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SUMMARY

This report describes a personal computer based system for automatic and semiautomatic tracking of objects on film or video tape, developed to meet the needs of the Microgravity Combustion and Fluids Science Research Programs at the 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 and 35-mm film transports, a high resolution digital camera mounted on a x-y-z micro-positioning stage, an S-VHS tapedeck, an Hi8 tapedeck, video laserdisk, and a framegrabber. All of the image input devices are remotely controlled by a computer.

Software was developed to integrate the overall operation of the system including device frame incrementation, grabbing of image frames, image processing of the object's neighborhood, locating the position of the object being tracked, and storing the coordinates in a file. This process is performed repeatedly until the last frame is reached. Several different tracking methods are supported.

To illustrate the process, two representative applications of the system are described. These applications represent typical uses of the system and include tracking the propagation of a flame front and tracking the movement of a liquid-gas interface with extremely poor visibility.

INTRODUCTION

Historically, the analysis of moving objects, whether they are flame fronts, particles, droplets, or fluid interfaces, was 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 few hundred the operator's fatigue undoubtedly became a factor, and the reliability and the operator's judgement diminished.

The Color Image Processing and Object Tracking System (Tracking System) 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 Tracking System 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. Several tracking methods (or modes) are implemented. A template matching method can be used as an alternate to the automated threshold-based method. The template matching techniques, including correlation and a subtractive technique, track image features rather than edges. A region parameters method can track movement of intensity-based parameters, such as intensity maximum, minimum, and mean, in a selected stationary region. The last tracking method currently implemented is the area measurement method, which can be used measure scaled or non-scaled areas.

The Tracking System was developed and is being used by the Space Experiments Division at the NASA Lewis Research Center primarily for combustion and fluid studies. The system is composed mostly of commercial off-the-shelf 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.

SYSTEM DESCRIPTION

The Tracking System consists of a number of discrete components as illustrated in Fig. 1. The Tracking System achieves the automation by integrating the discrete components into a cohesive system with a controlling program that directs the entire operation. The image input devices are controlled via a "smart" serial card which enables the usage of multiple ports, thus providing independent control of all devices. A framegrabber digitizes the incoming video signals and displays the output image to the secondary monitor. The system can track objects directly from 16-mm film, 35-mm film, VHS tape, S-VHS tape, Hi8 tape, or a recordable laserdisk. In addition, any other type of video tape can be tracked by copying the image data to the laserdisk video recorder and then tracking from the laserdisk.

The first step in the tracking process is to advance the image input device to the starting frame. The second step is to convert the film or video frames to digital image format with minimal image degradation. Once in digital form, the PC with an internal framegrabber is 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 so that it can be tracked more easily. The third step is to locate the object's position. Several methods for locating the object's position (or for locating various image parameters) are described later. The following Film Analysis System section describes the components used when 16 or 35-mm film is analyzed, and the Video Tape Analysis System section describes the components used when a video tape is analyzed. Both are part of the same Tracking System with the only difference being whether the framegrabber gets an analog video signal from the tapedeck or a digital video signal from a high-resolution camera.

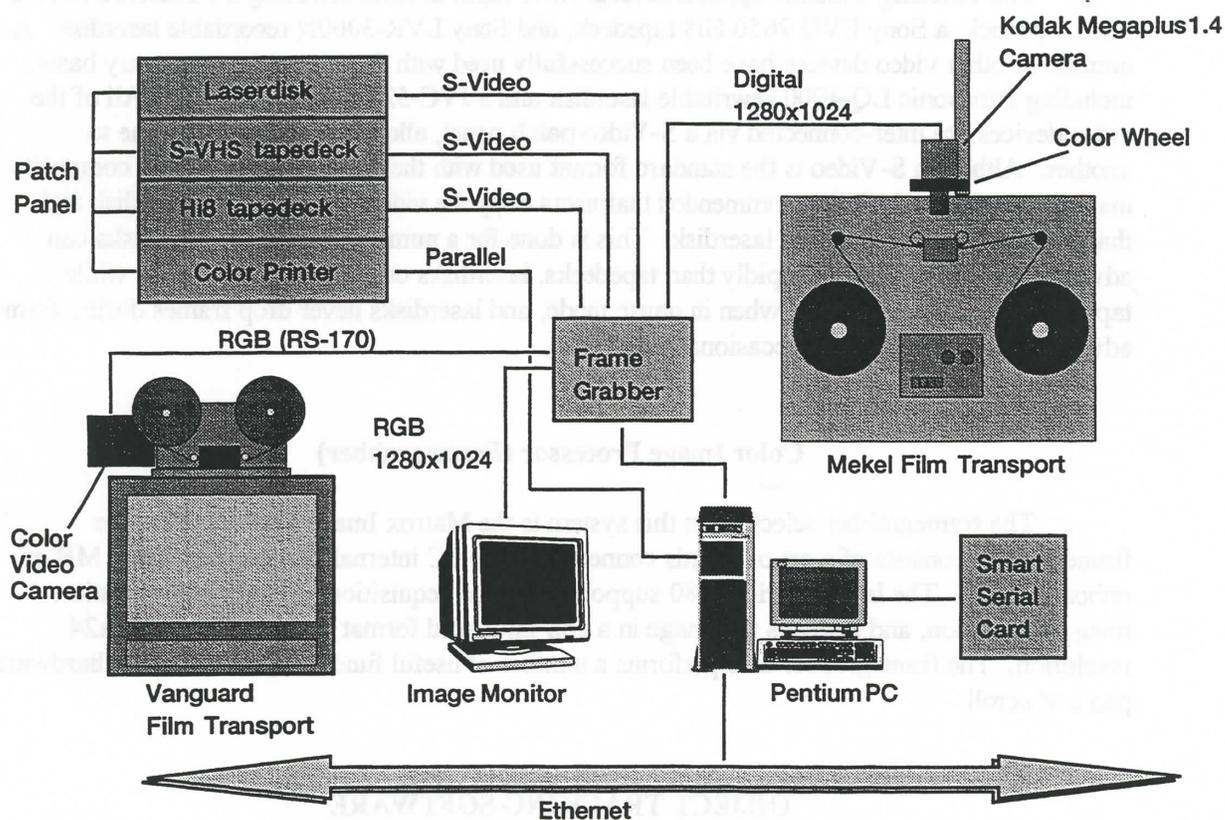


Figure 1.—Hardware configuration of Object Tracking System.

Film Analysis System

The film transport (Mekel model 31100) supports 16-mm and 35-mm film sizes by using interchangeable heads. Both heads are pin-registered, preventing any film slippage or rotation. The heads, due to their design, have a convenient feature of allowing the camera to look down directly at the film without having to resort to mirrors or prisms. The frames are digitized with a Kodak Megaplug 1.4 digital camera with a resolution of 1335x1024. Only 1280x1024 pixels are usable, as that is the maximum size handled by the framegrabber. The framegrabber has a special high-speed digital port which the camera uses. The maximum frame rate of the camera is 6 f/s,

but that speed is rarely realized in practice as it is limited by the shutter speed. The camera head is attached to a 3-axis translation stage which allows up to a 2:1 zoom by moving the camera head up or down. With the 2:1 zoom, a maximum resolution of 2560x2048 can be achieved, albeit over an area less than the full frame. A colorwheel (needed because the Megaplug 1.4 is monochrome) is located between the camera head and the lens and is used to generate a color image by rotating color filters (red, green, blue, or clear) in front of the camera before each frame is acquired. The colorwheel is also controlled by the Tracking System using a serial interface. Since most of the lamp energy is weighted towards the red (longer wavelengths), the computer compensates (balances colors) by adjusting the exposure duration for the four planes.

Video Tape Analysis System

The Tracking System supports several video input devices including a Panasonic 7300 S-VHS tapedeck, a Sony EVO 9650 Hi8 tapedeck, and Sony LVR-3000N recordable laserdisk. A number of other video devices have been successfully used with the system on temporary basis, including Panasonic LQ-4000 rewritable laserdisk and a JVC-525 S-VHS tapedeck. All of the video devices are inter-connected via a S-Video patch panel, allowing copying from one to another. Although S-Video is the standard format used with the video devices, NTSC composite may also be selected. It is recommended that users copy the video tape data to a laserdisk and that tracking be done from the laserdisk. This is done for a number of reasons: laserdisks can advance frames much more rapidly than tape decks, laserdisks can display a full frame while tape decks display only a field when in pause mode, and laserdisks never drop frames during frame advancement like tape decks occasionally do.

Color Image Processor (Framegrabber)

The framegrabber selected for this system is the Matrox Image Series 1280. The framegrabber consists of a set of boards connected to the PC internal ISA bus and has 8 MB of onboard RAM. The Image Series 1280 supports S-Video acquisition, digital high-resolution image acquisition, and displays the image in a non-interlaced format up to a 1280x1024x24 resolution. The framegrabber also performs a number of useful functions, including the hardware pan and scroll.

OBJECT TRACKING SOFTWARE

The most important and useful aspect of the Tracking System is its capability to track objects and intensity-based parameters 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.

Tracker

A Microsoft Windows-based program named "Tracker" was developed to automate the process of tracking objects and various image parameters. 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 an experiment container window. In addition, many of the objects analyzed are not objects with well defined outlines but wispy and hazy objects without hard edges, especially those related to flame and smoke studies.

There are two auxiliary software libraries used by Tracker. Most of the image processing is performed with functions from the Visilog (Noesis Vision, Inc.) function library. A number of image processing functions were also written by the authors. In addition to performing image processing, Visilog was also used to control interaction with the framegrabber, including acquiring frames and displaying them to the image monitor. Functions from Image Man (Data Techniques, Inc.) library are used to display the images to Microsoft Windows.

The Tracker program evolved from several earlier DOS-based versions¹. Tracker was written in Visual C++ and makes extensive use of the Microsoft Foundation Classes (MFC). Emphasis was placed on keeping the program user interface as simple as possible and on following accepted Windows conventions. The user interface and most of the tracking features were based on user input and suggestions. In addition to tracking objects and image parameters, the program also contains various options for performing image analysis and measurements, image processing, and controlling instruments using a serial interface.

The object tracking can be performed in two modes: automatic and semiautomatic. In the automatic tracking mode, the program increments the image input device by one or more frames, grabs a frame, performs the selected image processing operations within the user selected Area of Interest (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 or until stopped by user intervention. Four automatic tracking methods are supported: the threshold tracking, template match tracking, region parameters tracking, and the area and volume measurement tracking.

- **The Automatic Threshold Method** uses a threshold operation as the final processing step after which the object's position is determined by searching the AOI for the first occurrence of thresholded pixels in a given direction. Filtering or other image processing may be used to clean up the image before the final thresholding step is executed. The threshold may be fixed or variable based on maximum, minimum, or median intensities in the AOI. Tracking movement can be constrained to a line. Finally, a provision is made that if tracking is lost (i.e. no point is found inside the AOI), the user has the option to change tracking parameters and resume tracking, continue with the current selections assuming that the object will become visible again, or to quit tracking altogether.
- **The Template Match Method** is performed by searching an area of an image, called the search region, with a template image. The track point is the point of best match between the template and the corresponding area in the search region. Correlation and Subtractive template matching is supported.
- **The Region Parameters Method** records intensity-based parameters in a stationary (not moving) AOI as a function of time. This allows the user to make observations at a fixed point (area) in the image frame. The parameters recorded are the maximum intensity, x and y

positions of the maximum, minimum intensity, x and y positions of the minimum, and the mean intensity of all pixels inside the AOI.

- **The Area and Volume Measurement Method** calculates areas, volumes, and surfaces by lowpass filtering and thresholding the AOI and then summing up the thresholded pixels. Scaled as well as non-scaled area measurements are supported. The scaled area measurement employs a scale factor to account for distortion caused by viewing angle. The volume and surface area is calculated from the 2-d area with the assumption that the object in question is symmetric.

In the semiautomatic mode, the program performs all steps as in the automatic mode, except locating the edge. The user manually specifies the edge by moving a cross hair around the screen via a mouse. Once the object position has been specified, the program automatically advances to the next frame, the framegrabber digitizes the frame, and Tracker waits for user to specify the next object position. When tracking an object in the semiautomatic mode, sometimes it can be difficult to see where to place the cursor for exact position specification. The Tracker has a feature that helps deal with this predicament: the user can select a zoom factor to enlarge the object on the screen so that it is easier to see, and can continue tracking while in the zoom mode. If the object tracks off the screen, Tracker recalculates the display coordinates and scrolls the display area such that the object is once again centered on the screen. Depending on the zoom factor and the movement of the object, the scrolling of the zoom area may be repeated several times.

Pre-Tracking and Image Processing

The Tracker software also allows image processing to be performed on individual images before tracking is started. This allows the user to experiment with different processing options to see which would work the best in enhancing the object for successful tracking. Various tools, such as line profile, histograms, and other pixel readout utilities, may be employed to analyze and visualize the results and effects of the image processing operations. Once the user is satisfied with a particular sequence of processing functions which do the best job in enhancing the features of interest, those same processing functions can be specified for use during tracking.

Summary of Important Tracking System Features

The Tracker user interface and the tracking features are based on user inputs and the numerous suggestions which we've received over time, including various time saving shortcuts and helpful features. All of the image input devices can be controlled from the Tracker program, using pull-down menus or buttons on the button bar. Image processing can be used to enhance the object's features to help the tracking algorithm stay with the object. Frame averaging, frame subtraction, and various histogram equalization schemes are supported. A complete list of the image processing functions is given in Appendix A. Even though color images (24-bit) are captured from the input device, tracking is performed on monochrome images by extracting a single color plane (red, green, blue, or intensity) from the color image. This not only reduces the number of pixels needed to be processed, but also eliminates unwanted color components. Spatial and temporal scale factors can be used to track an object in terms of real spatial units (instead of pixels) and real time units (instead of frames). Tracking an object position can be performed in

terms of relative screen coordinates or relative to first point origin. Multiple objects can be tracked simultaneously. Tracker allows independent control of all AOI's including selection of different tracking techniques, tracking constraints, and image processing options. The tracking process can be temporarily suspended during any step of the tracking cycle. When tracking is suspended, the user has the option to change tracking parameters and resume tracking, continue with the current selections, or to quit tracking altogether. While the tracking is in progress, the incoming data points can be graphed (position vs. time) in real-time or displayed in a numeric format. An output file is generated in a convenient format for analysis/plotting/graphics. The system is connected via Ethernet to the network allowing easy transfer of data files and/or images. The Tracker program is quite flexible in terms of types of image acquisition devices it can use and where to display the acquired images. It can be used with a framegrabber or it can run in a stand-alone mode without a framegrabber. The image display can be to a framegrabber (typically) or it can be to Microsoft Windows. And finally, the complete tracking configuration, including image processing, scale factors, coordinate systems, and tracking methods can be saved to a file for future retrieval.

EXAMPLE APPLICATION

Two example combustion and fluid science experiments were chosen to demonstrate the usage and the capabilities of the Tracking System. The examples are quite different, employing a different set of processing functions and tracking criteria.

The first application involves tracking two propagating flames and the middle interaction region between the two flames. This tracking application demonstrates tracking multiple objects and constraining their motion to horizontal straight lines. This is a fairly easy tracking problem since the flame is clearly visible and the noise level is low. The second application involves tracking a very low visibility fluid interface, which presents a much greater challenge. The liquid-gas interface is nearly indistinguishable from the background. A significant amount of processing is necessary for the computer to find the interface.

Two Interacting Flames

This experiment involves the study of interaction of two flames spreading over thin surfaces in microgravity. The flame motion is linear, and the viewing conditions are not difficult, with a dark background and a bright flame clearly visible (see fig. 2). The solid surface samples are perpendicular to the plane of the paper so that the flame was viewed on edge. After ignition, the flames propagate from right to left until the sample is fully consumed. The flame spread velocities are studied as a function of oxygen concentration and total pressure.

The first step in the tracking process is to observe the blue component line profile (see fig. 3) across the leading edge of the flame. 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 is needed. A 3x3 convolution lowpass filter is employed to smooth out any noise spikes, which do occasionally occur and may yield an erroneous reading. The last step is to select a threshold level on which the exact location of the flame edge would be based. It was observed that the flame intensity stayed constant over the length of travel and thus a constant threshold would be sufficient. The threshold is selected just above the background noise level, ensuring that

the first and faintest occurrence of the flame was detected. Three different regions are tracked, the flame fronts from the upper and lower samples and the interaction region between the two flames. This is done by specifying three separate AOI's which were positioned at the appropriate locations. To ensure that the AOI's don't wander off from their selected positions on the flame, their movement is constrained to horizontal lines (i.e. the box in which the algorithm searches for the leading edge can only move along the line). The resultant data is shown in Figure 4.

Low-Visibility Liquid-Gas Interface

The second application chosen is the tracking of surface settling motion of an aqueous ethanol solution in a partially filled container. The visibility of the meniscus is extremely poor 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) reveals that the fluid interface could not be clearly distinguished from the background as the film grain noise is on the same level as the fluid interface itself. In this condition, the meniscus location is impossible to track. However, it is possible to improve the image considerably with several image processing operations. Five image processing 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 is performed within a 70x50-pixel AOI that can be seen in figure 5. For improved visualization, the unprocessed AOI as well as the results of the first four processing steps are plotted as a three-dimensional surfaces in figure 7.

The first processing step deals with increasing the signal with respect to the noise. A closer study of the film reveals that the film grain noise is 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 is kept low, compared with the 400 frames/sec at which the original event was filmed, to avoid any blurring problem due to the movement of the interface. Nine was found to be an effective number of frames for averaging, above which the S/N improvement was limited. The effect of frame averaging is illustrated in figure 7 (b).

The frame averaging helps immensely, but some noise still persists (fig. 7(b)). The AOI is lowpass filtered with a 5x5 convolution filter to reduce the noise level further. This filtering causes the remaining noise spikes to be averaged in with the neighborhood pixels. The smoothing effect on a lowpass-processed fluid interface is shown in figure 7(c).

The lowpass filtering cleans up the noise in the image very well. However, because of the uneven background illumination, the intensity levels of the fluid interface are 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 prevents the program from correctly finding the center of the interface. Even though a substantial amount of noise is eliminated, the fluid interface is still very faint, making identification of the interface still difficult. The technique that increases the image contrast the most is histogram equalization. This technique attempts to remap the intensity levels uniformly over the entire available intensity range. However, the area histogram equalization only accentuates the problem of the uneven background illuminations, making the slant in the intensity levels across the AOI (fig. 7(c)) even more pronounced. This problem is

overcome with a line histogram equalization perpendicular to the fluid interface (vertical). That is, a line histogram equalization is performed on each column of pixels in the AOI. The effect of this equalization is shown in figure 7(d).

A lowpass filter is employed once again to smooth out any leftover noise spikes that could be generated spuriously by the histogram equalization. The results of this step 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 final processing step is to use the median-inverse threshold. This adaptive threshold routine finds the maximum and minimum intensity levels in the processed AOI and sets the threshold at the midpoint. This sets all intensities below the threshold level to white and above the threshold level to black. To skip over some unwanted edge effects (noisy areas in the upper part of the AOI which are also erroneously thresholded), the search region within the AOI is decreased by 8 pixels on all sides.

The surface settling motion tracked automatically by the processor is shown in figure 9. The vertical 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 where these tests were performed, whereas the lower frequencies are the resonant frequencies for the liquid surface.

CONCLUDING REMARKS

The Color Image Processing and Object Tracking System (Tracking System) has become an important tool in film and video tape analysis of combustion and fluid science data. 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 been eliminated, 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, allowing the tracking of objects that would have been nearly impossible before. The Tracking System can also be used for analysis other than tracking object movements, such as color characterization, measuring changes in an object's size, measuring areas and volumes, or tracking intensity parameters.

ACKNOWLEDGMENTS

The authors wish to thank David Urban and Mark Weislogel for use of their data in presenting the two example applications: the interacting flame spread and the low-visibility liquid-gas interface, respectively.

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APPENDIX A

TRACKER IMAGE PROCESSING FUNCTIONS

The following list of image processing functions is supported in the Tracker program. The functions can be executed on a single image, perhaps when experimenting with enhancement techniques, or they can be used during a tracking process.

- **Threshold**

- **Normal** - sets all pixels to 0 (black) that are below or equal to the threshold value and sets all pixels to 255 (white) that are above the threshold value.
- **Inverse** - sets all pixels to 255 that are below or equal to the threshold value and sets all pixels to 0 that are above the threshold value.
- **Maximum (normal)** - finds the maximum intensity level and then thresholds based on that value (setting all values above the threshold to 255 and all values below the threshold to 0).
- **Maximum (inverse)** - finds the maximum intensity level and then thresholds based on that value (setting all values above the threshold to 0 and all values below the threshold to 255).
- **Median (normal)** - finds the median intensity level and then thresholds based on that value (setting all values above the threshold to 255 and all values below the threshold to 0). The median is defined here as $(\max + \min) / 2$.
- **Median (inverse)** - finds the median intensity level and then thresholds based on that value (setting all values above the threshold to 0 and all values below the threshold to 255). The median is defined here as $(\max + \min) / 2$.
- **Minimum (normal)** - finds the minimum intensity level and then thresholds based on that value (setting all values above the threshold to 255 and all values below the threshold to 0).
- **Minimum (inverse)** - finds the minimum intensity level and then thresholds based on that value (setting all values above the threshold to 0 and all values below the threshold to 255).
- **Threshold Mask** - performs a bandpass thresholding operation, eg. sets all values below and above a certain threshold setting to 0 and leaves the other intensities unaffected.
- **Smoothing Filters** - performs a convolution lowpass filtering operation. All filter kernel elements are 1. The kernel sizes supported are 3x3, 5x5, and 7x7.

- **Sharpening Filters** - performs a convolution sharpening operation. The kernel sizes supported are 3x3, 5x5, and 7x7.
- **Morphological Contrast** - performs a morphological type filtering operation (produces similar results to other sharpening filters).
- **Edge Detect Filters** - the following group of filters enhance object edges. They fall into two categories; gradient filters (first order derivative) and laplacian filters (2nd order derivative). Both types of filters have an effect of highlighting edges and setting all non-edge portions of an image to black.
 - **Gradient (Roberts)** - gradient filter using the Roberts convolution kernel. This filter produces a fairly thin edge lines and has little effect on highly blurred edges.
 - **Gradient (Prewitt)** - gradient filter using the Prewitt convolution kernel. This filter is an intermediate strength gradient filter and can be used in most applications. The Prewitt gradient amplitude is calculated using the Euclidean distance vector.
 - **Gradient (Sobel)** - gradient filter using the Sobel convolution kernel. This filter produces a thick edge line and has strong effect on edges.
 - **Gradient Max** - this function is identical to Gradient (Prewitt) except that amplitude is calculated using the maximums of absolute values.
 - **Recursive Gradient** - a gradient filter based on Canny-Deriche method. This is another variation of Prewitt gradient filter.
 - **Sup. Non-Local Maxima (Roberts)** - Roberts gradient filter with a suppression of non-local maxima. This method takes a Roberts gradient and then suppresses non-local maxima (sets to zero everything other than the edge maxima). This method is useful in that it produces edge lines of single pixel thickness.
 - **Sup. Non-Local Maxima (Prewitt)** - same as above except Prewitt filter is used.
 - **Laplacian** - a second order filter. The kernel sizes supported are 3x3, 5x5, and 7x7. This filter highly accentuates noise and thus should be always preceded by a lowpass filter.
 - **Zero Crossing** - this function first generates a laplacian and then labels values where the function changes curvature (zero-crossing) leaving a single pixel wide line. The kernel sizes supported are 3x3, 5x5, and 7x7.
- **Histogram Equalize** - the following group of routines perform line or area histogram equalization.
 - **Local Area** - performs a histogram equalization on the image by performing histogram equalization on small, local 16x16 pixel areas.
 - **Area** - performs an area histogram equalization using the Visilog histogram function.

- **Area2** - performs an area histogram equalization using an algorithm described in a book by Gonzalez and Wintz².
- **Horizontal Line** - performs a histogram equalization on an area one horizontal line at a time. This de-couples x and y components, thus negating vertical variation.
- **Vertical Line** - performs a histogram equalization on an area one vertical line at a time. This de-couples x and y components, thus negating horizontal variation.
- **Morphological** - the following group of routines perform morphological operation. All functions in this group operate on thresholded (binary) images.
 - **Hole Fill** - fills in all holes in an object.
 - **Erode** - performs a morphological erosion operation of a given number of iterations.
 - **Erode/Reconstruct** - performs a morphological erosion operation followed by reconstruction using the contents of the eroded image as markers.
- **Template Matching** - this group of routines performs template matching on a single frame between a template and a search region. They are included here so the user can test the performance and ability of these routines to locate an objects position under various conditions. The object position is determined by scanning the search region with the template and performing comparisons on groups of pixels between the two regions. The routines can remap the "match" surface to an image intensity range (0-255) and display it over the current image so that its characteristics can be analyzed by the tools mentioned above.
 - **Subt. Template Match w/surf.** - performs subtractive template match and plots the match surface. In a subtractive template match, the pixels in the template are subtracted from the corresponding pixels in the search region and the absolute value of the differences are summed. A new sum is calculated for each position as the template is shifted over the image. The minimum sum is the best match. The subtractive template match executes much faster than correlation.
 - **Subt. Template Match** - same as above but instead of plotting the surface a cross cursor is drawn at the location where the best match occurred.
 - **Normalized Correlation (L)** - performs normalized correlation match and plots the correlation surface. To speed up the computation long integers instead of floating point numbers are used to calculate the correlation, but this occurs at the expense of a round-off error.
 - **Normalized Correlation (D)** - performs normalized correlation match and plots the correlation surface. Double precision floating point numbers are used to improve accuracy, but at the expense of computation speed.
- **Frame Subtraction** - performs subtraction of two images.

APPENDIX B

IMAGE INPUT DEVICES CURRENTLY SUPPORTED

- Any RS-422 VLAN device. This includes nearly all of the high-end tape decks and laserdisks. The VLAN interface was tested with JVC-525 and Panasonic AG-DS850 tape decks.
- S-VHS tape deck - Panasonic 7300.
- Hi8 tape deck - Sony EVO 9650.
- Laserdisk - Sony LVR-3000N.
- Laserdisk - Panasonic LQ-4000.
- Meke Film Transport (16-mm and 35-mm films).
- Vanguard Film Transport (16-mm film).
- Kodak Megaplus 1.4 digital high-resolution camera.
- Digital image file input.

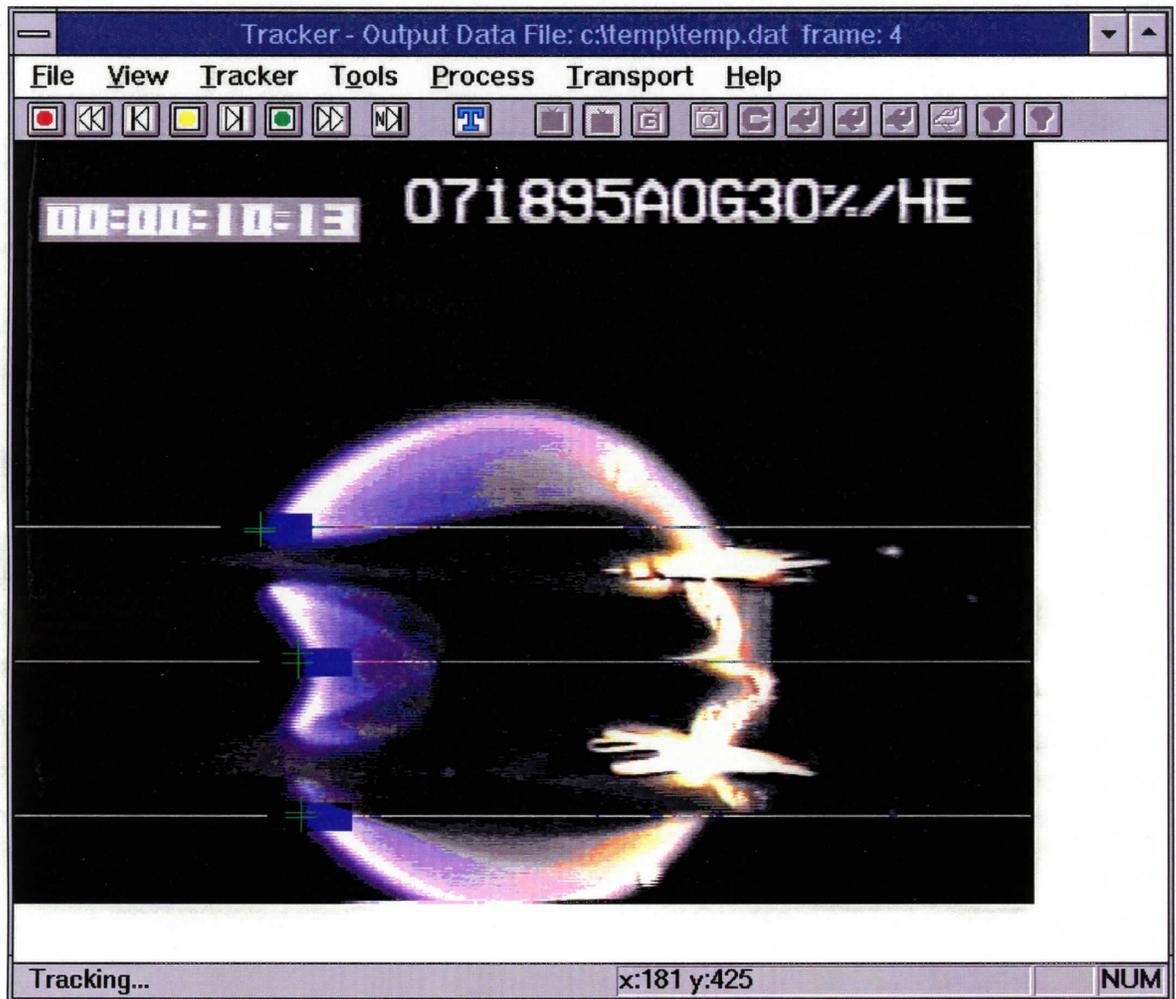


Figure 2.—Side view of interacting flames spreading over two layers of thin fuel.

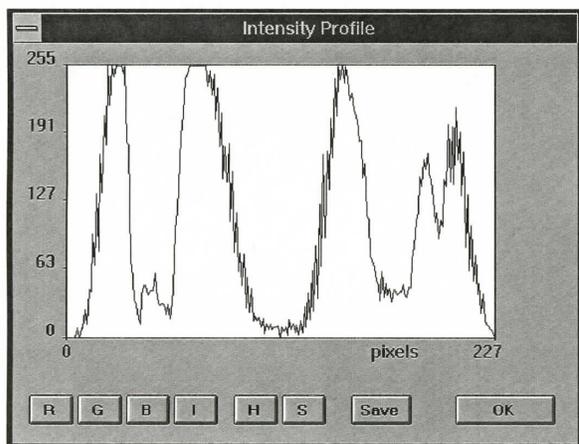


Figure 3.—Line profile across the leading edge of the flame.

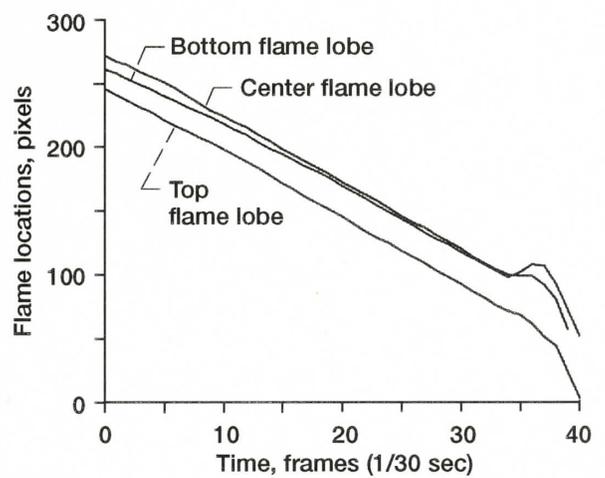


Figure 4.—Tracking results of interacting flames spread.

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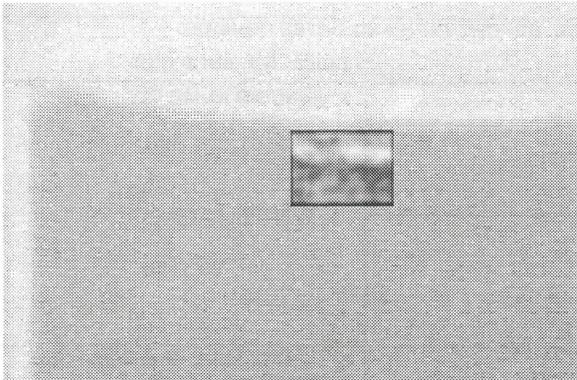


Figure 5.—Aqueous ethanol solution interface. The rectangular box at the center shows the final processed interface (before thresholding). Note that the meniscus is below the visible surface.

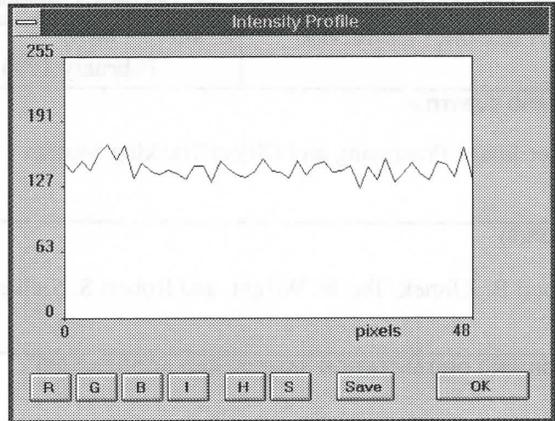


Figure 6.—Line profile across the unprocessed fluid interface.

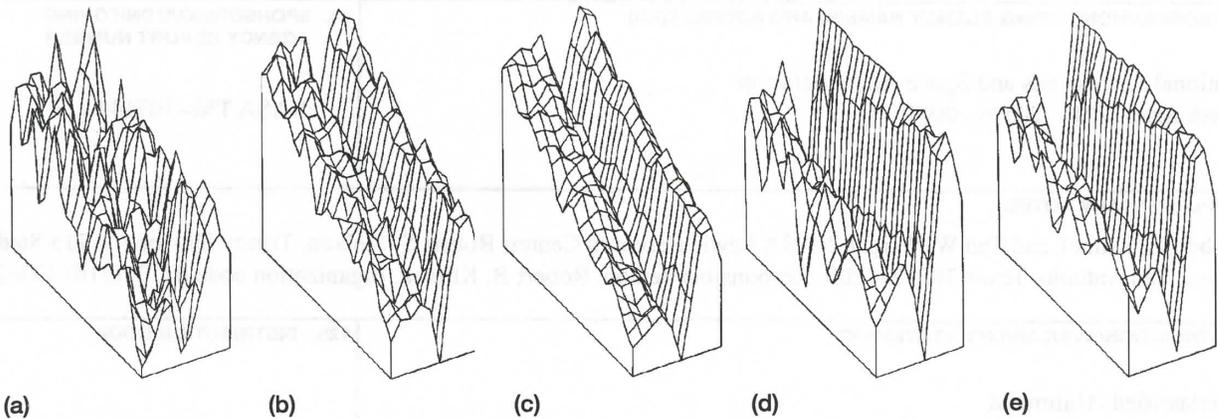


Figure 7.—Sequence of image processing steps performed on a 70x50-pixel area of interest and displayed as a three-dimensional surface. (a) Original, unprocessed area of interest. (b) Nine-frame averaging. (c) Result of step (b) and lowpass filtering. (d) Result of step (c) and line histogram equalization. (e) Result of step (d) and lowpass filtering.

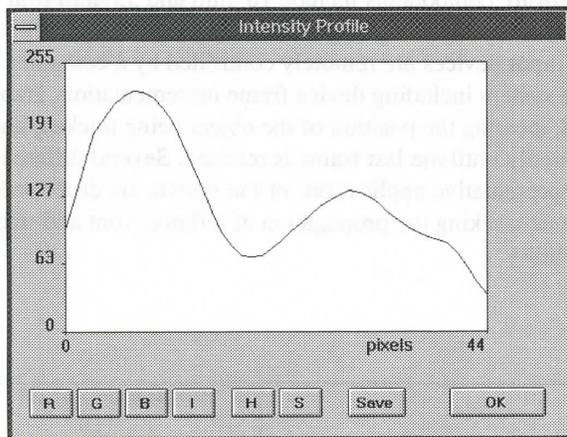


Figure 8.—Line profile across the processed fluid interface.

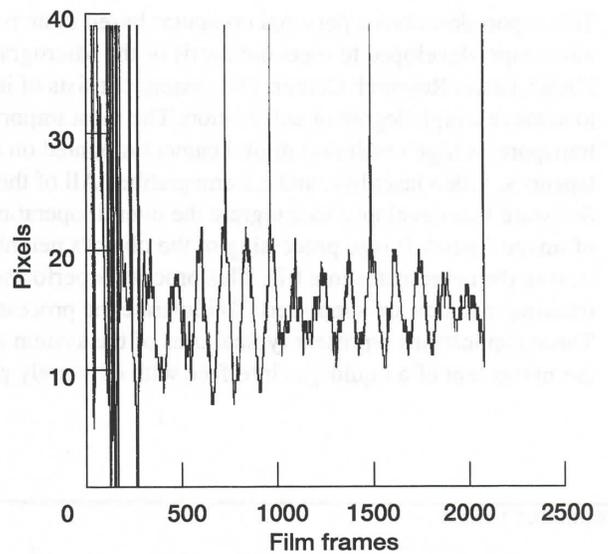


Figure 9.—Automated tracking of low-visibility surface of an aqueous ethanol solution.

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13. ABSTRACT (Maximum 200 words) This report describes a personal computer based system for automatic and semiautomatic tracking of objects on film or video tape, developed to meet the needs of the Microgravity Combustion and Fluids Science Research Programs at the 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 and 35-mm film transports, a high resolution digital camera mounted on a x-y-z micro-positioning stage, an S-VHS tape deck, an Hi8 tape deck, video laserdisk, and a framegrabber. All of the image input devices are remotely controlled by a computer. Software was developed to integrate the overall operation of the system including device frame incrementation, grabbing of image frames, image processing of the object's neighborhood, locating the position of the object being tracked, and storing the coordinates in a file. This process is performed repeatedly until the last frame is reached. Several different tracking methods are supported. To illustrate the process, two representative applications of the system are described. These applications represent typical uses of the system and include tracking the propagation of a flame front and tracking the movement of a liquid-gas interface with extremely poor visibility.				
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