

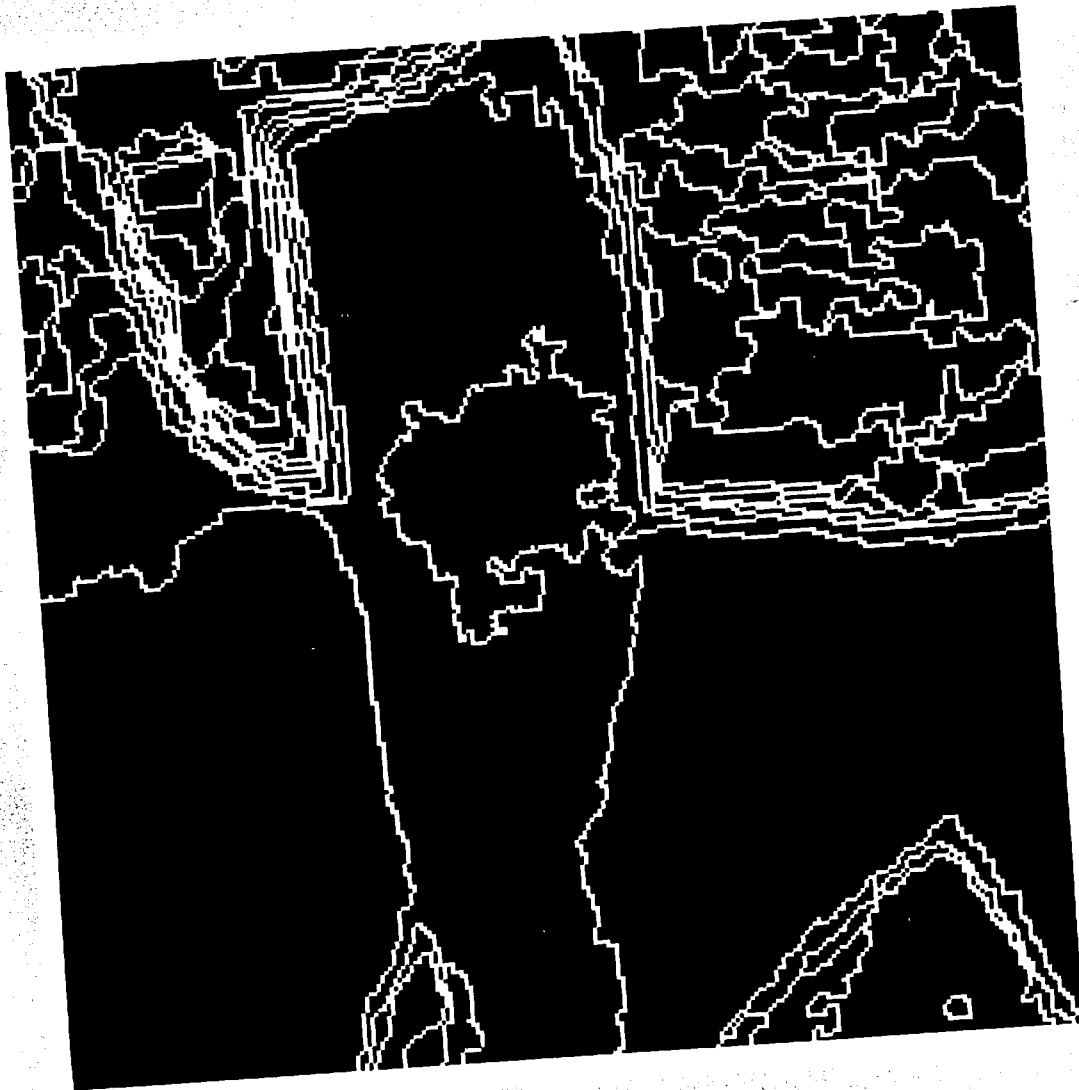
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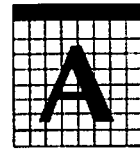


forensic image processing
law and the electronic highway

Forensic Image Processing

High-tech videotape enhancement now showing in court

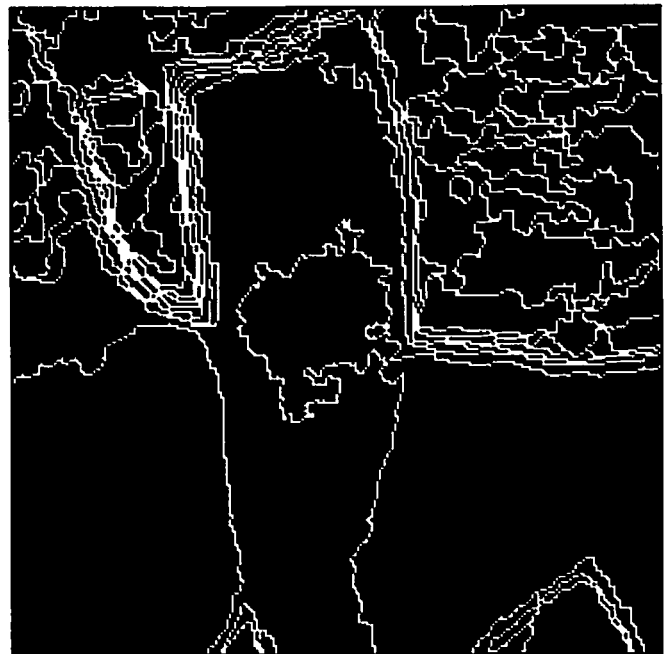
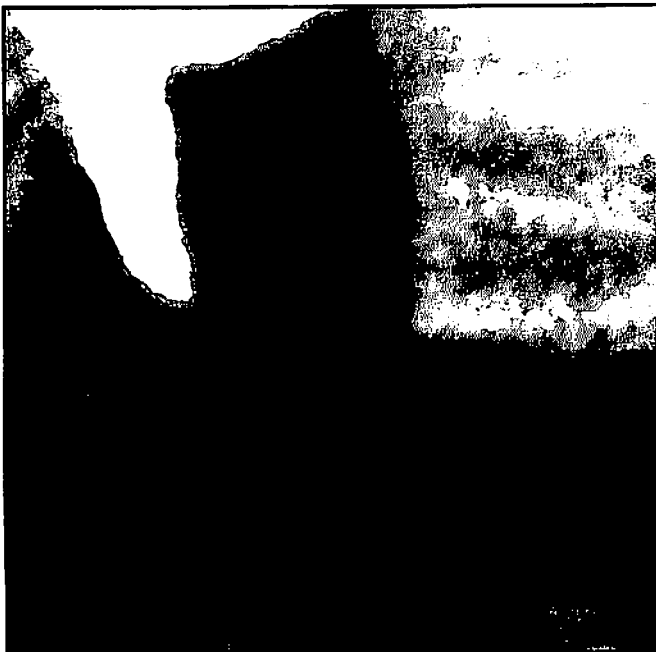
By DEBORAH L. MAHAN



Although initially developed for military defense applications, high-tech videotape enhancement recently became part of the criminal evidence arsenal. This impressive technology, when combined with ubiquitous security cameras and home video recorders, is revolutionizing criminal trials in the same way that fingerprint matching did almost a century ago.

Evidentiary videotape—a taped record of actual criminal activity or related incriminating activity—often suffers from blurry, snowy, and jumpy images caused by filming conditions that are inferior to those in a studio. Security cameras typically operate over long distances with slow frame rates and poor quality optics to capture images that often are useless as evidence—useless, that is, until forensic image-processing tools hit the courtroom.

Cognitech began 1994 searching for the killer of Police Officer Martin Ganz. A routine traffic stop gone bad left Officer Ganz dead and the Los Angeles County detectives without any clues. No clues, that is, except the videotape: A continuously scanning security camera at a nearby bank ATM captured the distant, blur-



ry image of the killer's vehicle as it sped away.

The technique

Forensic image processing was internationally pioneered by Cognitech, Inc., in Santa Monica, California. Lenny Rudin, the company's cofounder, discovered Cognitech's revolutionary approach to image processing in the mid-1980s while completing a Ph.D. in computer science at the California Institute of Technology. As the preeminent expert in the field, Rudin chairs forensic image-processing seminars throughout the United States and Europe.

Rudin's initial work was enhanced with contributions from Stanley Osher, an internationally acclaimed mathematician at the University of California at Los Angeles. The two wizards formed Cognitech in 1988 with funding support from the Department of Defense. The specialized technology they developed recently entered the court-

room and is now in use on desktop personal computers around the country.

In forensic image processing, evidentiary videotape is first converted to a digital format that is computer-readable. Digitized image frames are then merged together with algorithms that compensate for camera and subject motion. The resulting high-quality still image can be clarified with special algorithms to remove noise and blur.

Patterns in selected areas of interest can be located, expanded, and enhanced through additional forensic image processing. The computer algorithms that are used do not smear images because they are based on nonlinear mathematics and are programmed with methods that provide optimum resolution and accuracy.

An objective eyewitness

Cognitech's team of forensic image-processing engineers often extracts unexpected results from blurry im-

ages. In a recent case, they worked diligently with a public defender whose client was a suspected drug dealer.

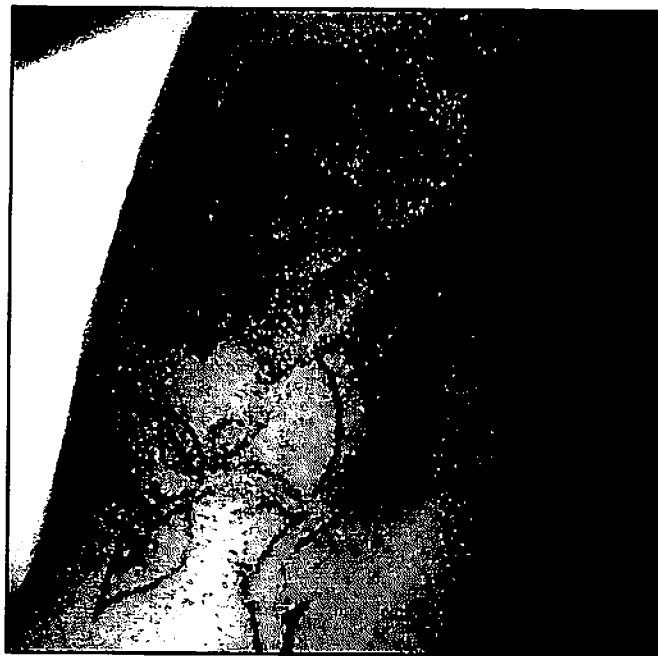
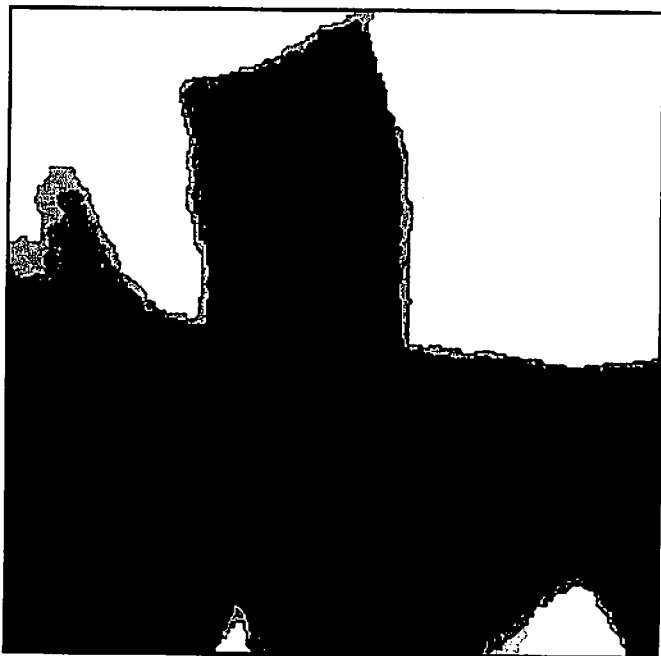
The suspect was filmed purchasing narcotics from an undercover police officer. Unfortunately, the surveillance camera was in such a poor position that it filmed only a few fuzzy frames of the suspect's face. The suspect claimed mistaken identity—that he was not the person on the tape.

After employing Cognitech to enhance the videotape, a surprised (and somewhat disgusted) public defender discovered that his client was lying.

Jurors traditionally consider photographic evidence, including evidentiary videotape, as highly objective. Such evidence holds significantly more weight than both faulty memories and expert opinions.

Videotape captures reality untainted by human interpretation and can help

Enhanced videotape from the Reginald Denny beating during the 1992 Los Angeles riots, filmed from a hovering helicopter. From left to right: (a) A small area—about 1/6000th of the original scene—was expanded to create the image of the forearm of defendant Damian Williams; (b) segmentation algorithms, which separate regions of interest, were used to develop the second image; (c) final reconstructed image shows the rose tattoo on Williams' forearm that helped lead to his positive identification as Denny's assailant; and (d) photograph of the actual tattoo. Cognitech, Inc.



clarify the *Rashamon*-ish testimony of numerous witnesses. Videotape is an objective eyewitness that can benefit prosecutors and defenders alike.

Acquiring the evidence

The plethora of video-recording cameras makes evidentiary videotape widely available. Case-breaking videotape can be uncovered even in unique circumstances.

One of Cognitech's strangest homicide cases involved a time-stamped convenience store receipt found on a countertop in the victim's home. The store security camera's videotape showed the victim buying beer and cigarettes with an unknown companion just prior to his death.

Cognitech expanded and restored the companion's face on high-definition display screens. The enhanced, still-frame photos that were produced are currently being used by detectives in their ongoing search for the unknown killer.

It may be necessary to subpoena tapes and to battle the news media for unbroadcast video clips of criminal activity. Most states hold that the news media has no special privilege to withhold information that bears on a criminal trial. To compel the release of videotapes, however, it is usually necessary to show that the tapes contain relevant information that is not available from an alternative nonmedia source, and that the state has a compelling and overriding interest in disclosure of the information.

After a lengthy battle, the court upheld the D.A.'s subpoena of news media tapes, shot from a hovering helicopter, that showed truck driver Reginald Denny's severe beating during the 1992 Los Angeles riots. Cognitech enhanced the videotapes to reveal a rose tattoo on the assailant's forearm. This allowed positive identification of defendant

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Damian Williams as Denny's assailant.

Enhancing and extracting forensic information

Instead of traditional ballistics techniques and blood-type analyses, the futuristic lab at Cognitech works with segments of videotape called "frame fields" and with digital "pixels" of an image on high-speed computers. Specialized tools and techniques are used to enhance and extract forensic information.

Until a videotape can be analyzed, it is not always evident whether there is any information to extract and what is likely to be revealed. Special measurement tools can establish the height and weight of suspects. A blurry human hand might reveal details about the wedding ring on a suspect's finger.

It is important to note that high-quality forensic image processing is not just clearing up fuzzy frames. Overzealous elimination of the "snow" from a video-

tape might remove important image detail that should be preserved for the case.

Forensic image processing involves more than simply slowing down the videotape or freezing frames with a VCR pause button. To extract case-solving information, each evidentiary videotape requires custom processing at an average cost of between \$3,000 and \$5,000. Processing time can vary from days to months because videotapes are sometimes reanalyzed when supporting information on a case is uncovered.

Currently, Cognitech's caseload is evenly divided between prosecution and defense clients. A forthcoming software package entitled "Police Video Workstation" will be available in mid-1995 to allow police detectives and crime labs to enhance videotapes themselves.

By mid-1994, there was a major breakthrough in the Officer Ganz homicide case. Working hand-in-hand with the Los Angeles County Sheriff's Department, Stephen

Lights! Camera! Action!

Think you are unobserved as you go about your daily business? Think again: You are being filmed all the time! Increased crime and lower-cost cameras have contributed to the proliferation of surveillance security cameras in convenience stores, gas stations, and parking lots. Security cameras are mounted on private homes and apartment buildings.

As camera-recording technology improved, high-risk banks began installing cameras to monitor both customers and employees. Longer distance videotaping on highways and at high-traffic intersections is possible with more sensitive cameras. Police departments are equipping patrol cars with cameras for protection against spurious officer-battery charges.

Courtroom use of videotape originated with undercover surveillance operations such as in the John DeLorean and Marion Barry cases. Hand-held home video cameras often record evidentiary videotape. There were more than 320 amateur videotapes of the Los Angeles riots reviewed by the Los Angeles District Attorney. The Los Angeles Police Department even canvassed local homeowners in O.J. Simpson's neighborhood for potentially incriminating videotape recordings! And, of course, the news media films significant events whenever possible.

Sometimes a defendant may videotape his or her own crimes, creating evidence that later is used in court. The defendants in a Washington, D.C., homicide videotaped themselves with the victim's camera. In another case, a victim unintentionally recorded his own murder. A video camera he set up outside his home to catch his neighbor harassing him instead captured his neighbor shooting him to death!

Jensen, Cognitech's Forensic Image Processing Manager, converted the distant, blurry image on the ATM's videotape into a recognizable vehicle—a 1988 Daihatsu—complete with unique dents and markings!

process known as "frame-fusion" (see sidebar).

It is acceptable to supplement an evidentiary videotape presentation with testimony from witnesses to tell jurors what they are viewing. An expert witness may be required to testify about the videotape enhancement process.

When testifying as an expert witness, Rudin sometimes discusses the technology first at bar because of the innovative nature of forensic image processing. He explains that image-processing techniques are conservative and do not add extraneous pixel information during processing. Rudin also clarifies that the processing accuracy of the mathematical

equations used in the technique is known exactly.

Simultaneously recorded audiotapes can be a valuable supplement to the presentation of an enhanced videotape. Quality audio may be unavailable, however, because sound is often drowned out by "noise." Audiotapes can usually be improved through processing using speech-enhancement techniques. (Linguistic analysis of tapes is discussed in Roger W. Shuy, *The Hidden Witness*, 8(4) Crim. Just. 26 (Winter 1994).)

Independent sound recordings are sometimes available. In 1992, New York Patrolman Michael O'Keefe was acquitted of shooting an innocent youth in the back. The major evidence in his favor was a home video camera recording and an independent audio recording. The separate audio recorded his terror-stricken voice as he cried for help just prior to the shooting.

First-rate trial presentations

The use of enhanced videotape at trial should be carefully orchestrated. Providing a flip-side, B-movie presentation of a fuzzy videotape will only confuse jurors. The most useful courtroom presentations are a mixture of enhanced videotape and still-frame photographs that are derived from a

Image-Processing Technology

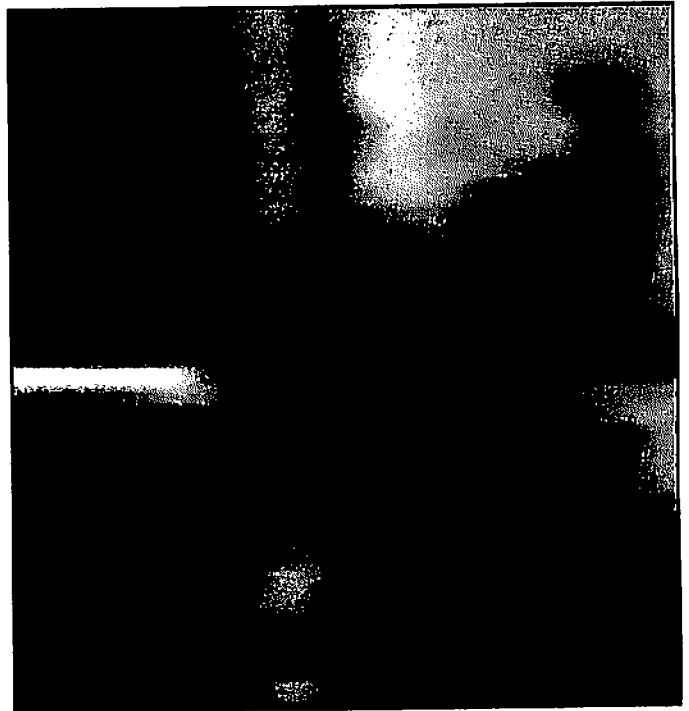
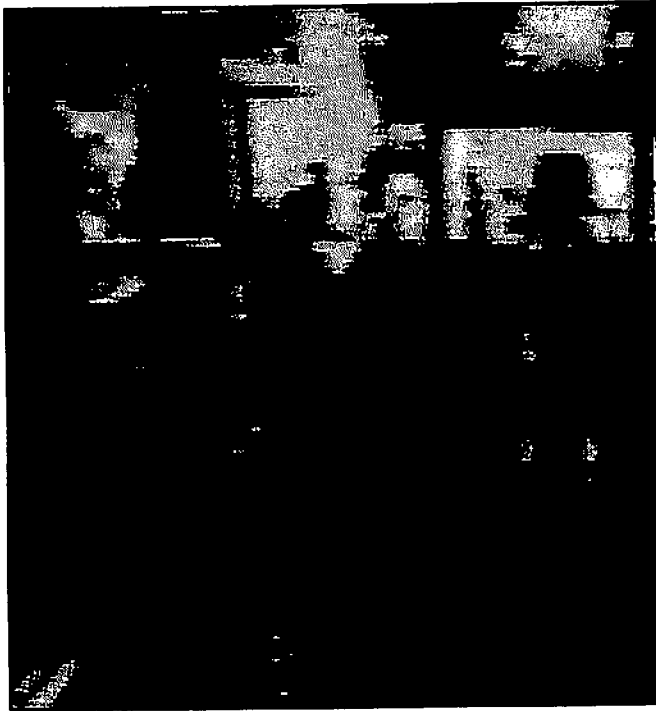
Cognitech Tools Frame-fusion	<i>Videotape Improvement</i> Merges adjacent video fields into single high-quality still image; expands one-half-height vertical video fields; compensates for motion between fields
Denoising	Improves sharpness of image; eliminates snow from electronic, film, and tape noise
Deblurring	Reduces image blur that results from long distance, low resolution, poor camera focus and recording mechanisms, camera/subject motion, lighting and atmospheric anomalies
Video restoration	Combines video denoising and video deblurring; estimates the variables that are degrading the image
Multi-scale segmentation	Isolates regions of interest at various intensities (scales)
Expansion/super-resolution	Produces accurate enlargements of an image without blur
Pattern enhancement	Enhancing, extracting, and matching image patterns (e.g., tire tracks, shoe marks, scratches) taken from crime scenes
Photogrammetry/videogrammetry	Software tools used to extract accurate sizing measurements from images using known object-size relationships at the crime scene

Effect on jurors

Forcing jurors to view film of vivid horrors such as beatings, molestations, wildlife poaching, and homicides can traumatize them. In particularly grisly cases, trauma counseling should be offered before the evidence is viewed to deal with jurors' potential anxiety, fear, and sleepless nights:

In one of Cognitech's most appalling cases, an unsuspecting security guard was approached from behind and shot in the head at close range. The killer's face was filmed before he put on his mask and robbed the store. Numerous other cases worked on by the Cognitech team have involved convenience store robberies in which terrified clerks were shot point-blank.

It is also important to note that jurors might not always objectively interpret an evidentiary videotape. They may be affected by a priori notions from their life experiences and beliefs. Videotape has even been known to inadvertently help jurors identify with defendants. This risk seems especially prevalent when an entrapment defense is used, as in the Marion Barry and John DeLorean cocaine trials.



Enhanced videotape from robbery case where the witness provided inconsistent testimony about the robber's hairstyle. Left: Original video field shows the robbery scene as taped by the security camera. The robber is standing upright at the counter in the left center of field. Right: The expanded and enhanced image shows that the robber was actually wearing a brimmed baseball cap and did not have the hairstyle indicated by the witness. The defendant was acquitted of attempted murder. Cognitech, Inc.

Attorney ingenuity still paramount

Even incriminating evidentiary videotape can be transcended with courtroom acumen. One proven technique is to desensitize jurors to the scenes being viewed by repeatedly playing the tapes. In both the Rodney King and Reginald Denny trials, the beating scenes were monotonously shown to jurors again and again until their significance was diminished. Jurors who watch true-crime shows on television may be less affected by graphic depictions of violence and may only give weight to exciting, high-drama video clips.

Another useful technique to discount evidentiary videotape is a frame-by-frame dissection. This eliminates the overall impact of motion and action. Evidence extraneous to the videotape also can be presented. Jurors may be swayed by events that happened before or after the recording. Even coincident events not filmed may hold significance.

An enhanced videotape can still leave room for considerable factual interpretation for the jury. Courtroom trial skills remain paramount to winning any case.

Sometimes Cognitech's work reveals interesting twists and conflicts that require truly ingenious attorney skills. In a robbery case, the primary witness identified a particular suspect but inconsistently recalled events.

After restoring the videotape, several significant discrepancies in the witness's story were uncovered—namely that she was in a room from which she could not possibly have seen what she claimed. In her testimony, she also provided specific details about the suspect's hairstyle. The enhanced videotape showed that he was actually wearing a baseball cap.

When the defense attorney zeroed in on these facts, the suspect was

justly acquitted of an attempted murder charge.

Preventing forgery

Doctored video (such as that central to the plot of Michael Crichton's *Rising Sun*) can soon be detected using nothing more high-tech than desktop personal computers. Cognitech is currently developing a novel system that makes forgery detectable from a direct reading of the electromagnetic, modulated recording on the videotape.

In the meantime, if an unscrupulous high-tech technician alters videotape frames, evidentiary rules on admissibility will prevent the forgery from entering the courtroom. Evidentiary videotape, like all evidence, must be authenticated.

A videotape can be authenticated under the "pictorial testimony" theory of admissibility by a sponsoring witness

who testifies that the videotape truly and accurately represents an object or scene. The witness is not required to have actually seen a videotape being made to testify to its correctness, because she is attesting that the videotape matches what she personally observed. Nor is she required to actually observe the recorded events with the naked eye—a closed-circuit monitor which allows real-time viewing of an object or scene is sufficient.

Another way to authenticate a videotape is under the "silent witness" theory. Admissibility is gained because the videotape evidence speaks for itself and is substantive evidence of what it portrays. It is admitted independent of a sponsoring witness. Usually testimony is provided on the videotape's content, working order of the camera, lack of gaps in the tape, camera maintenance, and continuous tape custody.

Future of forensic image processing

In August 1994, just months after Cognitech established the make and year of the vehicle belonging to Officer Ganz's killer, a suspect was apprehended. Roger Hoan Brady was arrested for an unrelated robbery and homicide in the Vancouver-Portland area when a witness got the license number of his getaway car—a 1988 gray Daihatsu.

Along with other evidence, authorities determined that the .380-caliber pistol found in Brady's apartment fired the bullet that killed Officer Ganz. Because the murder of a peace officer is a "special circumstance" in California, Brady could face the death penalty if he is charged and convicted. The Cognitech team, and high-tech forensic image processing, are sure to play a starring role in the trial.

Evidentiary videotapes are being shown routinely in courtrooms around the country. Many police departments and crime labs will soon be capable of processing evidentiary videotape for trial. High-tech videotape enhancement has become the newest crime-fighting partner in the criminal justice system. CJ

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Also in this issue:

For more on the implications of new science and technology for the criminal justice community, see Michael D. Wims's essay on law and the electronic highway (page 31) and Samuel A. Gaiberson's report on the CJS Ad Hoc Committee on Science and Technology (page 36).

THE WALL STREET JOURNAL.

California Company Uses Calculus to Pin The Crime on the Criminal Who Did It

By ROBERT LANGRETH

Staff Reporter of THE WALL STREET JOURNAL

The two men were on trial for murder. Convictions might have been easy: A gas station security camera had filmed the whole tussle, culminating in fatal gunshots. But the videotape was so blurry that no one could really tell who attacked whom. The two argued self-defense, and the Los Angeles County jury hung.

So local detectives turned to Cognitech Inc., a tiny company armed with a powerful new technique for enhancing fuzzy images. Cognitech's improved video clearly showed the suspects pinning the victim face down against the ground and firing into his skull. Both defendants eventually pleaded guilty.

In the past two years, analyzing crime and accident videotapes has blossomed into a full-time business for Cognitech, based in Santa Monica, Calif. It is among a handful of companies applying sophisticated mathematics to clearing up crime and accident videotapes.

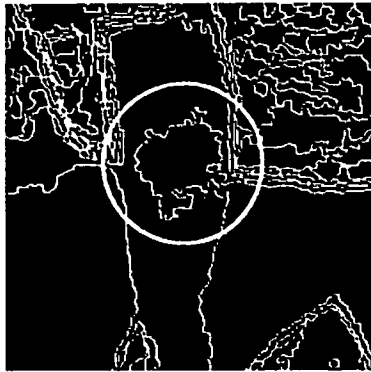
Before these companies existed, police trying to enhance poor videos had to buy commercial "Photoshop" software, which generally processes one frame at a time and is limited to simple operations such as improving contrast. Or they could send their videotape off to the Federal Bureau of Investigation's crime lab in Virginia, which often takes months to analyze videos. Thus companies like Cognitech "are filling a void," says Dave Brougham, deputy district attorney of Los Angeles County.

Cognitech's technique may give it a leg up on the competition. Based on a branch of calculus known as nonlinear differential equations, the technique "smooths out" static and other distortions in an image, while retaining the sharp edges that define key features of faces or objects. In contrast, previous techniques for cleaning up video tended to leave featureless blobs.

Cognitech founder Leonid Rudin makes an unlikely expert witness. A Jewish political refugee from the former Soviet Union, he came to the U.S. in the late 1970s to study computer science at California Institute of Technology. Among other things, he studied nonlinear differential equations used by physicists and engineers to mathematically describe sonic booms and other types of shock waves traveling through fluids. As opposed to simpler, "linear" equations, these shock-wave equations are particularly good at describing things with sharp edges or boundaries.

It occurred to Mr. Rudin that the shock-wave equations might also be useful for enhancing images. In his doctoral thesis, he proposed a method of improving images by assuming that the actual edges of objects or faces obscured beneath a blurry picture could be described by shock-wave equations. By finding solutions to these equations, one would remove distortions and other noise, without also wiping out important features.

Essentially, the differential equations assume both a logical outline for the sharp boundaries within each



This computer-generated image is the first step in a process that allowed Cognitech to identify a tattoo (circled) on the arm of Reginald Denny's attacker

frame and the nature of distortions caused by poor focus, atmospheric refraction, electronic noise and other factors that blur an image. The computer then solves the equations over and over again with each successive solution refining the assumed boundary curves.

The technique is roughly analogous to taking a satellite photo of the earth and trying to draw in topographic lines representing major geologic features. In this case, the "topographic lines" are the edges of objects, as represented by major changes in color or brightness. As the computer does this over a period of seconds or minutes, "the image, slowly, slowly gets better defined," Mr. Rudin says.

His thesis attracted the attention of mathematician Stanley Osher at the University of California at Los Angeles, and the two formed Cognitech to explore uses of the technique. Initially, the company's work focused on military applications. But Mr. Rudin had always been fascinated with forensic science, and a now-famous beating caught on videotape gave him a chance to indulge his interests.

At the height of the 1992 Los Angeles riots, cameras in TV-news helicopters videotaped a white truck driver, Reginald Denny, being pulled out of his truck and severely beaten by several black men. Defense lawyers for one of the main attackers contended the videotape was too poor to link it to their client. But Cognitech's analysis revealed a dark patch on the attacker's left arm in exactly the same location as a tattoo on the defendant's arm. The defendant was convicted.

Since then, business has been brisk. Cognitech's 12-person staff handles eight to 10 cases a week, at a price of several thousand dollars per case, from a small office in Santa Monica. One room is jammed with video gear for converting tapes from detectives and other clients to digital format. The actual enhancement

work is done on computer workstations at employees' desktops.

On a typical day, Mr. Rudin prowls the office looking over employees' shoulders as they analyze videotapes, asking questions and making suggestions. For particularly stubborn videotapes, the indefatigable Mr. Rudin often stays late into the night adapting computer programs to do that type of image better.

Cognitech isn't alone in the expanding video-enhancement field. Another small company, Trec Inc. in Huntsville, Ala. sells software for enhancing videotapes to the FBI and other law enforcement agencies. And Aerospace Corp., a nonprofit military-research agency, recently started a small unit to analyze crime videotapes. It now handles a couple of dozen cases per year.

Neither the FBI nor Trec will comment on their enhancement techniques. Aerospace, for its part, says a variety of standard mathematical methods for improving images serve it just fine. "Standard image enhancement is a whopping field," agrees Massachusetts Institute of Technology electrical engineer Alan Willisky. He adds that "the jury's still out on the overall impact" of Cognitech's method.

In any case, all sides expect their caseloads to increase, as more businesses buy sophisticated video-security systems. Cognitech, for example, has expanded its work to investigations of industrial accidents and even military jet crashes.

The ultimate goal, officials at both Cognitech and Aerospace say, is to develop fast, user-friendly software for sharpening videos. "Our dream is to have real-time video processing," Mr. Rudin says. "A detective would put a poor tape in one end of a machine, and at the other end the enhanced video would come out."

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