor to highlight entries from the menu.
- Press the left button to select an entry.
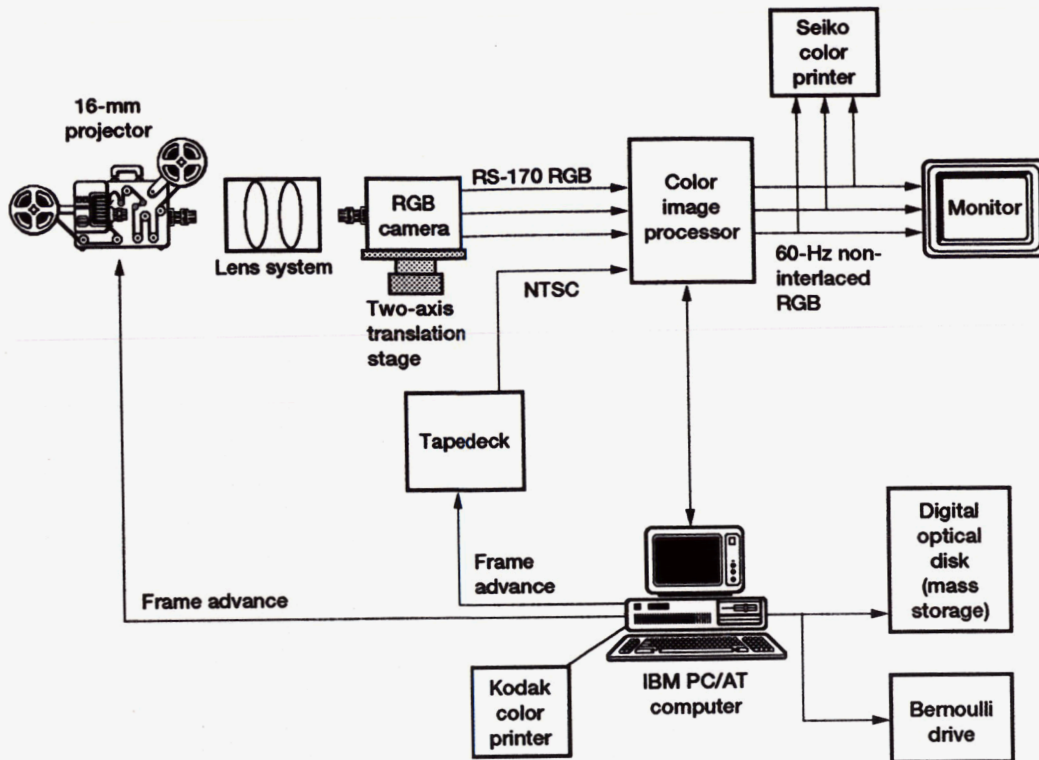
Figure 1.—Color Image Processing and Object Tracking Workstation.
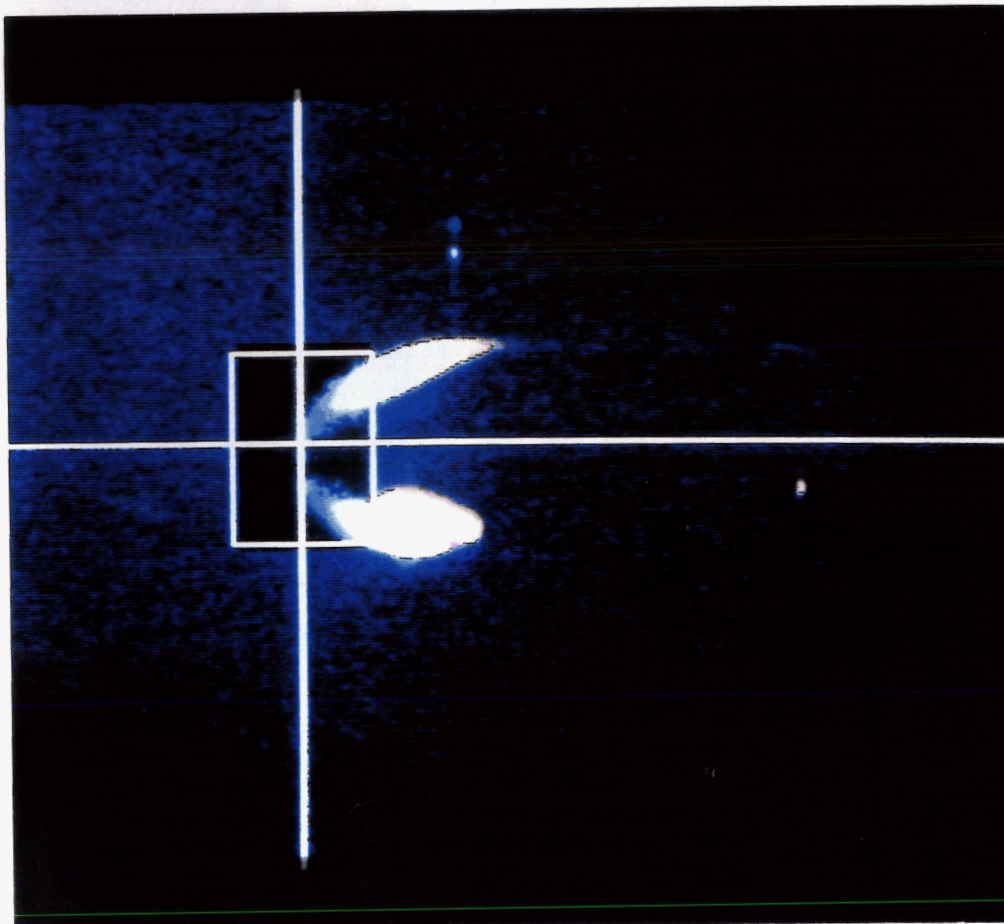


Figure 2.—Side view of flame spread over a thin fuel. An area of interest surrounds the leading edge of the flame.
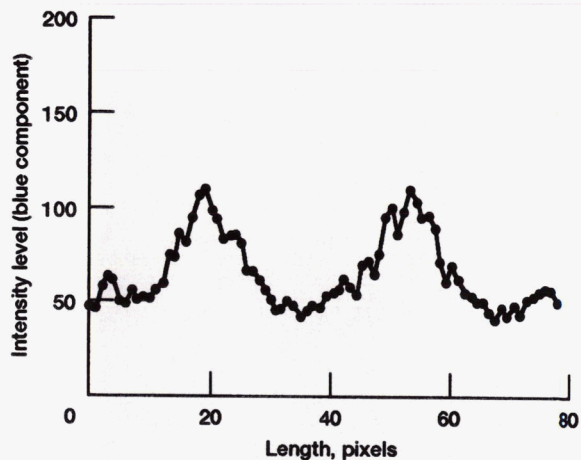
Figure 3.—Vertical line profile of the blue component across the flame front.
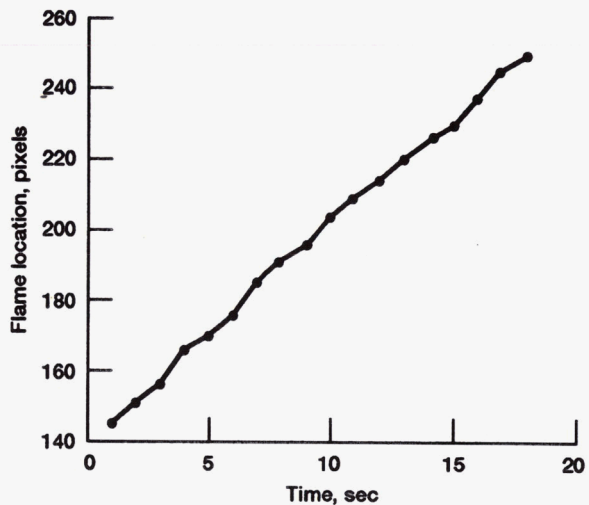


Figure 4.—Typical flame propagation data.
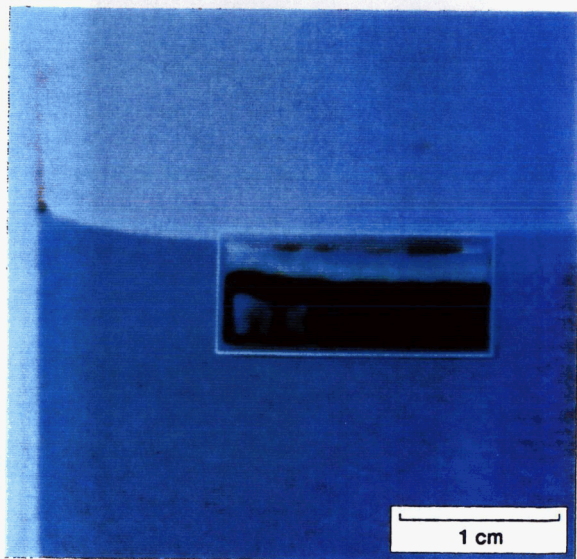


Figure 5.—Aqueous ethanol solution interface. The rectangular box at center shows the final processed interface, whereas the area just outside the box is unprocessed. Note that the meniscus is below the visible surface.
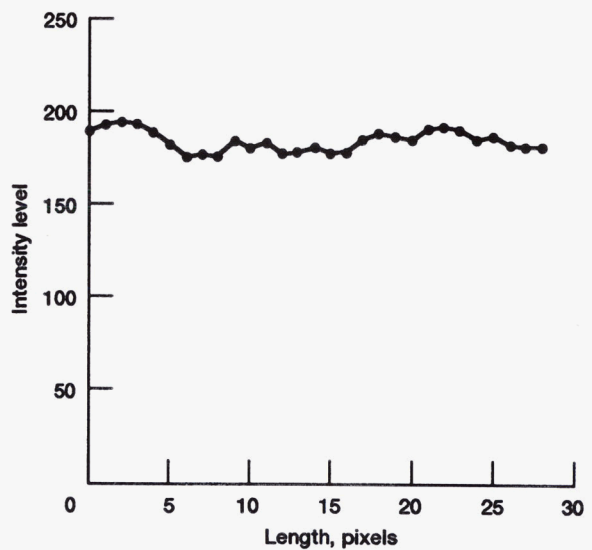


Figure 6.—Line profile across the unprocessed fluid interface.
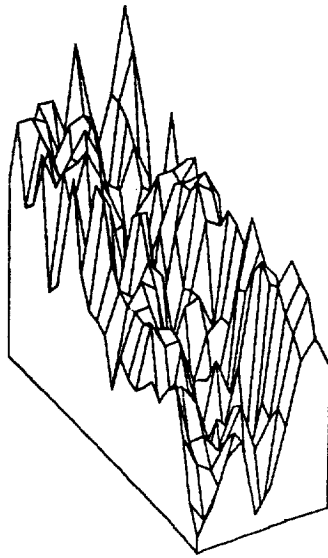
(a) Original, unprocessed area of interest.
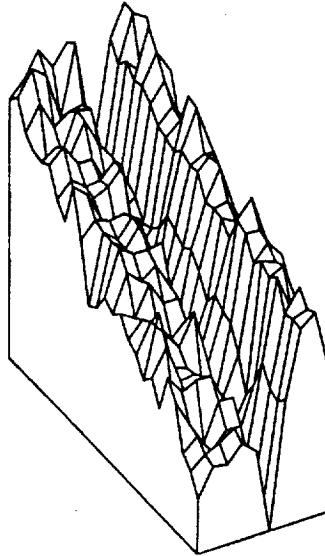
(b) Nine-frame averaging.
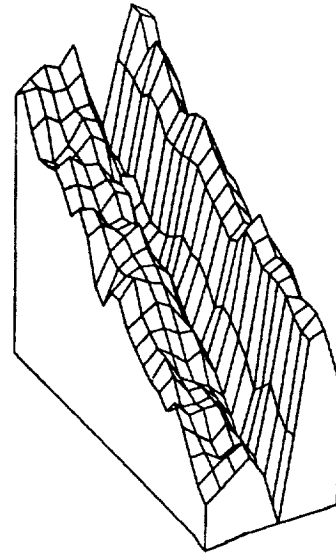
(c) Result of step (b) and lowpass filtering.
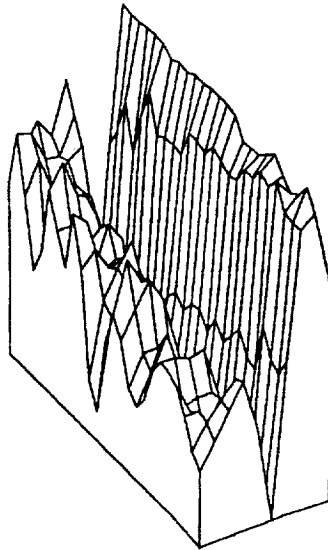
(d) Result of step (c) and line histogram equalization.
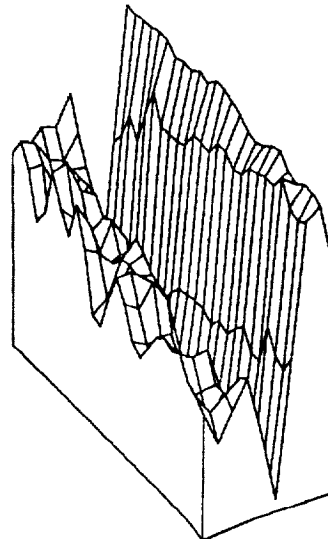
(e) The final outcome. Result of step (d) and lowpass filtering.

Figure 7.—Sequence of image processing steps performed on a 100x50-pixel area of interest and displayed as a three-dimensional surface.
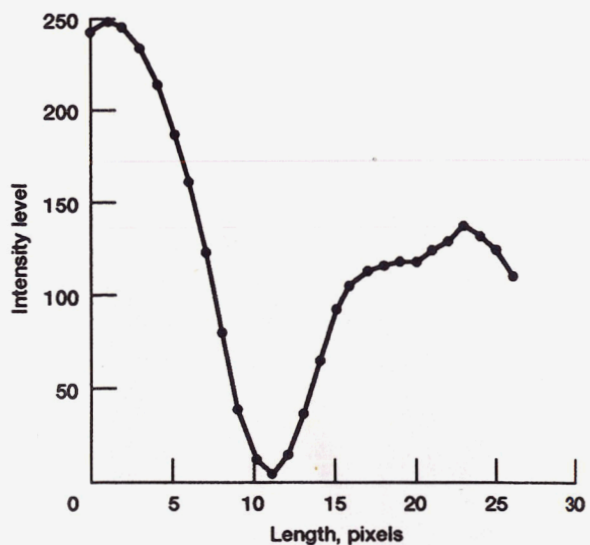
Figure 8.—Line profile across the processed fluid interface.
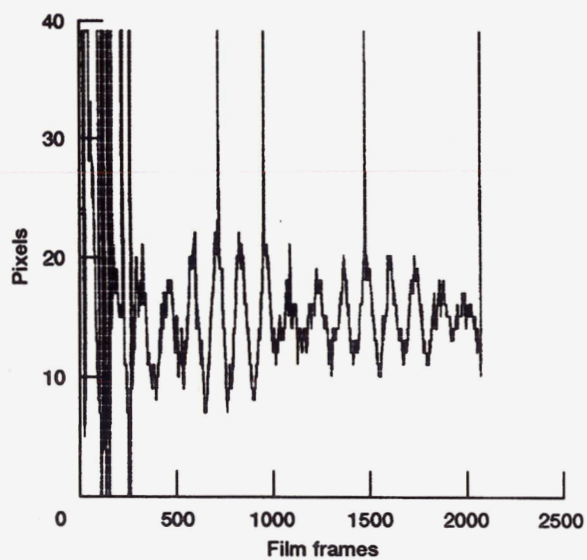


Figure 9.—Automated tracking of low-visibility surface of an aqueous ethanol solution.
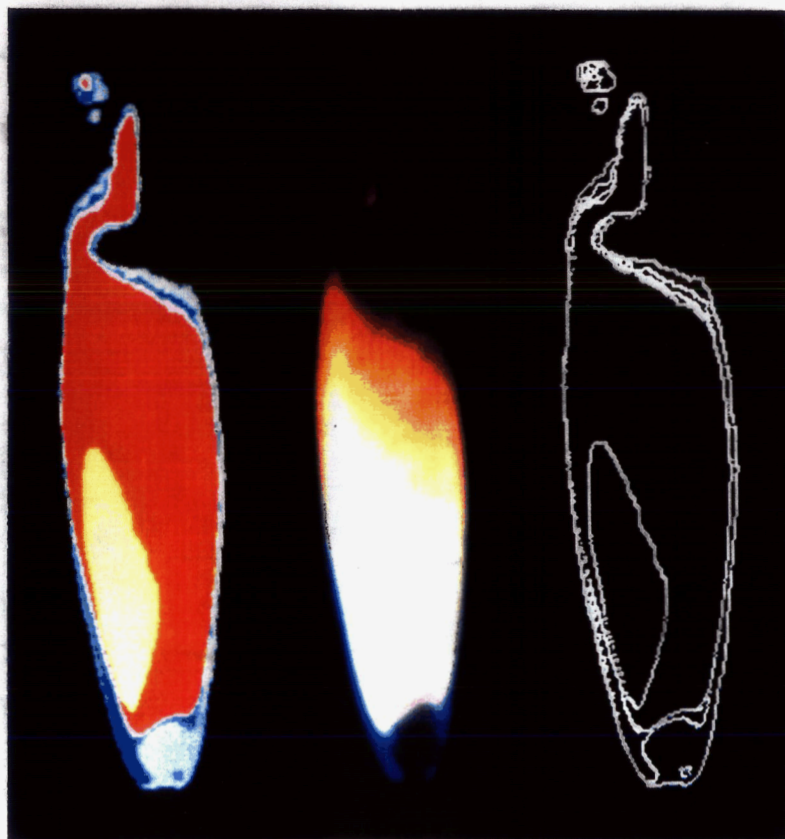


Figure 10.—Color characterization of a diffusion flame. Pseudocolored flame, original flame, and flame boundary contours (from left to right, respectively).

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Robert B. Klimek, NASA Lewis Research Center and Michael J. Paulick, Baldwin-Wallace College, 275 Eastland Road, Berea, Ohio 44017 (work funded by NASA Cooperative Agreement NCC3–206). Responsible person, Robert B. Klimek, (216) 433–2837.

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**13. ABSTRACT (Maximum 200 words)**

This report describes a system for automatic and semiautomatic tracking of objects on film or video tape which was developed to meet the needs of the microgravity combustion and fluid science experiments at NASA Lewis Research Center. The system consists of individual hardware components working under computer control to achieve a high degree of automation. The most important hardware components include 16–mm film projector, a lens system, a video camera, an S-VHS tapedeck, a frame grabber, and some storage and output devices. Both the projector and tapedeck have a computer interface enabling remote control. Tracking software was developed to control the overall operation of the system. In the automatic mode, the main tracking program controls the projector or the tapedeck frame incrementation, grabs a frame, processes it, locates the edge of the objects being tracked, and stores the coordinates in a file. This process is performed repeatedly until the last frame is reached. Three representative applications of the system are described. These applications represent typical uses of the system and include tracking the propagation of a flame front, tracking the movement of a liquid-gas interface with extremely poor visibility, and characterizing a diffusion flame according to color and shape.

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