A COMPUTER INTERFACED TIME-RESOLVED LUMINESCENCE IMAGING SYSTEM

by

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ABSTRACT

This thesis describes a time-resolved luminescence imaging system utilizing a computer interfaced gateable digital camera. The system is shown to be useful for the laser development of latent fingerprints on strongly luminescent surfaces. The system is optimized for rare earth chemistry suitable for all surface types and compatible with existing fingerprint treatments currently in use by law enforcement.

Precursors to this system are described and lead to the motivation for the design of this present system. The system specifications are detailed and the operation is discussed. Other potential applications are included.

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CHAPTER I

INTRODUCTION

1.1 Significance of the Study

This thesis deals with a time-resolved imaging system designed for the specific application to latent fingerprint detection. Sufficient motivation is provided for by the appalling severity of the crime problem in the United States today. Nearly 1.44% of the adult population (2.7 million) in the US (1991 statistics) is presently on probation, some 531,000 are out on parole and some 804,000 are presently incarcerated in federal and state penitentiaries[1]. Since prevention and rehabilitation efforts are largely unsuccessful, crime solving remains the only viable way to maintain a reasonable degree of public safety. Fingerprint evidence plays a central role in crime solving in that it provides a unique identification and, as such, remains the strongest physical evidence that can be introduced into a court of law. Although there are available other methods, such as DNA typing, these techniques are not yet mature. Fingerprints are even more valuable now that the Automated Fingerprint Identification System (AFIS) makes it possible for law enforcement to perform "cold" searches (searches for matching fingerprints without the benefit of a suspect's prints a priori being available for correlation) in a matter of a few minutes. With this AFIS system, any fingerprint

previously identified and stored is now available for the search and subsequent matching. Some 60 AFIS units are currently in use in the United States.

1.2 Historical Perspective

For many years, the law enforcement community relied on traditional methods of fingerprint detection, e.g., dusting with powders on smooth surfaces, and ninhydrin development on porous surfaces[2]. Both of these techniques rely on the basic mechanism of absorption/reflection of light.

On smooth surfaces such as glass, metal or plastic, a dusting powder (usually black) is sprinkled over a fresh (no more than two days old) latent print. Assuming the print to be heavy (well-defined with a good amount of secretions), the powder will then adhere to the fingerprint ridges. Ambient light will then be reflected (scattered) from the areas surrounding the ridge detail and will be absorbed by the powder adhering to the ridges.

For porous surfaces such as paper, cardboard, wood and leather, the ninhydrin development is used. Here, the latent print can be either fresh or old and still remain tractable. Ninhydrin reacts with the amino acids which are present in the fingerprint residues and forms a reaction product known as Ruhemann's Purple[3], a purple/blue stain. Again, ambient light is reflected by the area between the ridge detail and is absorbed by the stain on the fingerprint ridges.

These methods both involve observing the differences between the light reflected from around the ridge detail and that reflected from the ridges. In the case of weak or poorly developed latent fingerprints where only a small amount of powder adheres to the ridges or only a little Ruhemann's Purple is formed in the reaction, there is reflection from the background and only slightly less reflection from the ridge detail which forces the investigator to try to discern a very small difference between two large signals, a detection mode of inherently poor sensitivity. This is analogous to looking at the stars during the daylight hours; they are in fact there but the faint signature they present is overwhelmed by the daylight.

Returning to the dusting technique for smooth surfaces, suppose that it were possible to dust with white powder a heavy print on a black surface. Here there is reflection from the ridge detail but very little from the background. Now the investigator is detecting a small signal with very little background, a clearly superior method of detection. Returning to the previous analogy, the signature of the stars is readily visible in the night sky. Unfortunately one cannot hope to have all crime scenes perfectly black with heavy moist prints to dust with white powders. However, it is possible to simulate that condition with luminescence detection.

1.3 Fingerprint Detection By Laser Excited Luminescence

When a fingerprint is placed on a surface, a small amount of material, approximately 100 micrograms ($1x10^{-4}$ g), is deposited during contact. This fingerprint material is predominantly water, which soon evaporates and leaves about 1 microgram ($1x10^{-6}$ g) of residue. Of this remaining residue, approximately one-half is inorganic compounds and the other half is organic compounds such as amino acids, lipids and exuded vitamins. Thus only nanograms of material are useful to the investigator.

By utilizing the portion of fingerprint residue that is inherently luminescent (e.g., riboflavin), or better, by enhancing fingerprint luminescence via chemical treatment, detection of latent prints becomes quite easy via laser light excitation[4,5]. Since only a small amount of material is luminescent and as the intensity of this luminescence is proportional to the intensity of the excitation, laser light is the appropriate choice for the excitation source due to the high powers available. After all, the fingerprint luminescence must be intense enough to be visible to the naked eye. This laser detection of fingerprint luminescence is presently in worldwide use. Commercially available lasers and filters make possible not only the detection of latent prints, but fibers and bodily fluids as well.

Various treatments for use on different surfaces have been devised for compatibility with traditional methods, so as to make possible subsequent examinations by well-equipped laboratories after more conventional field techniques have failed to provide adequate success. Again, the treatments are segregated into types dependent on the substrates which bear the latent prints. The two main substrate types are the smooth surfaces and the porous surfaces.

Smooth surfaces are dyed with a luminescent chemical, typically after cyanoacrylate fuming[6] to stabilize the print to prevent it from being washed off by the solvents used to distribute the dyes. The fuming also provides for a degree of preferential staining by certain dyes, such as the highly fluorescent laser dye rhodamine 6G[7]. Prints on smooth surfaces can also be dusted with luminescent powders[8]. These dyes and powders are typically selected to be amenable to excitation by the color (wavelength) of the available laser excitation source as well as to be easily discernible from the color of the substrate. In most cases, this is highly successful.

Porous surfaces again receive the ninhydrin treatment to form the (nonluminescent) Ruhemann's Purple reaction product but are then further treated with zinc chloride to form an intensely luminescent coordination compound[9]. Various ninhydrin analogues are available from the criminalistic supply catalogues and from chemical suppliers.

These produce better results than ninhydrin[10]. It is of interest to note that one of the main benefits of this technique is that it will often yield latent prints on articles that showed little or no visible reaction product following the ninhydrin treatment.

Following treatment requisite to the surfaces involved, the examination of the article is performed under laser light (typically the blue-green argon ion laser) in a dark room. For sake of convenience, the article is usually illuminated via a fiberoptic cable from the laser output to the work area. The investigator views the luminescent print through a suitably selected filter which blocks reflected laser light and transmits only the luminescent emission of the treated fingerprint. If the print is deemed useful as evidence, a photographic camera (equipped with a similar filter on the front of the lens) is then used to make a permanent record of the fingerprint. A high contrast film, such as Kodak Technical Pan film, is ideal for this.

1.4 Highly Luminescent Surfaces

Unfortunately there exists a fair number of highly luminescent surfaces for which the previously described techniques fail. Certain plastics, varnished woods, dyed leathers, decorated product packaging cardboard and brightly painted items, such as soft drink cans and auto body panels, have remained intractable to standard techniques due to their high background luminescences. This is particularly

true when the background luminescence is similar in color to the fingerprint luminescence such that suppression of the background via optical filters becomes ineffective.

However, as the background luminescences generally are short-lived (lifetimes on the order of nanoseconds), one can take advantage of differences in luminescence lifetimes by a suitable choice of the chemistry utilized on the latent fingerprint (in order to yield microsecond or millisecond luminescence lifetimes) and by time-resolved or gated imaging techniques.

1.5 Principle of Time-Resolved Imaging

The basic principle of time-resolved luminescence imaging is depicted in Figure 1.1. The laser light is repetitively modulated (chopped on and off) at a suitable rate that allows the long-lived fingerprint luminescence of interest to be excited. Of course, the short-lived background luminescence is also excited. The luminescence intensity decay,

$$I = I_0 e^{-t/\tau}, \qquad (1)$$

after illumination cut-off is rapid for the short-lived (nanosecond τ) background and slower for the longer-lived (microsecond to millisecond τ) fingerprint luminescence.

By gating the imaging device sufficiently far into the dark (laser off) period, the background luminescence will

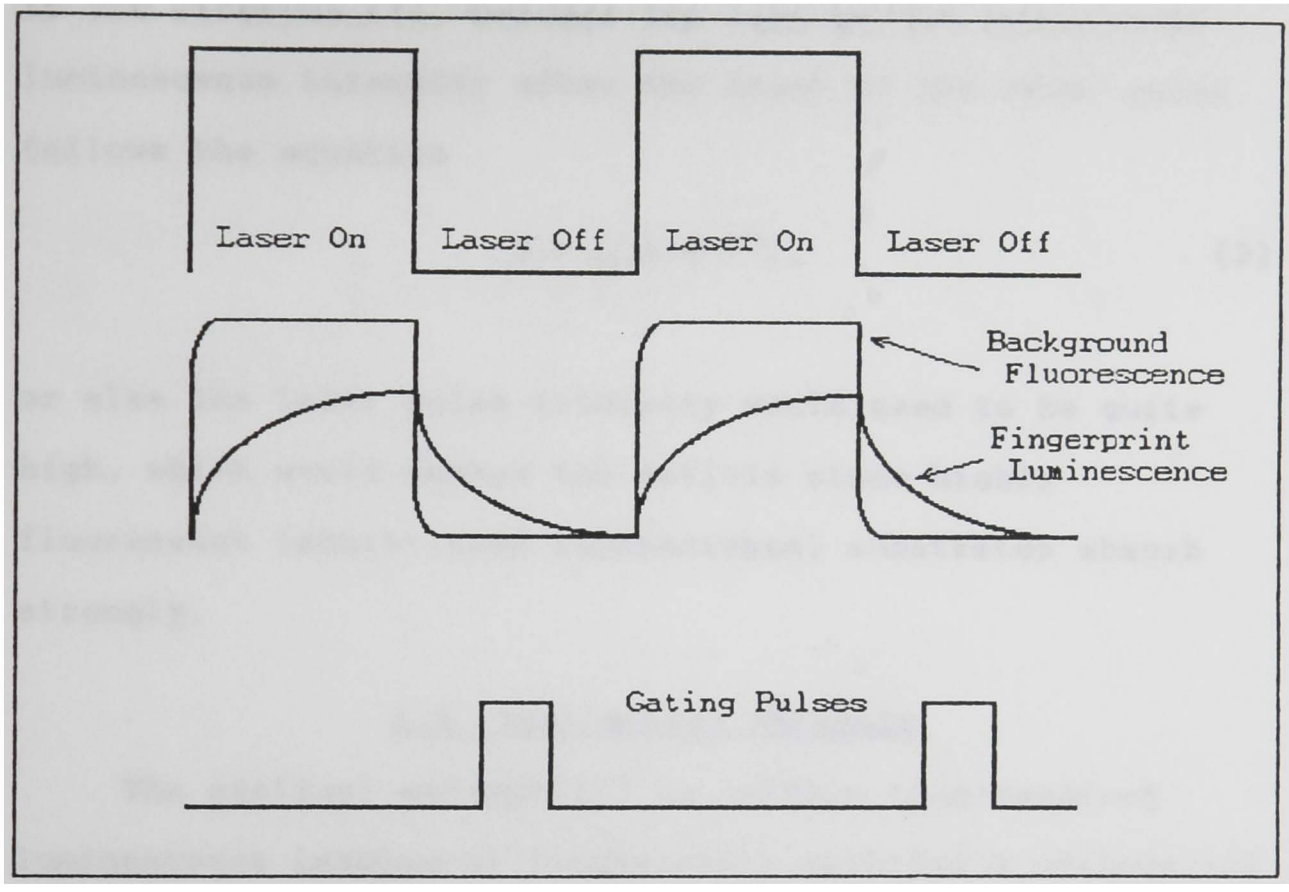

Figure 1.1 Principle of Time-Resolved Imaging

have decayed and only the fingerprint emission will be recorded. It is important to note that pulsed lasers are a poor choice as the excitation source because laser pulse widths are typically on the order of t=20 nanoseconds, too short to effectively excite phosphorescence (long-lived luminescence). The laser pulse width should be comparable to the lifetime (τ), because the rise of the fingerprint luminescence intensity after the onset of the laser pulse follows the equation

$$I = I_0(1-e^{-t/\tau}), \qquad (2)$$

or else the laser pulse intensity would need to be quite high, which would damage the article since highly fluorescent (short-lived luminescence) substrates absorb strongly.

1.6 Preliminary Attempts

The earliest attempt[11] to perform time-resolved luminescence imaging of fingerprints utilized a cylindrical light chopper that enclosed the article being examined (see Figure 1.2). The cylindrical chopper provided the modulation of the excitation source, the size of the slots controlled the gate width and the position of the camera controlled the delay. This system imposed limitations on the size of the articles that could be examined and chopping speeds were low due to the mass of the cylinder. The actual

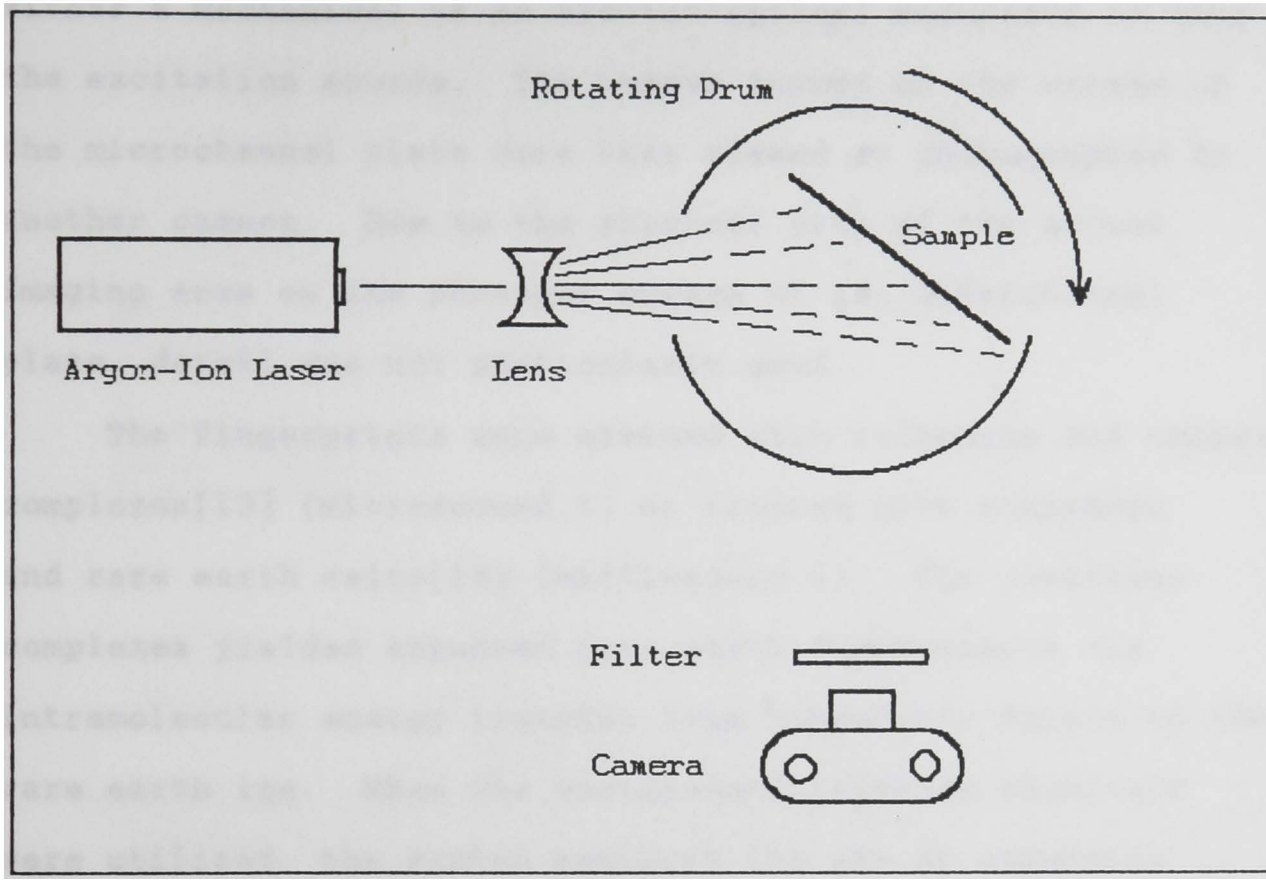

Figure 1.2 Cylindrical System, Block Diagram

imaging was performed by a photographic camera placed outside of the rotating cylinder.

Next came a first-generation time-resolved luminescence imaging system[12] (refer to Figure 1.3) which consisted of a gated microchannel-plate image intensifier mounted to a photographic camera body (for ease of focusing) and utilized either a mechanical or an electro-optical modulator to chop the excitation source. The images formed on the screen of the microchannel plate were then viewed or photographed by another camera. Due to the physical size of the actual imaging area on the phosphor screen of the microchannel plate, detail was not particularly good.

The fingerprints were stained with ruthenium and copper complexes[13] (microsecond τ) or treated with ninhydrin and rare earth salts[14] (millisecond τ). The resulting complexes yielded enhanced rare earth luminescence via intramolecular energy transfer from Ruhemann's Purple to the rare earth ion. When the microsecond lifetime chemicals were utilized, the system required the use of expensive electro-optic (E-O) modulators. More importantly, though, these E-O modulators required careful optical alignment and biasing in order to achieve adequate extinction of the laser intensity during the dark (laser off) period. If, however, the longer-lived rare earth compounds were used, a simple mechanical light chopper (basically a rotating disk with holes in it) was sufficient.

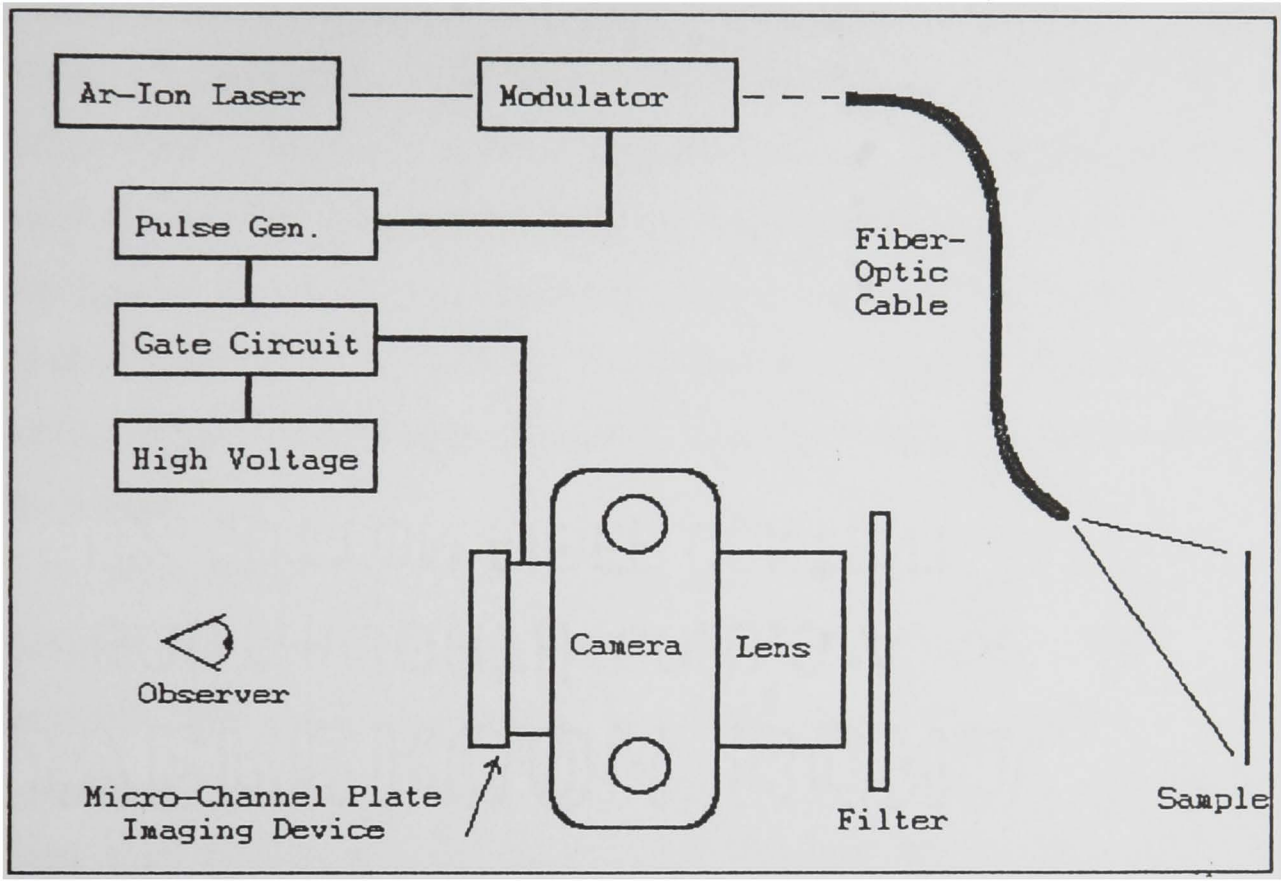

Figure 1.3 First-Generation System, Block Diagram

While this first-generation device was successful in its ability to perform fingerprint imaging with background suppression, the cumbersome instrumentation made it suitable only for research in the laboratory environment. Practical application of the time-resolved luminescence imaging technique still remained out of reach.

CHAPTER II

FINGERPRINT TREATMENT STRATEGIES

2.1 Charge Transfer Phosphorescence Compounds

One fingerprint chemistry strategy investigated for use with time-resolved imaging was that of the charge transfer phosphorescences which provided microsecond lifetimes. This class of chemistry utilized transition metal coordination complexes. In particular, certain ruthenium compounds[13] were promising for use on smooth surfaces since they exhibited intense luminescence (under blue-green laser light) and could be easily applied via solution staining after superglue fuming as had been done with the rhodamine 6G stain.

One major drawback to this strategy was due to this relatively short (microsecond) emissive lifetime. To perform the time-resolved imaging in this time domain required the use of expensive and recalcitrant electro-optic (EO) modulators to effect a rapid modulation of the laser light. Another drawback was that this chemistry was incompatible with the standard porous surface treatments.

2.2 Dusting with Phosphorescent Powders

Another technique to obtain long-lived luminescence utilized phosphorescent dusting powders applied to the latent fingerprint[8]. The powder could be applied directly to the print or subsequent to superglue fuming. These

powders, routinely used by law enforcement personnel, are best illuminated with ultraviolet light, whether from a hand-held field lamp or from a more powerful laser source. These powders are, however, useful only on smooth surfaces bearing fresh fingerprints.

2.3 Rare Earth Based Strategies

The long time standard treatment for porous surfaces has been to use the ninhydrin reaction with amino acid to form the reaction product Ruhemann's Purple, followed by zinc chloride to form a coordination compound that is luminescent[9] (as described in sections 1.2 and 1.3). However, the short-lived luminescence generated is in the same time domain as that of most background luminescences.

One may substitute a rare earth (lanthanide) salt for the zinc chloride, though, and the resulting coordination compound is luminescent (albeit less than with the $ZnCl_2$). Taking advantage of the intramolecular energy transfer from the organic ligand, e.g., from the Ruhemann's Purple, to the rare earth ion, greatly enhanced emission by the rare earth is produced, with a long-lived lifetime (on the order of milliseconds)[15]. Rare earth emission lifetimes are long because one is dealing with transitions that are both spin- and parity-forbidden. Emission quantum yields are nonetheless high because the 4f valence shell is shielded. Europium and terbium are the preferred rare earth ions. Of the two, the europium ion, Eu^{3+}, is the most promising.

Ninhydrin analogues such as 5-methoxyninhydrin and several anions (of the rare earth salt) have been examined to optimize the ninhydrin/rare earth type chemical strategy[16]. The europium coordination compounds are also suitable for use on smooth surfaces since they are readily prepared in solution. In view of the suitability to both surface types and due to the relatively long-lived emission of these compounds, we were thus motivated to match the design criteria of the proposed time-resolved imaging system to this chemistry.

Furthermore, the one chemistry approach is advantageous in that one does not have to contend with laser light modulation frequency changes depending on the type of article to be examined, or having to change the illumination wavelength.

CHAPTER III

THE SECOND-GENERATION TIME-RESOLVED LUMINESCENCE IMAGING SYSTEM

A choice was made to match the system design criteria to the rare earth compounds with which fingerprints are treated either in a manner analogous to the now routine ninhydrin/zinc chloride treatment (for porous surfaces) or rhodamine-6G staining (for smooth surfaces). These rare earth compounds not only offer the prospect of a single chemistry useful for both porous and smooth surfaces[16], but also allow the utilization of an inexpensive and easy to use mechanical light chopper. Our second-generation time-resolved luminescence imaging system (Figures 3.1 and 3.2) utilizes a desk-top computer and a digital charge-coupled device (CCD) camera incorporating a gateable microchannel-plate image intensifier, providing flexibility of image acquisition and processing, hard-copy output and the "user-friendly" operation required of a viable investigative tool.

3.1 Laser Source

The continuous wave output argon-ion laser was chosen as the excitation source for a number of reasons. Due to the exponential nature of the luminescence intensity rise and decay, as mentioned in Section 1.5, pulsed lasers such as the nitrogen, frequency-doubled Nd:YAG and copper vapor lasers have pulses that are far too short to effectively

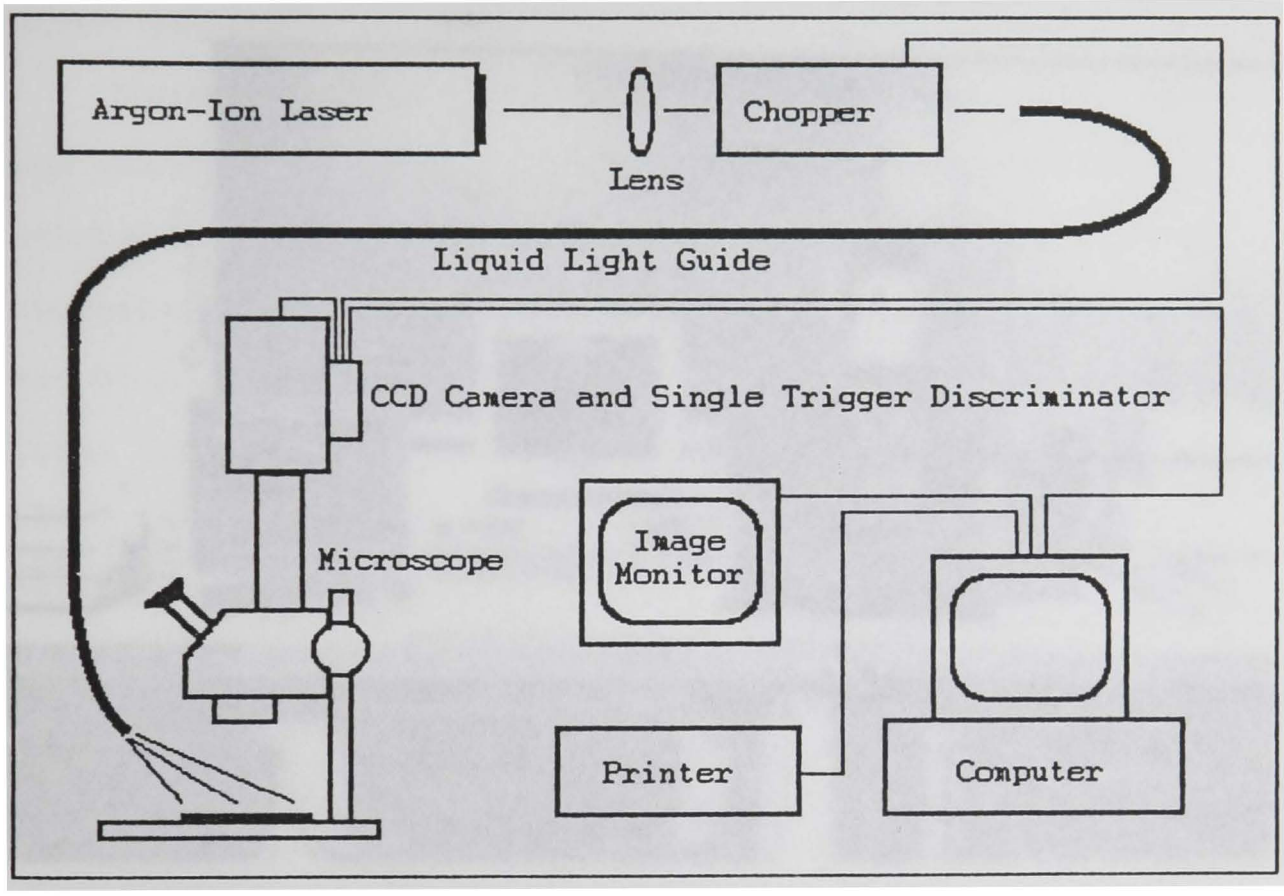

Figure 3.1 Second-Generation System, Block Diagram

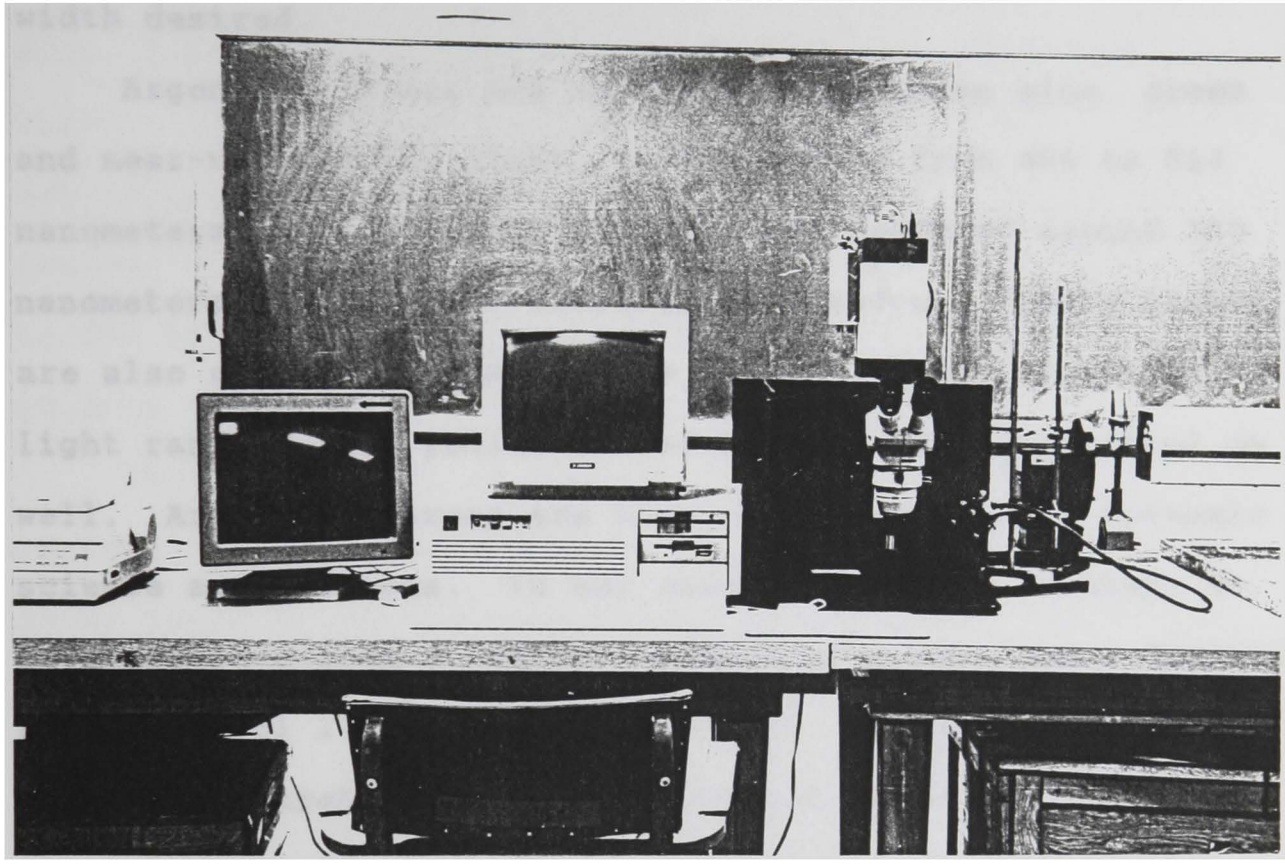

Figure 3.2 Second-Generation System

excite the phosphorescent rare earth (Eu^{3+} and Tb^{3+}) compounds. The repetition rate of the pulsed Nd:YAG lasers is also too low, typically 12 to 20 Hertz in the units utilized by some law enforcement agencies. The Argon-ion laser, however, produces a continuous output which can be chopped at any desired frequency, hence any specific pulse width desired.

Argon-ion lasers are capable of producing blue, green and near-ultraviolet light, in the ranges from 488 to 514 nanometers in the visible spectrum and centered around 360 nanometers for the near-ultraviolet spectrum. These lasers are also capable of pumping dye lasers, making available light ranging from yellow to red (560 to 650 nanometers) as well. Argon-ion lasers are thus very versatile in forensic science applications. In our second-generation system, we have utilized both a Coherent INNOVA 90-6 unit and a Spectra Physics Model 171 as the laser source. Modern argon-ion lasers are capable of producing output powers of approximately 25 watts in the visible and, as appropriate for the proper excitation of the rare earth luminescences, approximately 7 watts in the near-ultraviolet (near-UV).

The main characteristic of laser light is that it is typically monochromatic (or very nearly so). Because of this inherent monochromaticity, any light reflected from the work can be easily filtered out from the imaging device through the use of standard optical (long wavelength pass)

filters. These filters block the laser light while allowing the luminescence signal of interest to pass.

3.2 Light Chopper

For modulation of the laser light in our system, we have chosen the EG&G Princeton Applied Research Model 125A mechanical light chopper. The unit consists of a slotted disk driven by an adjustable speed electric motor and a circuit incorporating a simple electro-optic device (an LED detector/emitter pair) mounted in the blade housing to provide a trigger output. Our chopping speed has been set to 650 Hz as dictated by the choice of rare earth chemistry (0.4 ms τ for Eu^{3+} and 1.3 ms τ for Tb^{3+})[16].

The laser light is focused to a sharp spot at the front surface of the chopper blade. As the blade rotates, the laser light is alternately passed and then blocked by the blade, generating a modulated light source for the article under scrutiny and a signal with which the imaging system can be synchronized. Tight focusing of the light incident on the blade is necessary to ensure the square-wave modulation of laser light requisite to the operation of the time-resolved imaging technique.

3.3 Liquid Light Guide

The modulated laser light is transmitted to the article via a liquid light guide manufactured by Oriel. This liquid light guide, as opposed to a fiber-optic cable, was chosen

because of its large (approximately 0.5 cm) diameter, obviating the need to refocus the divergent laser beam as it exits the light chopper. Area illumination is regulated by positioning the output end of the liquid light guide nearer to (for greater energy density) or further from (for greater coverage) the article. Additionally, the light guide transmits both visible and near-UV light.

3.4 Camera

Our system utilizes a Stanford Intensified Camera 05 (SIC 05) manufactured by Stanford Computer Optics, Inc., an ultra high-speed gated intensified monochrome video camera capable of operation at gating speeds/exposure times down to 5 nanoseconds. This charge coupled device (CCD) camera incorporates a gateable proximity-focused microchannel-plate (MCP) image intensifier driven by an internal microcomputer. The camera is activated by a single trigger discriminator in line with the mechanical chopper trigger output in order to open and close the shutter, i.e., gate the microchannel-plate imaging device.

Our system incorporates a specially modified single trigger discriminator (STD) that allows gating up to a maximum of eight pulses per video frame. The STD module controls the CCD array exposure (eliminating multiple exposures during frame transfer) during the repetitive external trigger signal from the chopper so as to ensure proper synchronization of the video timing sequence during

the 15.5 ms frame integration time. This 15.5 ms frame integration time is the maximum allowable time that the camera can be active during the 16.6 ms (60 Hz) duty cycle. The choice of a 650 Hz chopping frequency, together with the imaging integration over eight laser pulses, is ideal in that it (almost) fully makes use of the available 15.5 ms video frame. Refer to Figure 3.3 for a timing diagram.

3.4.1 Camera Specifications

The camera has an 18 mm diameter proximity-focused MCP with an S20 spectral response photocathode. The gain of the MCP is adjustable in 32k steps from 0 to 1000 volts with a rated luminous gain greater than 10^4. The coupling phosphor, MCP to CCD, is a 6 x 4.5 mm (image area) fiber optic, giving far greater sensitivity than a relay lens. The CCD chip contains 610 x 492 pixels in the 6 x 4.5 mm image area. The CCD-video unit has a rated maximum sensitivity of 5 μLx @ -6 dB (1 V_{pp} output), 5 x 10^{-7} fc. The video interface is an RS 170/NTSC composite, the scan mode is selectable for interlaced or progressive and the synchronization can be either internal, external, TTL or free running[17].

3.4.2 Mounting

The camera may be mounted either on a stereo-zoom microscope or on a standard tripod. Mounted on the stereo-zoom microscope, an Olympus SZ40 as in our system, a wide

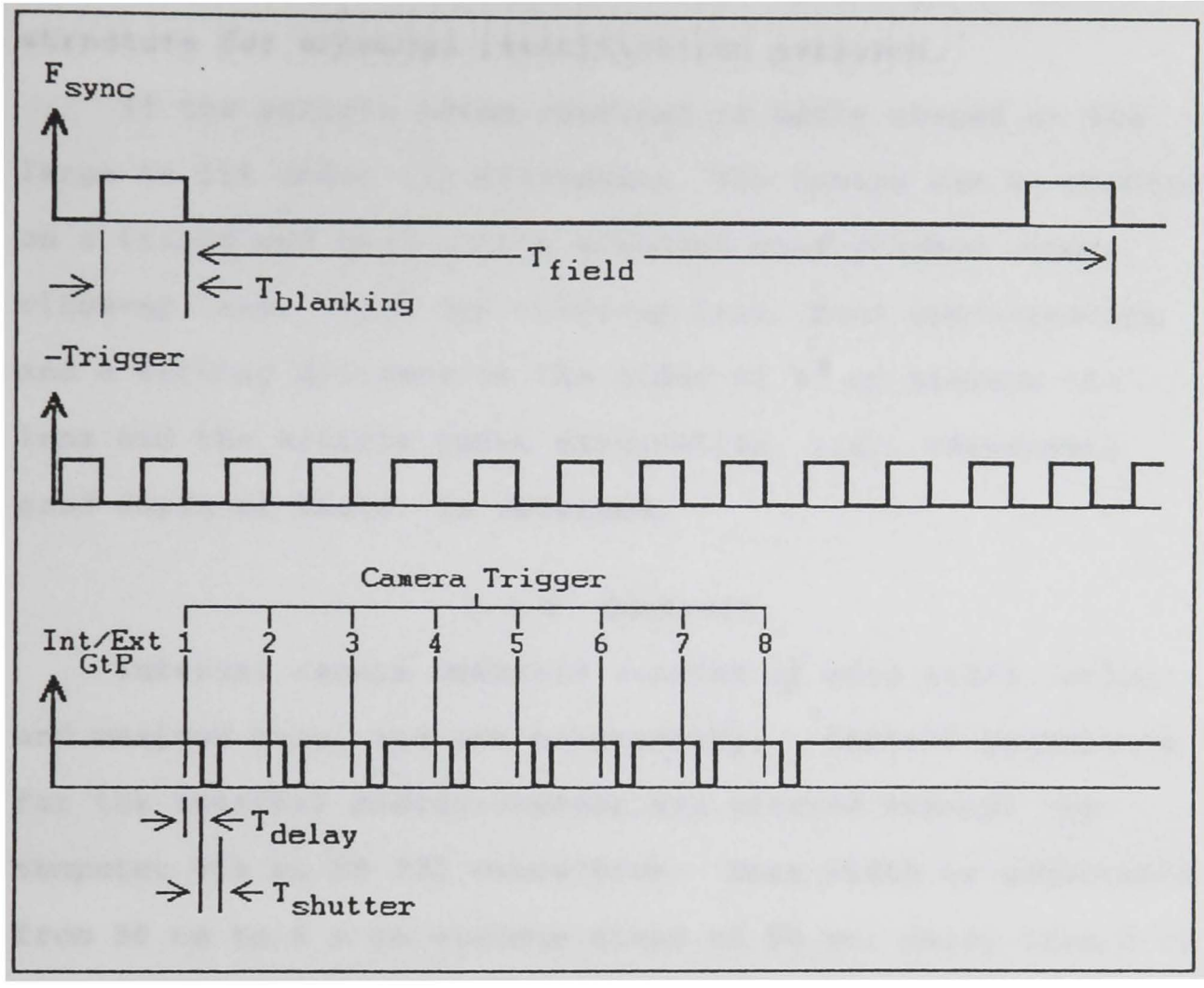

Figure 3.3 Camera Timing Diagram

range of magnification is available for varied requirements. At low magnification the entire fingerprint can be imaged (Figure 3.4) for cataloging and matching. When using higher magnification a small section of the print (Figure 3.5) is shown in greater detail, potentially making use of pore structure for enhanced identification purposes.

If the article being examined is oddly shaped or too large to fit under the microscope, the camera can be mounted on a tripod and used with a standard photographic camera close-up lens. With our close-up lens, good magnification and a working distance on the order of 20 cm between the lens and the article under examination, i.e., reasonably good depth of field, is obtained.

3.4.3 Controls

Internal camera controls consist of gate width, delay and maximum gain, and are programmable. Control parameters for the internal microprocessor are entered through the computer via an RS 232 connection. Gate width is adjustable from 50 ns to 8 s in minimum steps of 50 ns, delay from 0 to 8 s, also in 50 ns minimum steps. The gain is adjustable from 0 to 1000 volts maximum in the parameter setup. Once these parameters are set, the gain is manually adjusted by a 41 step potentiometer on the camera in real time to protect the MCP from overexposure.

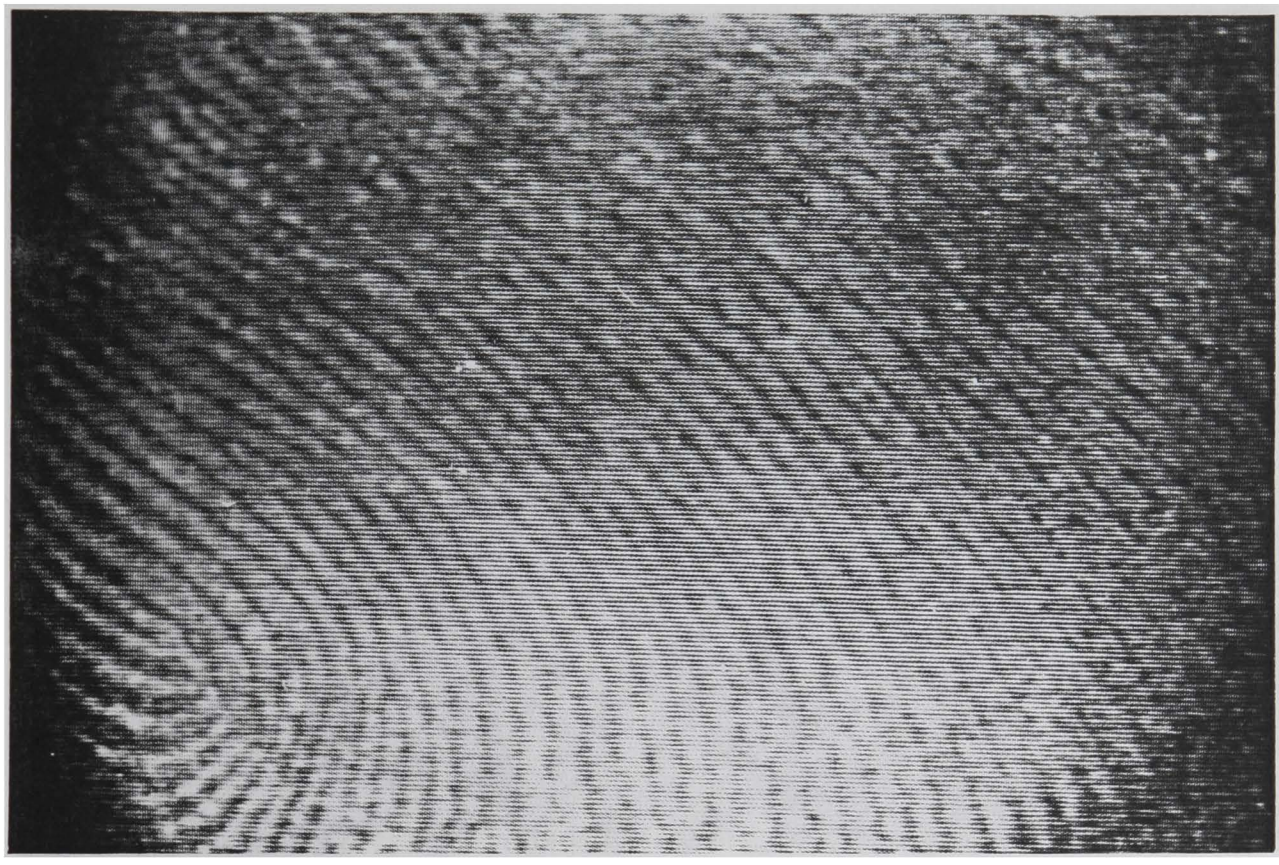

Figure 3.4 Entire Print, Low Magnification

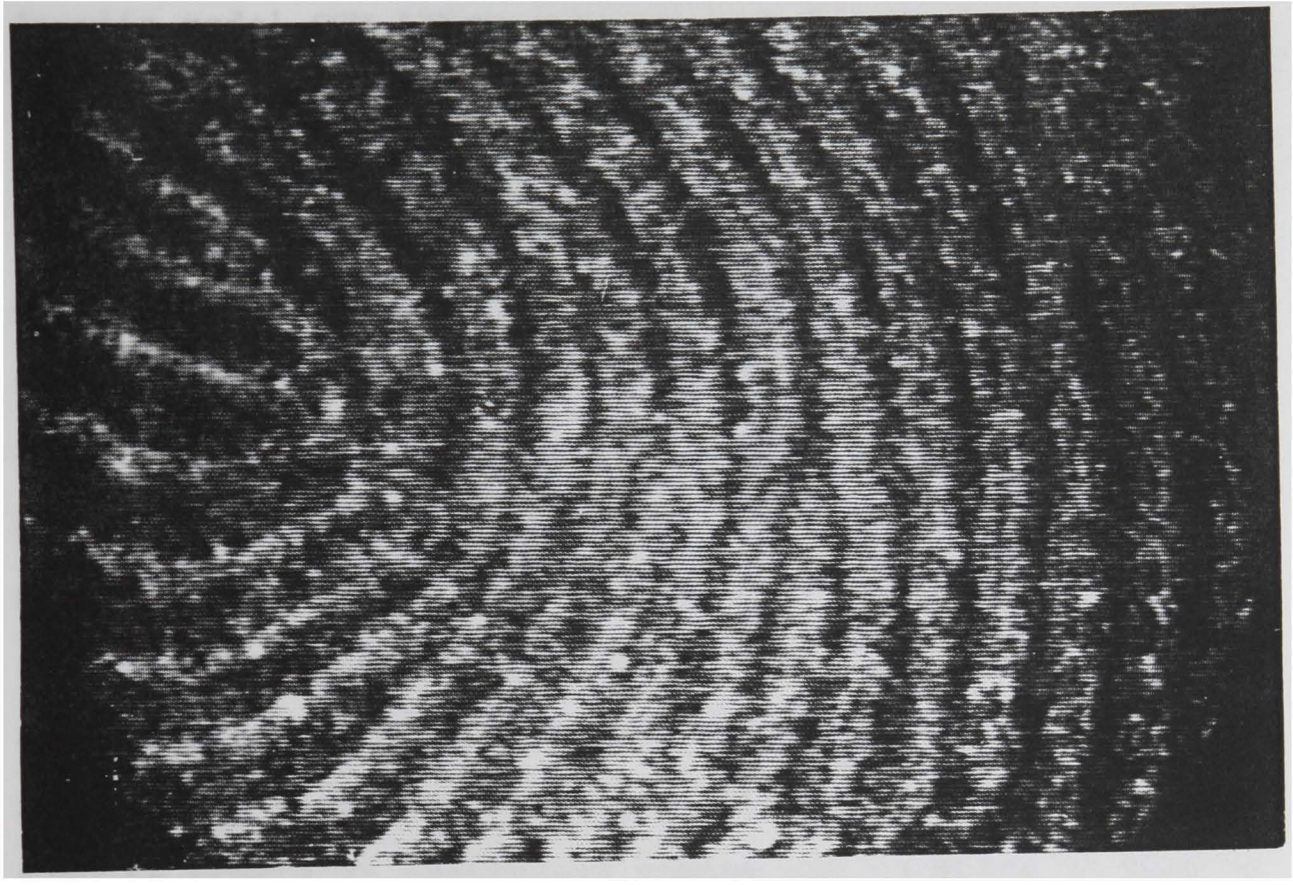

Figure 3.5 Magnified Section of Print

3.5 Interface

The interface consists of a 33 MHz Intel 80386 microprocessor based Gateway 2000 computer, equipped with 4 MB of RAM, an 80 MB hard disk drive, two floppy disk drives (1.2 and 1.44 MB, respectively) and two high-resolution monitors (a Gateway model PMV14VC to manipulate the computer and a Javelin model CVM-13B to display the fingerprint image). Additional image processing hardware and software completes the package.

The images are captured from the camera and stored to disk by a Data Translation DT 2851 high-resolution frame grabber. The DT 2851 converts (digitizes) the video signal at 10 MHz into 480 lines by 512 pixels per line by 8 bits per pixel (for 245.8×10^3 pixels per image, at 256 grey scales). The entire frame is digitized in 1/30 second.

The camera parameters are set initially by a terminal program provided by the camera manufacturer. ImagePro V2.0 software is then used to control the frame grabber to acquire single or continuous images and to store or display the images. ImagePro also provides some rudimentary image processing capabilities such as contrast adjustment, edge enhancement and spectral, or fast Fourier Transform (FFT), editing of the images. Refer to the Appendix for system operation.

3.6 Image Processing

An in-depth discussion of image processing is beyond the scope of this thesis. Nonetheless, a short discussion of FFT editing is appropriate. With the various rare earth treatments, particularly on porous surfaces, there is a tendency for formation of a uniform background due to the deposition of unreacted rare earth salts everywhere on the treated surface. This can be eliminated by taking the Fourier transform of the image and then editing, or removing, the central spot (DC component of the spectrum) from the field. The inverse transform of the edited field then yields the original image minus the uniform background. Several examples of this technique are shown in Figure 3.6 and Figure 3.7.

3.7 Output

Various forms of image output are available in our system. The image files, in tagged image format (TIF), can be stored on any magnetic media. Hardcopy can be produced by the many type of printers available: dot matrix (ours is a Panasonic KX-P1624), laser and thermal. Of the three types tested, the thermal printer seems to have the optimum combination of resolution and grey scale reproduction for fingerprint images. Additionally, the digitally stored images can potentially be transferred directly into AFIS, the Automated Fingerprint Identification System.

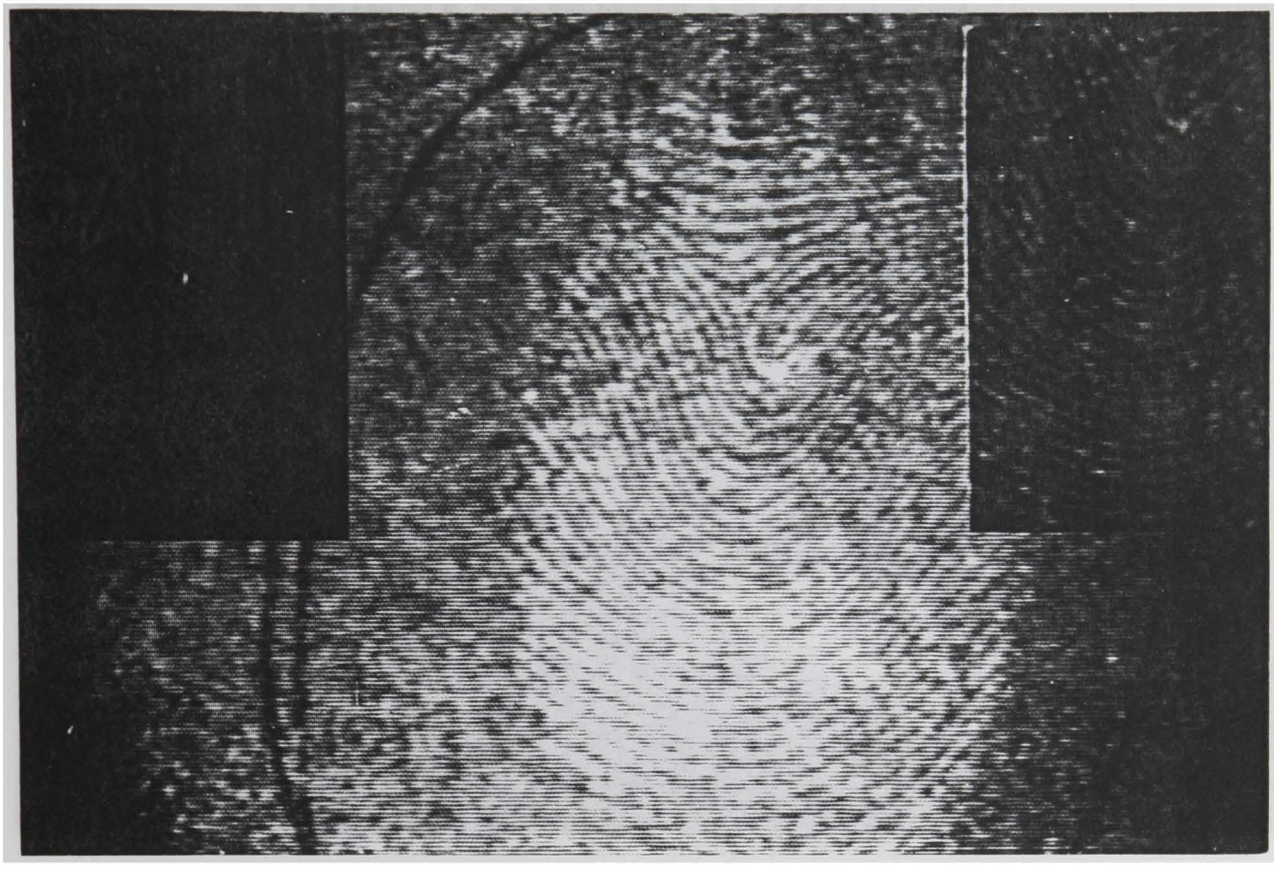

Figure 3.6 Example of Image Enhancement, Number 1
Edited FFT (left), Original Image (center),
Processed Image (right)

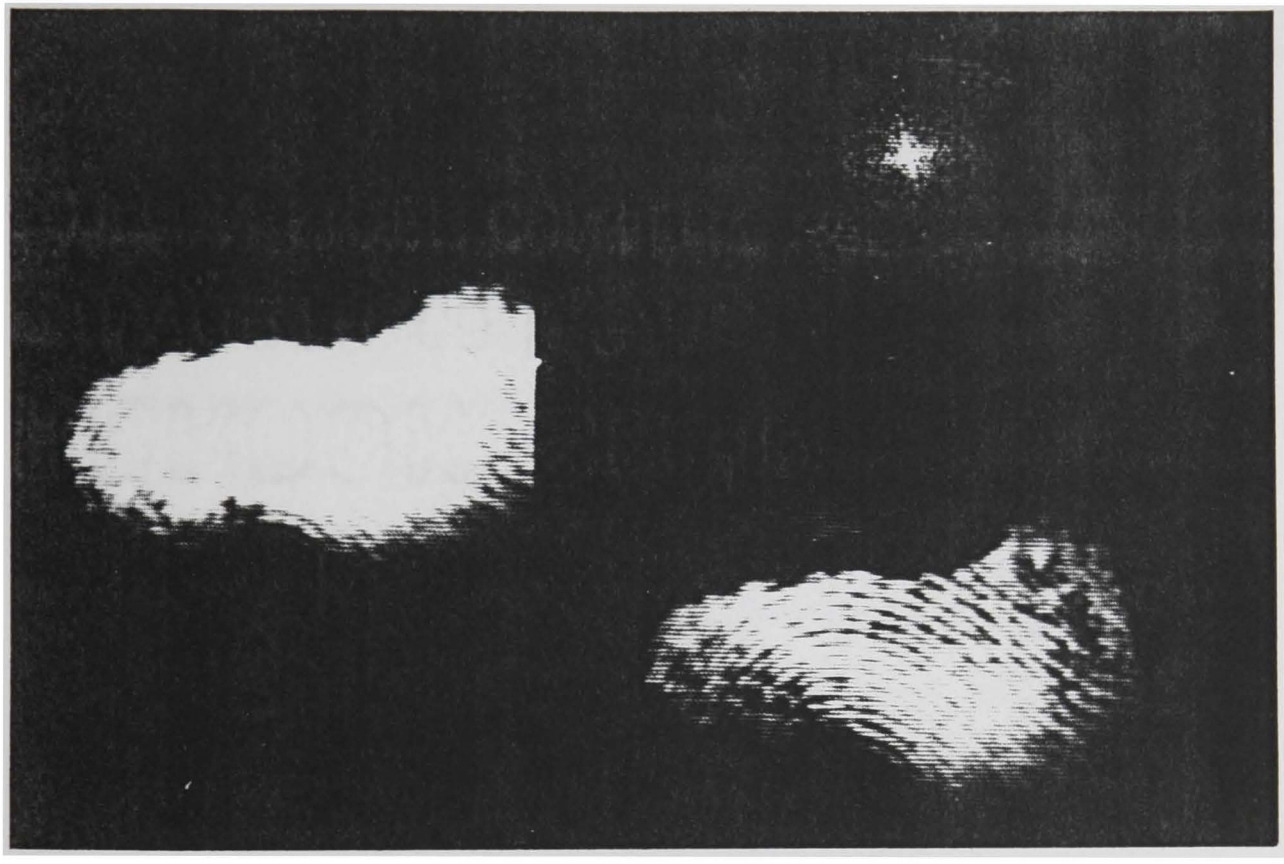

Figure 3.7 Example of Image Enhancement, Number 2
Original Image (left), Edited FFT (at upper right), Processed Image (at lower right)

CHAPTER IV

RESULTS

4.1 Background Suppression

An example of the ability of our second-generation time-resolved imaging system to suppress background luminescence is most easily demonstrated by a simple trial contrived to initially set up, verify and troubleshoot the system. A ruby crystal was used to simulate the phosphorescent signal of interest. Ruby has an emissive lifetime of τ = 4.3 ms. A vial of rhodamine 6G solution was used to simulate the short-lived background fluorescence. Both samples were illuminated by green laser light from the argon-ion laser. Figure 4.1 depicts the ungated image in which both samples are clearly visible. The camera gating was then initiated to suppress the background image. Figure 4.2 depicts the gated image of the ruby crystal alone, the rhodamine 6G fluorescence now effectively suppressed.

4.2 Fingerprint Detection

In a preliminary test of fingerprint detection, prints were placed on a thin layer chromatography (TLC) plate. The prints were made with the rare earth reaction product placed directly on the finger and Rh-6G was spotted on the plate as a background fluorescer. Figure 4.3 illustrates the ungated image while Figure 4.4 shows the gated image with the background spots suppressed.

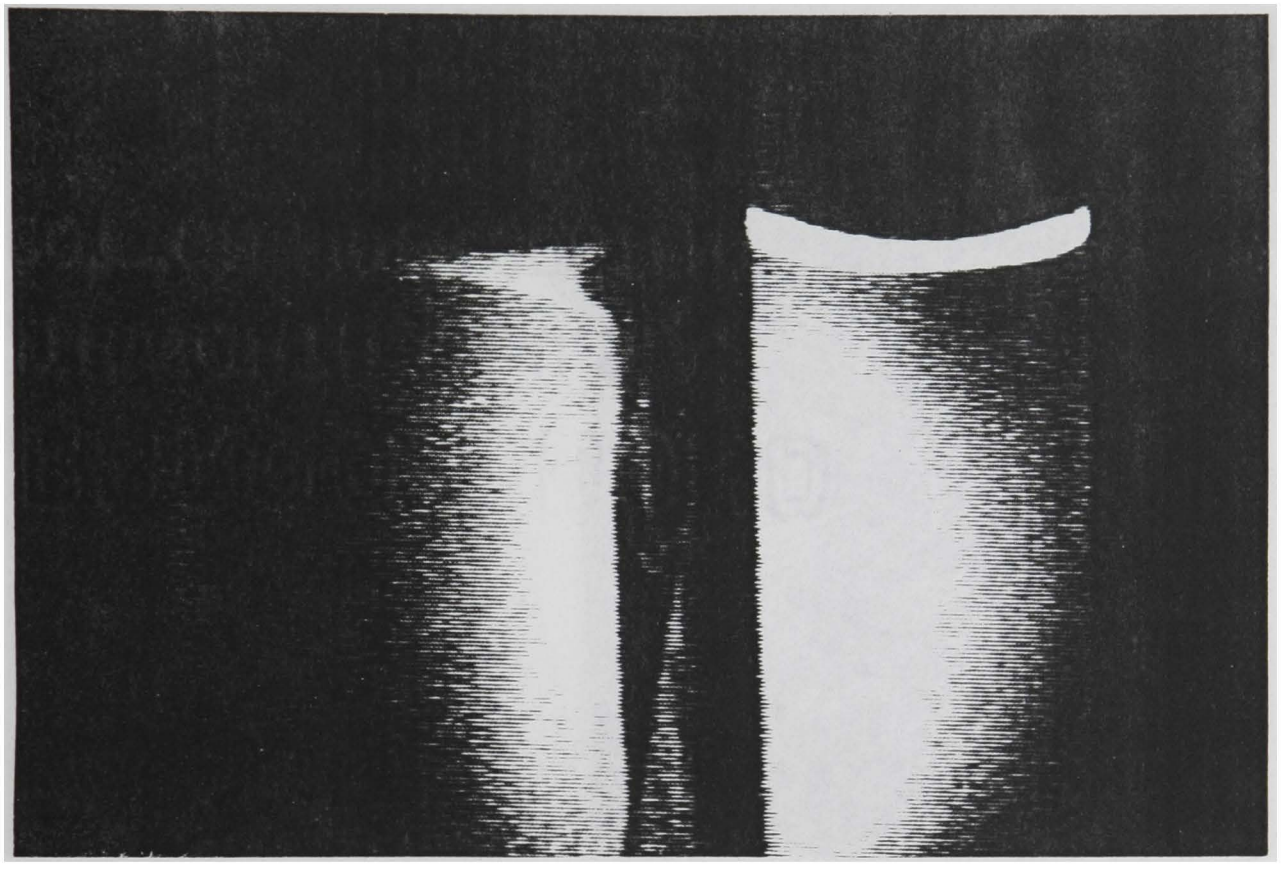

Figure 4.1 Ruby Crystal/Rh-6G Solution, Ungated Image

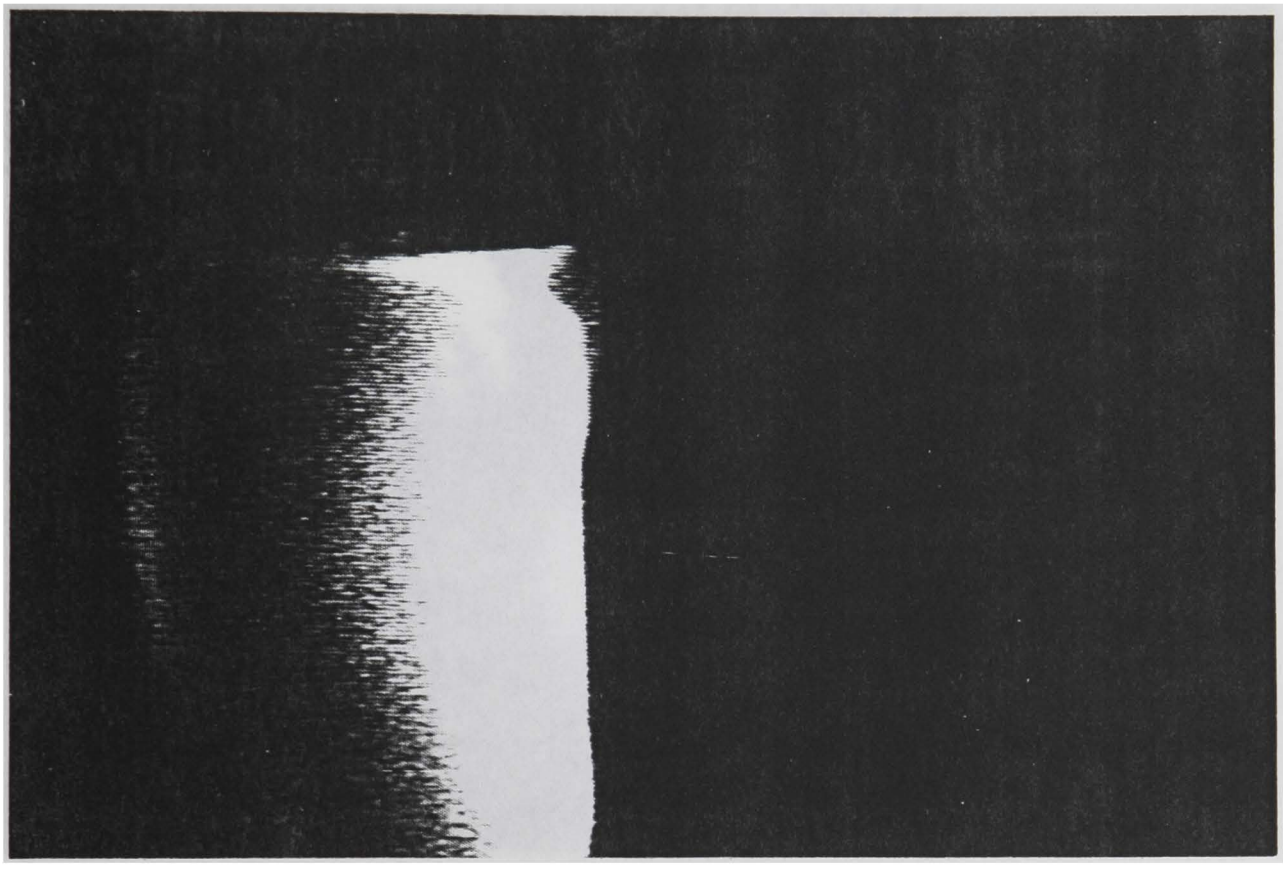

Figure 4.2 Ruby Crystal/Rh-6G Solution, Gated Image

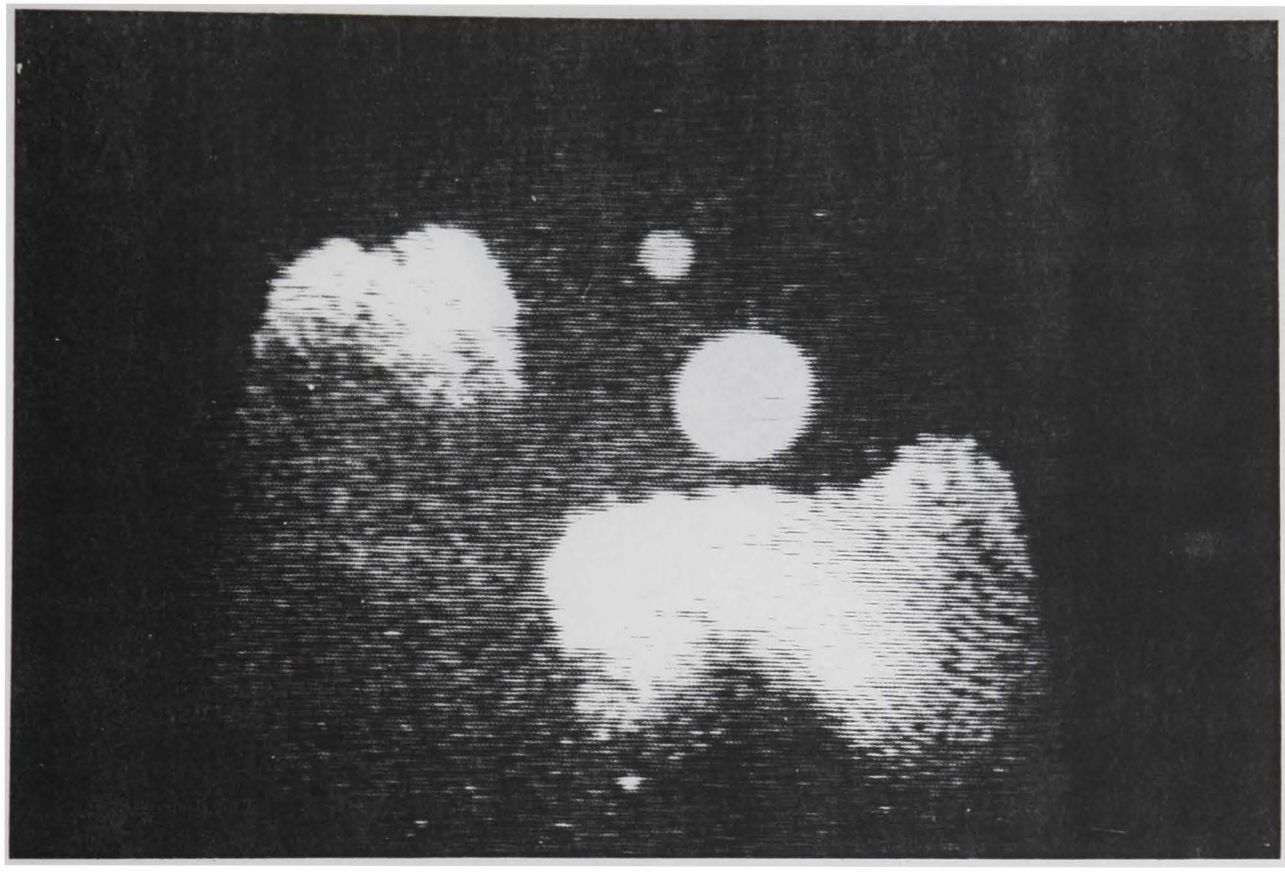

Figure 4.3 Prints on TLC Plate, Ungated Image

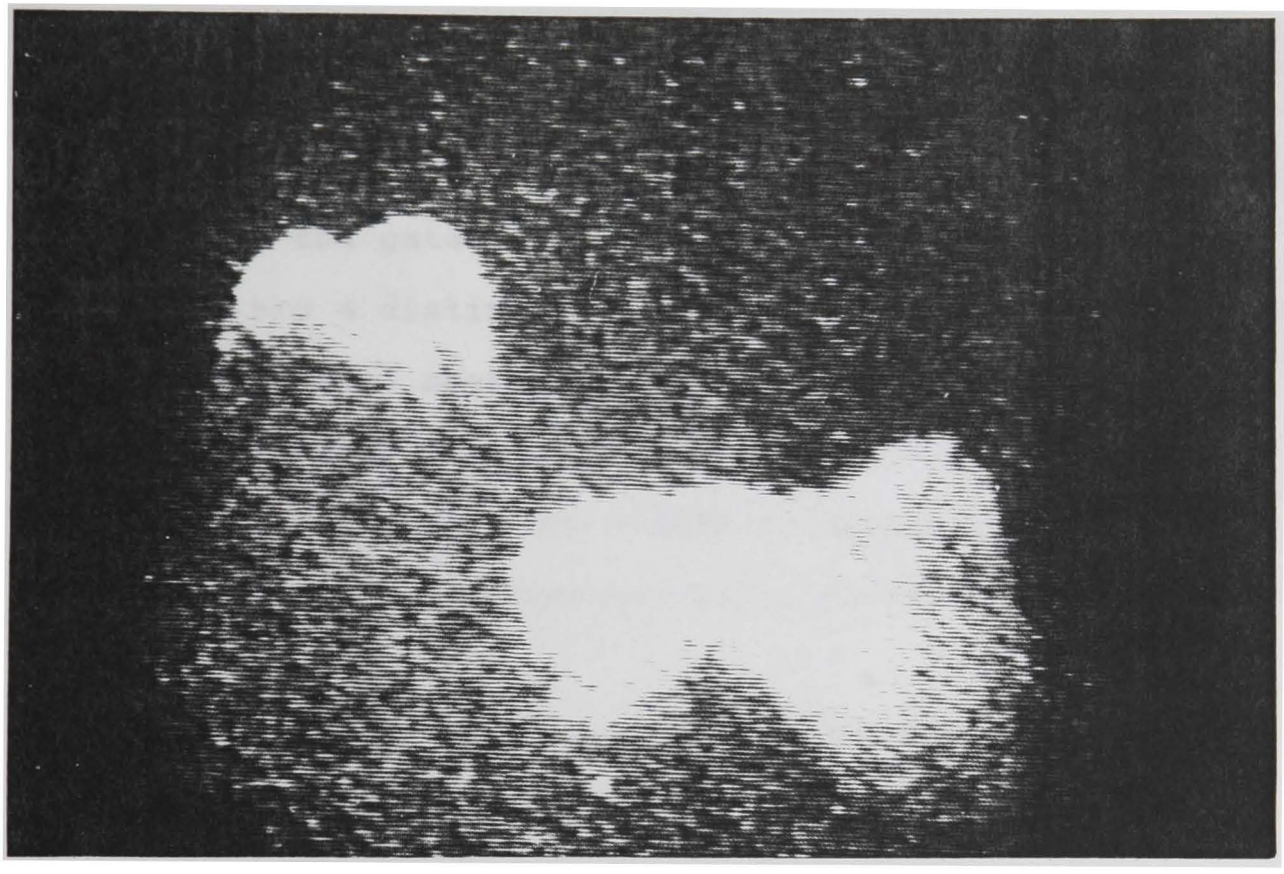

Figure 4.4 Prints on TLC Plate, Gated Image

Next a latent print was placed on a soft drink can (one of the more intensely fluorescent painted surfaces generally encountered), and subsequently received the superglue fuming followed with the rare earth RP staining. Notice that the print is barely visible on the white area and not visible at all on the red area in the ungated image (Figure 4.5). In the gated image (Figure 4.6), though, the print is clearly visible over both areas.

Another image of a print on a soda can is shown ungated (Figure 4.7) and gated (Figure 4.8). Notice in this series that there are 4 distinctly visible landmarks in both images where concentrated spots of the dye have formed during the drying subsequent to the staining process. Here these landmarks clearly allow the viewer to define where the problem area of the surface was prior to the gating of the image.

The system is, of course, useful for fingerprint work when background luminescence is not a problem. One then simply shuts off the light chopper thus providing continuous laser illumination of the article under scrutiny, and operates the camera in the ungated mode. This mode is similar to previous luminescence detection of latent prints but with the added advantages of variable magnification, digital image acquisition and image enhancement capabilities.

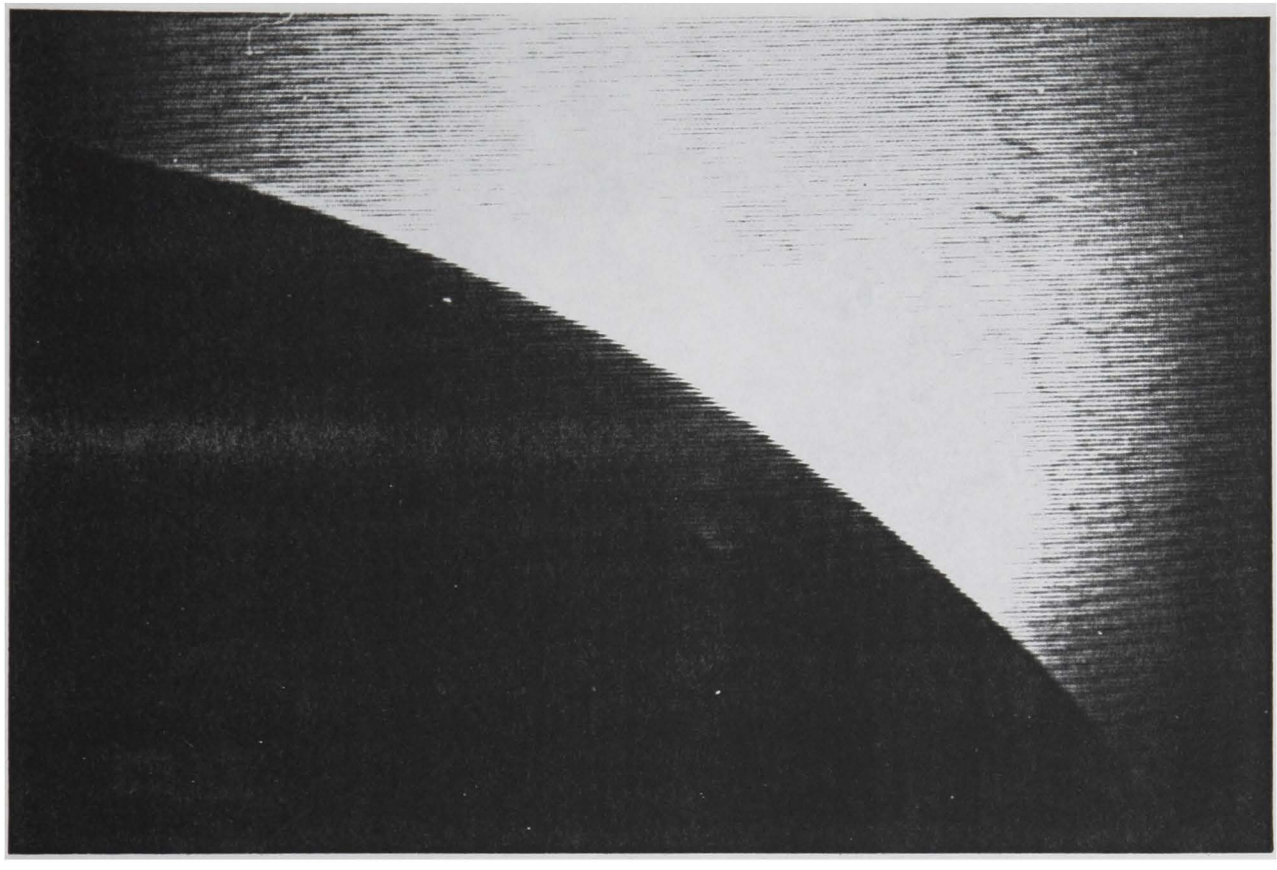

Figure 4.5 Print #1 on Soda Can, Ungated Image

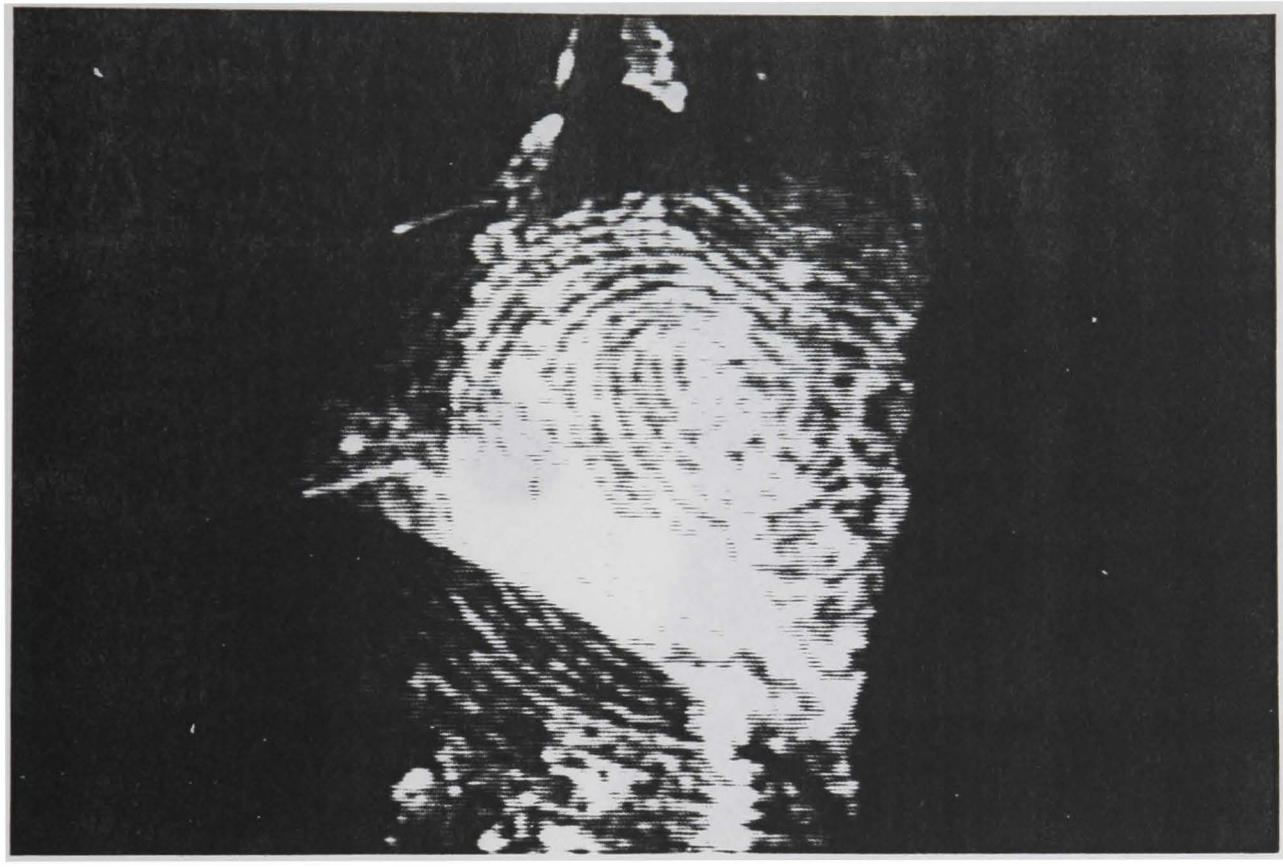

Figure 4.6 Print #1 on Soda Can, Gated Image

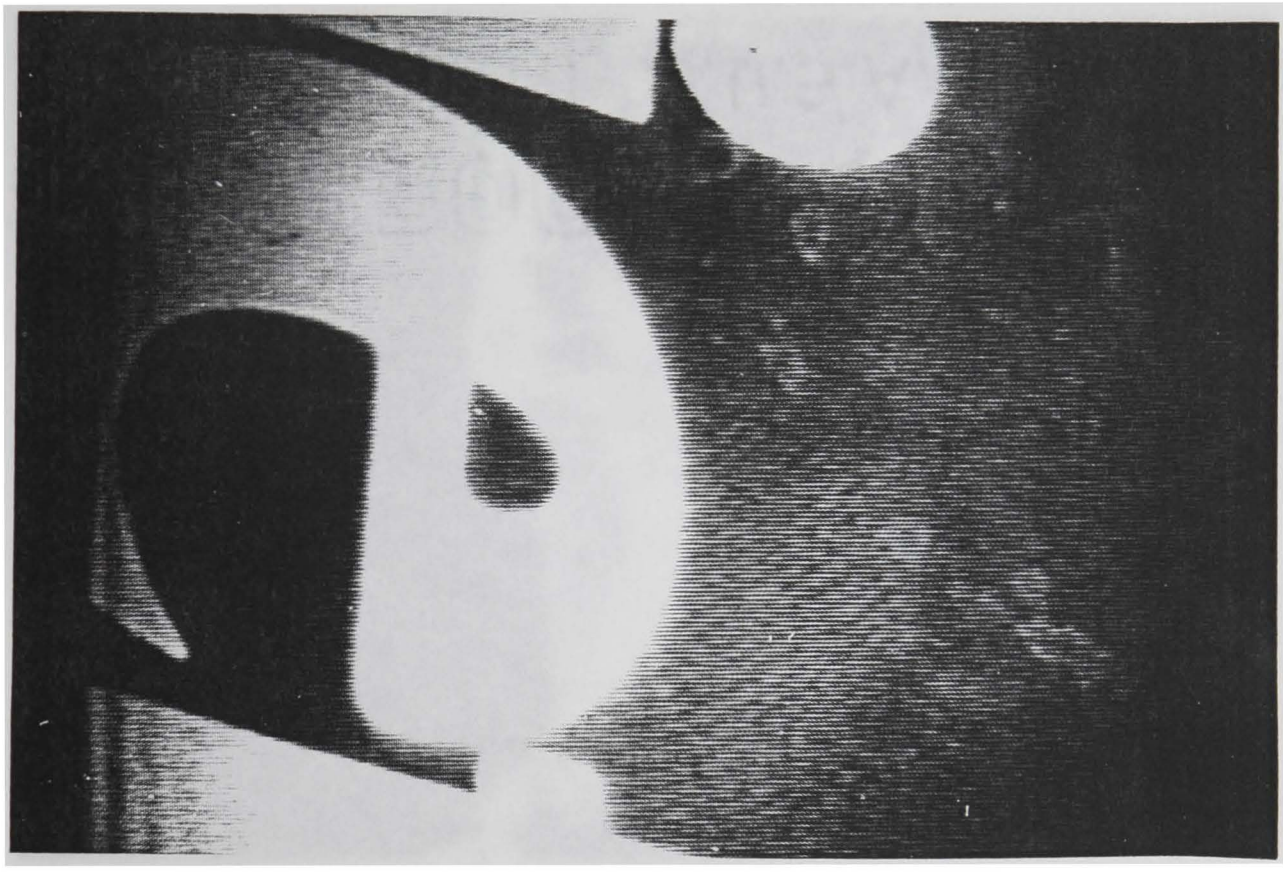

Figure 4.7 Print #2 on Soda Can, Ungated Image

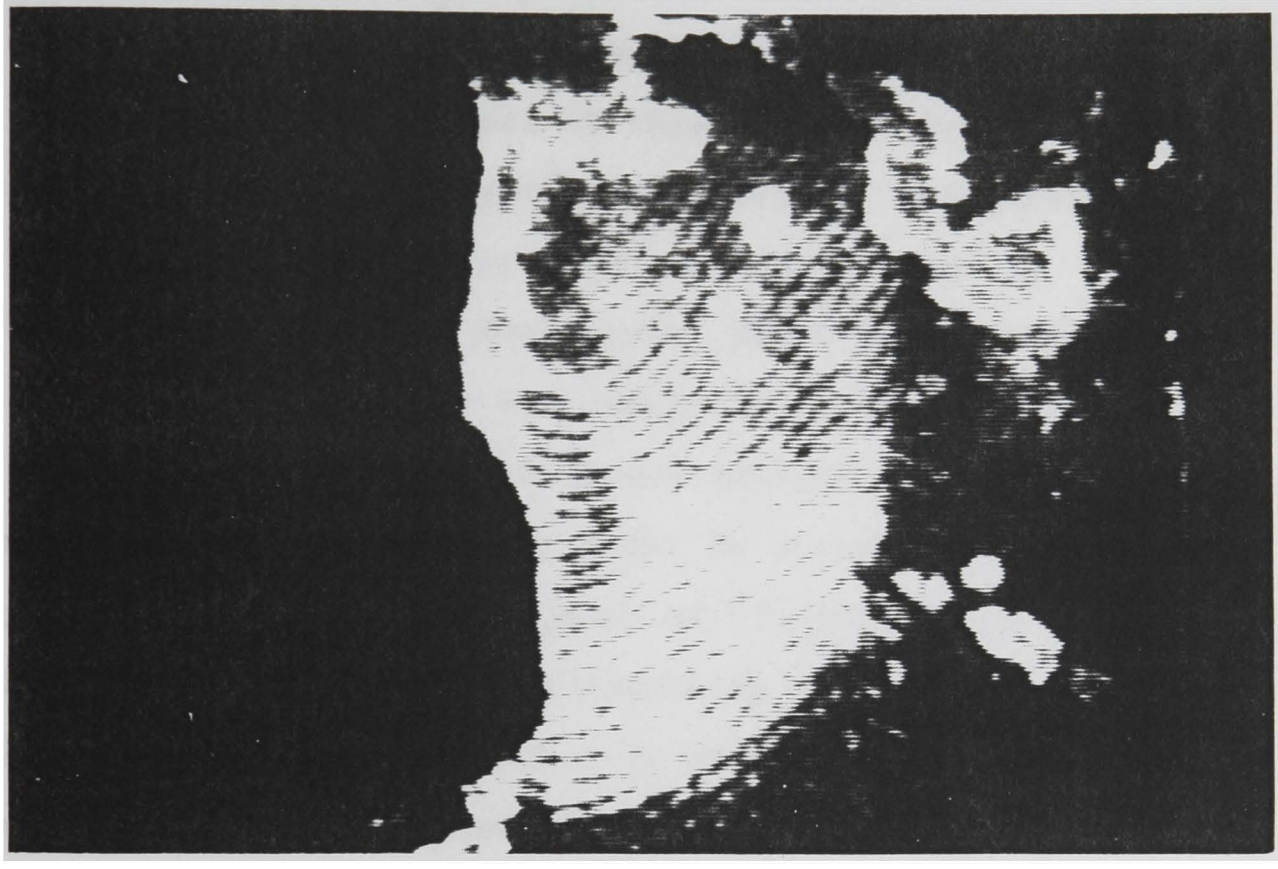

Figure 4.8 Print #2 on Soda Can, Gated Image

In presenting the images obtained with our system, we have chosen to photograph the monitor screen rather than to print the image files presented in the figures. It was our belief that too much detail would be lost in reproduction in print of the images obtained from our dot matrix printer or from the available thermal printer.

4.3 Other Potential Uses

Other potential uses of this time-resolved imaging system extend to DNA typing and labeling, immunoassays and bioassays in conjunction with rare earth labeling compounds[18,19,20]. Rare earth labels for a variety of biological purposes are commercially available (e.g., from Pharmacia Wallac and Kronem Systems). We believe that much speed and sensitivity might be gained in forensic DNA profiling if radiolabels (such as ^{32}P) were to be replaced by rare earth labels. Our reasoning is that a radioactive element produces one event only whereas a rare earth ion will yield many (luminescence) photons during the excitation time (which spans some 6 ms per image with our system). Sensitivity is obtained by the high powers (up to 7 watts) in the near-UV (as appropriate for the excitation of rare earth luminescences) available from modern argon-ion lasers and is also provided by the digital cameras which, after all, are designed for very low light level imaging. Finally, the long X-ray film development involved in

radiolabeling is bypassed and entry of the image to the computer for analysis is direct.

REFERENCES

[1] U.S. Department of Justice, *Bureau of Justice Statistics, National Update,* 1 (3), January 1992, NCJ-133097.

[2] S. Oden and B. von Hofsten, "Detection of Fingerprints by the Ninhydrin Reaction," *Nature* 173 (4401), 449 (March 6, 1954).

[3] S. Ruhemann, "Triketohydrindene Hydrate," *J. Chem. Soc.* 97 (2), 2025 (1910).

[4] B.E. Dalryrmple, J.M. Duff, and E.R. Menzel, "Inherent Fingerprint Luminescence--Detection by Laser," *J. Forensic Sci.* 22 (1), 106 (1977).

[5] B.E. Dalryrmple, "Case Analysis of Fingerprint Detection by Laser," *J. Forensic Sci.* 24 (3), 586 (1979).

[6] F.G. Kendall and B.W. Rehn, "Rapid Method of Super Glue Fuming Application for the Development of Latent Fingerprints," *J. Forensic Sci.* 28 (3), 777 (1983).

[7] E.R. Menzel, J.A. Burt, T.W. Sinor, W.B. Tubach-Ley and K.J. Jordan, "Laser Detection of Latent Fingerprints: Treatment with Glue Containing Cyanoacrylate Ester," *J. Forensic Sci.* 28, 307 (1983).

[8] E.R. Menzel and J.M. Duff, "Laser Detection of Latent Fingerprints--Treatment with Fluorescers," *J.Forensic Sci.* 24 (1), 96 (1979).

[9] D.W. Herod and E.R. Menzel, "Laser Detection of Latent Fingerprints: Ninhydrin Followed by Zinc Chloride," *J. Forensic Sci.* 27 (3), 513 (1982).

[10] J. Almog, A. Hirshfeld, and J.T. Klug, "Reagents for the Chemical Development of Latent Fingerprints: Synthesis and Properties of Some Ninhydrin Analogues," *J. Forensic Sci.* 27 (4), 912 (1982).

[11] E.R. Menzel, "Laser Detection of Latent Fingerprints--Treatment with Phosphorescers," *J. Forensic Sci.* 24 (3), 582 (1979).

[12] K.E. Mitchell and E.R. Menzel, "Time-Resolved Luminescence Imaging: Application to Latent Fingerprint Detection," *Proc. SPIE* 1054, 191 (1989).

[13] E.R. Menzel, "Laser Detection of Latent Fingerprints: Tris(2,2'-bipyridal)ruthenium(II) Chloride Hexahydrate as a Staining Dye for Time-Resolved Imaging," *Proc. SPIE* 910, 45 (1988).

[14] E.R. Menzel and K.E. Mitchell, "Intramolecular Energy Transfer in the Europium-Ruhemann's Purple Complex: Application to Latent Fingerprint Detection," *J. Forensic Sci.* 35 (1), 35 (1989).

[15] C.J. Lennard, P.A. Margot, M. Sterns and R.N. Warrener, "Photoluminescent Enhancement of Ninhydrin Developed Fingerprints by Metal Complexation: Structural Studies of Complexes Formed Between RP and Group IIb Metal Salt," *J. Forensic Sci.* 32 (3), 597 (1987).

[16] I. Mekkaoui, "Spectroscopy of Rare Earth-Ruhemann's Purple Complexes," Ph.D. Dissertation, Texas Tech University, 1992.

[17] Stanford Computer Optics, Inc., "Operating Manual for the SIC 05," 1990.

[18] E.P. Diamandis, R.C. Morton, E. Reichstein and M.J. Khosravi, "Multiple Fluorescence Labeling with Europium Chelators. Application to Time-Resolved Fluoroimmunoassays," *Anal. Chem.* 61 (1), 48 (1989).

[19] E. Soini and H. Kojola, "Time-Resolved Fluorometer for Lanthanide Chelates--A New Generation of Nonisotopic Immunoassays," *Clin. Chem.* 29, 65 (1983).

[20] E. Soini and T. Lovgren, "Time-Resolved Fluorescence of Lanthanide Probes and Applications in Biotechnology," *CRC Critical Reviews in Analytical Chemistry*, 18, 105 (1987).

APPENDIX

The operation of the time-resolved imaging system is fairly straightforward. The prepared sample is placed in the imaging area (under the stereo-zoom microscope or in front of the tripod mounted camera). The laser is turned on and the beam is focused onto the front surface of the chopper blade. The liquid light guide is placed so as to carry the beam as it exits the chopper to the article under examination. The computer and monitors are then powered up and the room lights extinguished. Make sure that the gain potentiometer is set to zero and the camera shutter is closed. The camera can be powered up at this point.

In our system, a few one letter batch programs are used to reduce the number of keystrokes needed to start the programs. The terminal program is then run to initiate the camera, by typing the letter T followed by hitting the ENTER key. Once in the terminal program, the gain, gate width and delay parameters are set (G1000, T1E-4, D5E-5, for example). The terminal program is exited with the ALT-Q combination to retain the parameters.

At this point, the ImagePro program is run by typing the letter S and hitting ENTER. Once in the program, a menu appears for selecting the desired operations. For imaging, the cursor of the mouse would be clicked on the command ACQUIRE and then on CONTINUOUS. Then the camera shutter (an external protective device) is opened. The gain is slowly

raised by the manual potentiometer on the camera until such time as the image appears on the monitor. Extreme care must be taken not to overexpose the microchannel plate. Once the image is properly focused, a "snapshot" can be taken by changing from CONTINUOUS to SINGLE. The captured image can be saved into a file (by clicking on FILE and the SAVE) or modified with the software's image enhancement facilities (by clicking on any of the menu items desired).

To quit using the system, the gain is turned down to zero and the camera's shutter is closed to protect the microchannel plate. After the camera is protected the room lights can be turned on. If no further use of the camera is expected then it should be powered down. Removing power from the camera resets the terminal program to zero gain. A menu command exits the ImagePro program when the user is finished.